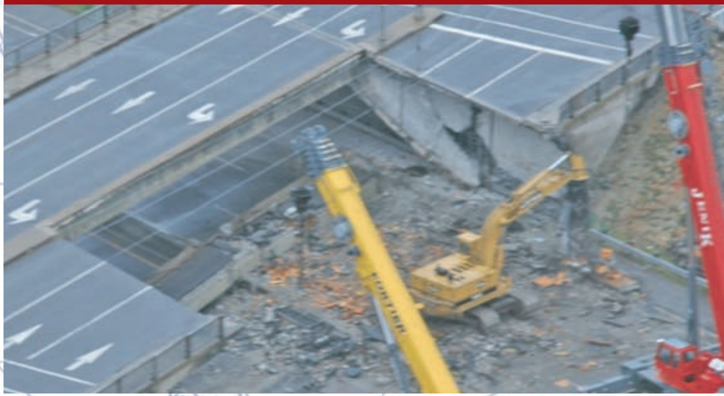
Commission of Inquiry
into the Collapse of a Portion of the
de la Concorde Overpass

October 3, 2006 - October 15, 2007

REPORT



**Commission d'enquête
sur le viaduc
de la Concorde**

Québec

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Throughout its inquiry, the Commission has sought to understand the causes and the circumstances of the tragic events that occurred on September 30th 2006.

In the memory of

Mathieu Goyette
Véronique Binette

Jean-Pierre Hamel
Sylvie Beaudet

Gilles Hamel

In tribute to

Gabriel, son of Jean-Pierre Hamel and Sylvie Beaudet
Mélanie and Yannick, children of Gilles Hamel

The persons who were injured

Louise Bédard
Paul Cousineau
Claude Bastien
Mohamed Ashraff Umerthambi
Anne Leblanc
Robert Hotte

To all persons whose lives where touched.

Montréal, le 12 octobre 2007

Monsieur Gérard Bibeau
Secrétaire général du Conseil exécutif
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Québec (Québec)   G1A 1AZ

Objet : Rapport d’enquête sur l’effondrement d’une partie du viaduc de la Concorde

Monsieur le Secrétaire général,

Nous, les Commissaires, conformément au mandat qui nous a été confié par le décret 875-2006, pris le 3 octobre 2006 et conformément à la *Loi sur les commissions d’enquête*, vous soumettons respectueusement notre rapport d’enquête.

Pierre Marc Johnson, avocat
Président

Armand Couture, ingénieur
Commissaire

Roger Nicolet, ingénieur
Commissaire

This English language report is a translation of the original French version. The French version prevails.

All the evidence adduced during the Commission's public hearings has been made available along with this report, thanks to DVD technology; those interested can access all of the same at www.cevc.gouv.qc.ca, where they may also review our hearings in audio, video and written formats.

FOREWORD OF THE CHAIR

The sudden collapse of the de la Concorde overpass killed five people and wounded six others. Not only did this event deeply distress the persons close to the victims; it also touched a great number of people, because it was an abnormal and intolerable event. It was essential to discover its root causes and to propose the corrective measures that need to be taken.

Both physical and human causes explain what happened on September 30, 2006. Amendments to codes, standards and manuals, with the knowledge now available, will correct the former. As for the latter, we now know that nearly forty years ago, there was negligence on the construction site of the de la Concorde overpass, and lapses in the managing of the structure throughout its useful life. These problems must be prevented or corrected, so as to ensure citizens using our bridges and freeways that such a lethal and rare chain of circumstances and events does not recur. To prevent such events, there need be consistent awareness and vigilance in relation to the demanding discipline of building or managing structures.

Our mandate was carried out with the utmost independence and transparency. Our conclusions as to the causes of the event are based on evidence adduced to us during our hearings.

Our recommendations deal with modifications to the legal and administrative framework of structure building processes, inspections and repairs. They also address the importance of looking toward the future. I am convinced that they will not only correct the failures we observed but also durably improve the state of our bridges. A daunting task awaits Government and the hundreds of persons whose work is essential to ensure public safety and the maintaining of adequate and efficient infrastructures.

Before identifying and thanking those who have supported me in the task of chairing the Commission, I express appreciation to all those who have accomplished their duty as citizens in cooperating with the Commission by coming forward voluntarily, without being served summons, as witnesses and experts. This duty is not always easy to perform. It can be very intimidating to present oneself in public, under oath, and to speak openly and honestly about facts and doings of important institutions and organizations, and of persons working for such. I believe it would be useful to overhaul the dating *Act concerning public inquiry Commissions*, in particular to provide for protection of those who bring their cooperation to such public processes. Drawing from the *Charter of Human Rights and Freedoms*, the *Act* should create an offense sanctioning those who threaten to or exercise retaliation against persons who have collaborated with a Commission and entrust a tribunal with adopting redress and punitive damages in such cases.

I thank first my two experienced and wise colleagues, Commissioners Armand Couture and Roger Nicolet, both remarkable engineers. Their contribution was paramount in defining the work programme of the Commission's technical team, framing mandates of the experts looking into the causes of the failure of the bridge and in appreciating to its full extent the significance of evidence relating to full thick slabs without shear reinforcement. We were thus able, in the course of our mandate, to provide information useful for the *ministère des Transports du Québec's* action plan to identify and intervene toward vulnerable structures.

Mr. Michel Décary, our chief counsel, a man of rare experience, conducted the preparatory work and hearings rigorously, with intelligence and honesty, and nurtured a strong team spirit. He could rely on the stamina and meticulousness of assistant Counsel Marie Cossette as well as on attorneys Jean-Patrice Dozois and Poseidon Retsinas, whose contributions were important.

The general coordination of our work was under the responsibility of Attorney Nicole Trudeau, Secretary of the Commission. She was remarquable by her patient, efficient and disciplined work, as was Monique Michaud, lawyer, clerk of our hearings, who managed the critical documentary part of our work exceptionally well.

Engineer-lawyer Michel Lemoine and engineer Paul Croteau, Ph.D. proved remarkably efficient in shedding light on the causes of the collapse and I thank them both for their particular contribution to serve the public interest and public safety during our mandate.

Mr. Julien Lemieux and all his staff discreetly provided support services: administration, communications, and the technical and Internet wizardry that made it possible for citizens to follow the public hearings. I thank him and all the support staff that devoted unending hours, particularly in the last two months of our mandate.

I am thankful to Ms. Martine Desprez, coordinator for the French, English and electronic production processes, who put up with a quasi impossible, yet unavoidable time schedule.

My gratitude goes to our special assistants, Vincent Regnault, Attorney and Mr. Guy Versailles, APR, for their multiple contributions and unrelenting completion of each and every mandate assigned to them.

Finally, I thank everyone who has supported our work in so many ways, including Counsel of parties, the experts, and the numerous persons who took of their time to participate in the consultations that nourished the Commissioners in the formulation of their recommendations.

To all those who will recognize themselves for their support, I express my gratitude because they have made my task easier as chair of the *Commission d'enquête sur l'effondrement d'une partie du viaduc de la Concorde*.

Pierre Marc Johnson
Chairman

Montreal, October 12, 2007

INTRODUCTION OF THE COMMISSIONERS

The Government has mandated the Commission to investigate the circumstances and causes of the partial collapse of the de la Concorde overpass and to make recommendations on the measures to take to ensure such an event never recurs.

Our first words are for the people who lost loved ones and for the injured and their families. The tragic event of September 30, 2006 caused five deaths and disrupted the lives of many people for many years to come. We would like to express our deepest sympathy and hope that our investigation and the contents of this Report provide some measure of closure and help them understand how this tragedy came about.

The Commission strictly followed the principles set out in the *Krever* case delivered by the Supreme Court of Canada in 1997 with regards to the power of inquiry commissions, even though the Court interpreted the *federal Inquiries Act* rather than Québec law. These principles are as follows:

- A commission of inquiry is not a court or tribunal and has no authority to determine legal liability;
- A commission of inquiry does not necessarily follow the same laws of evidence or procedure that a court or tribunal would observe;
- In light of the foregoing, the commissioners should endeavour to avoid setting out conclusions that are couched in a specific language of criminal culpability or civil liability for the public perception may be that specific findings of criminal or civil liability have been made;
- The commissioners have the power to make all relevant findings of fact necessary to explain or support the recommendations, even if these findings reflect adversely upon individuals;
- The commissioners may make findings of misconduct based on the factual findings, provided that they are necessary to fulfill the purpose of the inquiry as it is described in the mandate;

- The commissioners may make a finding that there has been a failure to comply with a certain standard of conduct, so long as it is clear that the standard is not a legally binding one such that the finding amounts to a conclusion of law pertaining to criminal or civil liability;
- The commissioners must ensure that there is procedural fairness in the conduct of the inquiry.

Following preliminary research conducted by the Commission's staff and some statements volunteered by many persons, the Commission held public hearings where 58 witnesses who could shed light on the issue under inquiry testified.

We analysed many documents, read the briefs of participants and stakeholders as well as studied scientific reports prepared by experts selected by the Commission and by some of the participants. The Commission examined the de la Concorde overpass from all angles, from the preliminary concept and design to its ultimate collapse including its construction, the materials used and the people who worked on the structure. We then examined the impact of the weather and seismic elements and traffic, the inspections of the structure, its maintenance and repair works carried throughout its useful life. Both the Commission and the *ministère des Transports du Québec* built replicas of a section of the cantilever of the overpass.

The Commission therefore amassed an impressive corpus of research, analyses and even scientific discoveries. The meticulous work performed over thousands of person hours allowed us to take a retrospective look at the life of the de la Concorde overpass with knowledge that the parties involved did not have at the time. We understand that what we learned in hindsight could not have been as clear during the structure's lifetime. We took this fact into account in our findings and conclusions.

The Commission's work produced various types of results.

The research into the causes of the de la Concorde overpass collapse made it possible to clearly identify a risk that was not addressed by the standards in effect in the 1970s during which many structures were built, or even by the current standards for the construction of thick slab bridges without shear reinforcement, in the presence of deteriorated concrete. We thought it relevant to immediately inform the government of this finding so that the *ministère des Transports* could adjust its action plan prepared to locate and examine similar structures. We also notified the Canadian and American authorities given that these types of structures exist throughout North America.

The Commission also established the chain of causes that led to the collapse. A point needs to be made here: the Commission is of the opinion that the collapse cannot be attributed to any single entity, organisation or person. None of the defects and shortcomings that were identified could have by itself caused the collapse, which resulted from a series of causes that occurred in sequence. It is with this in mind that the blames and reproaches stated in this report should be understood and interpreted.

The Commission has clearly demonstrated the regrettably inadequate role played by some companies and some of the individuals involved in the construction and supervision of the de la Concorde overpass nearly 40 years ago. After hearing the evidence and reading the documents filed, the commissioners concluded that Desjardins, Sauriol & Associés, Inter State Paving Inc. and Acier d'armature de Montréal (1968) Ltée as well as their managers responsible for the site, must be blamed.

The Commission wanted to know how the defects of the de la Concorde overpass escaped the attention of the personnel responsible for the management of the bridge until it collapsed. While the Commission reproaches and deplores certain shortcomings, it has chosen to blame the *ministère des Transports du Québec* for its inadequate management of structures. Faced with the evidence of the collapse, we can only conclude that the system in place to ensure that bridges are safe for public use has shortcomings that must be identified and corrected. In the Commission's view, the MTQ must acknowledge these shortcomings; it must take corrective measures. Central agencies in government must support this essential effort to ensure public safety.

Lastly, we noted the deteriorated state of Québec's bridges. Two comments are in order in this regard. First, the Commission does not want to send the message that it is dangerous to travel on or under Québec's bridges. As a result of the collapse of the de la Concorde overpass, the parties responsible for inspection have become more vigilant. Indeed, the causes of the collapse have been clearly identified and the *ministère des Transports* is already taking the necessary measures to make the bridge network safe. Second, road infrastructures are deteriorating everywhere in North America. However, because the problem is more pronounced in Québec, the Commission recommends a quick and aggressive shift to not only stabilise the situation but also to ensure that Quebecers once again enjoy top quality infrastructures.

We would like to thank our staff and all the experts who helped us in our work. These individuals – lawyers, engineers, scientists, management and support staff, and other collaborators – worked very hard in a very short period of time, often putting their professional obligations on hold for several months and sometimes postponing personal projects in order to devote their time to organising and conducting studies, hearings and consultations, and to preparing this report. We would also like to thank the many people who generously gave of their time to help us with various aspects of our work. Lastly, we thank the government of Québec for entrusting us with this mandate.

Pierre Marc Johnson, attorney
Chair

Armand Couture, engineer
Commissioner

Roger Nicolet, engineer
Commissioner

SUMMARY

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SUMMARY

S.1 The Commission, its organisation and its work

On October 3, 2006, the Government of Québec established the Commission of Inquiry to investigate the circumstances of the collapse of the de la Concorde overpass on Autoroute 19 in Laval on September 30, 2006, to determine its causes, and to recommend to the Government measures to preclude any recurrence of such events.

After forming its technical and legal teams, the Commission focused on the protection and preservation of the elements of the structure it needed to perform the investigation and took samples for future testing. It then commissioned scientific investigations in order to determine the causes of the collapse. It compiled and analysed all the available documentation in order to reconstruct the life of the structure, from its design right through to its tragic collapse. It identified, sought out and met with the individuals and organisations involved in the design, construction and maintenance of the structure, and witnesses of its collapse. During public hearings, it heard the testimony of 58 witnesses and experts. It also consulted with persons and organisations likely to shed light on various aspects of bridge management systems. The Commission then drafted its report.

S.2 Design and construction of the de la Concorde overpass

When a decision is taken to build a structure such as the de la Concorde overpass, the *ministère des Transports du Québec*[1] ("MTQ") requests its own team of engineers, or as was the case with the de la Concorde overpass, a consulting engineering firm, to design a concept and prepare the drawings, specifications and documents required for a call for tenders. Desjardins Sauriol & Associés ("DSA") was awarded the engineering contract for Autoroute 19, including for the de la Concorde overpass.

The *Ministère* then issues the call for tenders to select the contractor who will build the structure in accordance with the drawings and specifications. Inter State Paving Inc. ("ISP"), lowest bidder, was awarded the Autoroute 19 extension contract, including construction of overpasses comprising the de la Concorde and the de Blois overpasses.

Although it had already built an overpass above Autoroute 19 in Montréal, ISP had little bridge construction experience. The company retained the services of several subcontractors, including Francon for the prestressed box girders, Coffrage Dominion for formwork, Acier d'armature de Montréal ("AAM") for the rebars and their placing, and Prud'Homme & Frères ltée ("Prud'Homme"), for the concrete. Prud'Homme outsourced the placing of the concrete to Coffrage Dominion, while AAM used the services of a rebar placer.

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[1] In 1969, the department in charge was the *ministère de la Voirie*, which later became the *ministère des Transports du Québec*.

The *Ministère* also retains a consulting engineering firm to supervise the construction work, usually the same firm that prepares the drawings and specifications. As such, DSA became contractually responsible for supervising the work. The supervisor's role is to be on the jobsite at all times, to monitor construction on a daily basis, and to ensure that everything is built according to drawings and specifications. The supervisor is also responsible for approving the monthly invoices and the contractor's final invoice, accepting delivery of the structure, and acting as a liaison between the contractor and the designer if problems arise on site. When the work is finished, the supervisor usually provides the owner (the *ministère de la Voirie* in this case) a file containing the "as built" drawings and the jobsite documentation.

It is important to note that the contractor has an obligation of result for itself and for its suppliers, i.e. the structure as delivered must comply with the drawings and specifications regardless of whether or not a supervisor is present.

DSA was also responsible for material quality control. To help with this aspect of the supervision mandate, it retained the services of its subsidiary, Laboratoires Ville-Marie Inc.

S.3 Special characteristics of the de la Concorde overpass

At the time, the design of the de la Concorde overpass was innovative, at least in North America. The use of prestressed concrete box girders made it possible to cross Autoroute 19 with a single span without intermediate support. Placing the box girders side by side resulted in a uniform surface underneath the central span, which rested on a beam seat continuous over the entire width of the bridge. This thin and elegant superstructure minimised the excavation depth required for the open-cut construction of the freeway.

The box girders forming the central part of the deck rested on beam seats located at the ends of the cantilevers, directly under the expansion joints (Figure S.1). The end of the cantilever is a particularly complex load transfer area. The expansion joints are highly exposed parts which lose their ability to seal off water when damaged, contributing to the accumulation of water, road salts and debris on the chair bearing support. This vulnerability is even greater because the seats cannot be inspected and maintained without lifting the deck. To do so, traffic would have had to be interrupted on both Boulevard de la Concorde and Autoroute 19. The expansion joints and the ends of the cantilevers on this type of structure thereby constitute critical zones requiring special attention during inspections and maintenance work.

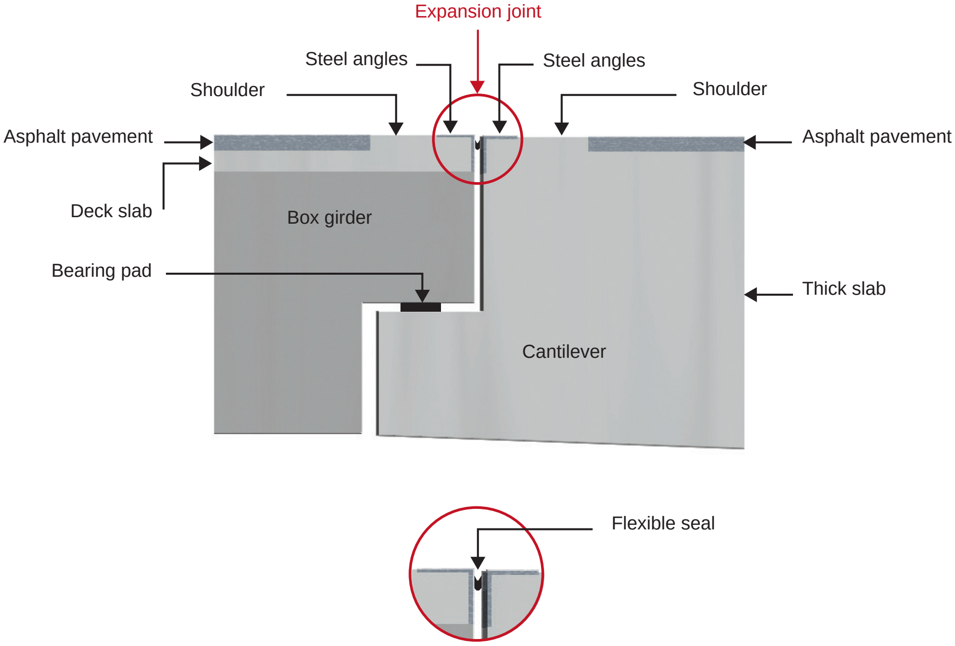

Figure S.1 Diagram Illustrating the Position of the Expansion Joint above the Seat

The two cantilevers were built as thick reinforced concrete slabs. Concrete is a very strong material in compression but relatively weak in tension. Steel reinforcing bars – steel has high tensile strength – are used to provide resistance in tension. Once the concrete hardens, these two materials work together to form a new material called reinforced concrete. If the design of the reinforcement is defective, or if the bars are misplaced, the load bearing capacity of the structure can be seriously compromised.

Besides allowing the reinforced concrete to resist considerable loads, the reinforcement gives it ductility. A ductile structure deforms before collapsing whereas a brittle one collapses suddenly, without any notable prior deformation. Poorly designed, incorrectly placed or insufficient reinforcement not only compromises the strength of a reinforced concrete structure, but it may also make it brittle. The concrete itself must be strong enough to provide proper anchorage for the reinforcing bars.

Concrete is made from a mixture of cement, water, sand and gravel. Small air bubbles are usually incorporated into the mix during its manufacturing to protect it against the effects of freeze-thaw cycles. The proportions of the mixture, especially the water/cement ratio, directly affect the concrete's durability and mechanical strength. If the quality is insufficient for the type of structure in which it is used, or if it is unable to resist repeated freeze-thaw cycles, the concrete will deteriorate, with serious consequences for the structure.

Lastly, on a structure exposed to freeze-thaw cycles and de-icing salts such as a bridge, current practice calls for the installation of a waterproofing membrane to prevent the infiltration of salt-laden water which could deteriorate the concrete. While not a common practice at the time of construction of the overpass, the installation of waterproofing membranes had become current in 1992 when major repairs were made to the de la Concorde overpass.

The design of the reinforcement is critical and the rebar must be installed in accordance with the drawings. The quality of the concrete must also be suitable for the structure. The waterproofing membrane plays a very important protective role. Once the structure is operational, the critical zone located at the junction of the cantilevers and the box girders must be carefully inspected and the expansion joints promptly repaired to prevent the infiltration of salt-laden water from the road and ensuing damages.

To sum up, the de la Concorde overpass was a unique, vulnerable structure. In fact, because they are impossible to inspect, continuous beam seats along spans have not been built for the last 30 years and would not be allowed under current codes.

S.4 Inspection, maintenance and repair

The completed structure became the responsibility of the *ministère de la Voirie* and later, the *ministère des Transports du Québec*. When the *Ministère* was reorganised in 1993, the de la Concorde overpass was transferred to the *Direction territoriale de Laval-Mille-Îles* which took on the responsibility for its inspection, maintenance, and repair. The overpass was a "shared jurisdiction" structure, meaning the City of Laval maintained the sidewalks, roadway, handrails and signalisation.

The different types of inspection are defined in the *Ministère*'s manuals. They allow the identification of the problems and defects as they arise and the tracking of the evolution of the structure over time. Each inspection is typically followed by a report containing the observations, measurements, inspector's photographs, and defects or weaknesses noted. This report is filed in the inspection dossier maintained by the *direction territoriale*.

Maintenance and repair work is planned according to the instructions from the manuals and based on inspection results. The manuals set out a repair timetable for each type of defect or problem.

If necessary, a *direction territoriale* can request assistance from the *Direction des structures* a dedicated unit of the *Ministère* with specialised expertise.

The *direction territoriale* and the *Direction des structures* each keep separate files for each structure. The content of the bridge files vary according to their respective responsibilities, i.e. for design and construction, repairs or inspections. Therefore one cannot find in any location a complete set of documents for a given structure.

S.5 Findings of the Commission

The evidence clearly shows that the design of the de la Concorde overpass did not contravene any critical provisions of CSA Standard S6-1966.

Moreover, the specifications regarding the type of concrete to be used were confusing and resulted in the use of low quality concrete.

The construction of the overpass was punctuated with unfulfilled obligations and faulty installation. The same is true of its management which was characterised by lax inspections and interventions.

The general lack of accountability for the quality control of the work and materials was the most obvious weakness observed during the construction phase of the overpass. DSA failed to live up to its responsibilities with regard to work supervision. In spite of the clear legal and contractual obligations regarding quality of work and compliance with drawings and specifications to which they were bound, ISP and its subcontractors did not fulfill their responsibilities; instead, they passed them on to workers and to the consulting engineers.

Based on the inspection reports submitted and the testimonies heard by the Commission on this matter, it is clear that for over 30 years, the *Ministère*'s staff was aware of the peculiarities of the de la Concorde overpass, a structure built according to an unusual concept that posed serious inspection problems.

Yet for the entire period of time during which the MTQ was responsible for the overpass, the structure was never subjected to an inspection and maintenance programme that took into account its particular characteristics, notably, the critical beam seats at the ends of the cantilevers. The fact that scheduled maintenance activities were delayed demonstrates this clearly. The 1992 repairs were a missed opportunity to understand and repair the structure. Indeed, despite the evidence of serious deterioration in the concrete and improper installation of the rebars, the repairs were performed without re-evaluating the condition of the structure and without installing the specified protective membrane. A second opportunity to conduct a detailed evaluation was also missed in 2004 when an engineer expressed his concern about the condition of the structure.

S.6 Causes of the collapse

The Commission concludes that no single entity or individual can be assigned the responsibility for the collapse. None of the defects or omissions identified could have in itself caused the collapse, which resulted from a chain of causes.

The tragic event of September 30, 2006, results from an accumulation of shortcomings: the design codes applicable at the time which would be considered inadequate today; the design itself; the construction work; and the management of the structure during its useful life. It is with this in mind that the blames and reproaches expressed in this report should be understood and interpreted.

The collapse of the de la Concorde overpass stems from a chain of physical causes that have been identified with a high degree of certainty. Both the participants' and the Commission's experts agree on the main physical causes of the collapse. However, different opinions have been expressed as to the secondary causes. The Commission believes that some of the secondary causes are significant, as are the human interventions which allowed the physical circumstances of the collapse to develop.

The fact that the physical causes were not detected and corrected before September 30, 2006, raises two questions: could the collapse, or at the very least, the existence of a major structural defect, have been foreseen, and was it avoidable? The MTQ experts answered no. For its part, the Commission sought to answer another question: how did we get to this point?

While the collapse of the de la Concorde overpass happened in an instant, this tragedy is the culmination of a gradual deterioration that was many years in the making. At play were both organisational and human causes that include failure to fulfill obligations and to comply with procedures, incomplete files, lack of team work, missed evaluation opportunities, and an approach that did not take into account the special character of this overpass. On September 30, 2006, the de la Concorde overpass just about collapsed under its own weight. To do so, it had to have reached an advanced state of deterioration.

S.6.1 Principal physical causes

Experts agree that the overpass collapsed as a result of shear failure of the south-east cantilever.

The deterioration of the concrete and not of the rebar was behind the collapse.

The collapse was due to the development and growth of a crack in a zone of weakness located under the upper rebars starting from the beam seat area. Over the years, the freeze-thaw cycles, along with de-icing salts, caused the concrete to deteriorate in this area. This deterioration caused a cracking plane to spread inside the thick slab.

While the exact source of the cracking has not been determined with certainty, there is consensus among the experts as to the main physical causes of the collapse and agreement on the following points:

Improper rebar detailing during design
In the structure as designed, the concentration of numerous rebars on the same plane in the upper part of the abutment created a plane of weakness where horizontal cracking could occur. Top bars No. 14 were not anchored at the end. Detailing by today's standards would require that the No. 8 U shaped hanger bars be hooked around No. 14 bars.

Improper rebar installation at the time of construction
There was a potential horizontal plane of weakness due to the high concentration of rebars at the top of the beam seat. The incorrect placement of the U shaped hangers and diagonal bars created a much larger zone of weakness extending deeper inside the thick slab.

Low quality concrete used for the abutments
The expert studies showed that the concrete in the abutments did not have the necessary characteristics to resist freeze-thaw cycles in the presence of de-icing salts; the concrete was, in fact, too porous and the air bubble network was deficient.

As for the exact origin of the cracks, the experts pointed to a number of possible causes, including:

- The high bond stress between the No. 14 bars and the concrete in the area of the bearing support.
- The presence of a zone of weakness above the U-shaped hanger bars.
- Concrete deterioration due to successive freeze-thaw cycles in the presence of de-icing salts.
- Shrinkage of the concrete at the level of the longitudinal bars.
- Thermal stresses induced by the heat of hydration of the concrete, by solar radiation and by the placement of hot asphalt.
- Repeated traffic and vehicle impact on the expansion joint.
- Corrosion of the No. 8 and No. 14 bars.

S.6.2 Contributing physical causes

Lack of shear reinforcement in the thick slab
The thick slab of the de la Concorde overpass should have included shear reinforcement if the calculations had taken into account current Code requirements. According to the experts, the shear reinforcement would have intercepted the zone of weakness and controlled the internal cracking. The collapse could then have been prevented, or at the very worst, would have occurred gradually, accompanied by noticeable deformations.

Surface of the thick slab was not watertight
Absence of an adequate protection of the thick slab, which should have been installed during the 1992 repairs, exacerbated the deterioration of the concrete, one of the main factors that led to the collapse. In 2006, the thick slab of the cantilever had deteriorated severely in some places. Successive freeze-thaw cycles do not cause the concrete to deteriorate if it is not saturated with water. The need to protect concrete structures under roads has long since been documented, and high-performance membranes have been included in the MTQ's general specifications since 1978.

Damage caused during the 1992 work
All but the MTQ's experts believe that the work performed in 1992 played a role in accelerating the growth of the critical crack already present in the mass of the cantilever. Extensive damage was noticeable during the work and a lot more concrete than planned had to be removed, which exposed the U shaped hanger bars and the main No. 14 bars over a considerable distance. The Commission agrees with most of the experts that these observations should have prompted the MTQ to evaluate the structure and shore up the cantilevers.

S.6.3 Conclusions with respect to persons, firms and organisations involved

The Commission blames DSA, its supervising engineer Marcel Dubois, and its managers responsible for the site for not fulfilling their contractual obligation to exercise full-time supervision of the construction of the overpass and therefore, for not preventing the faulty installation of the steel reinforcement that resulted in a structure not in accordance with the drawings and specifications.

The Commission blames contractor ISP and its managers responsible for the site for failing to meet their legal and contractual obligations. It also blames ISP's principal subcontractor, AAM, and its President, Claude Robert, for failing to adequately control the quality of the work by passing on their responsibilities to the workers and to the supervising consulting engineer. This lack of quality control explains the faulty installation of the steel reinforcement, one of the main physical causes of the collapse.

The Commission is of the opinion that the vulnerabilities of the de la Concorde overpass a unique structure that was difficult to inspect, were not taken into account adequately by the MTQ; in its interventions, the MTQ did not rigorously and effectively deploy all the means at its disposal to properly evaluate the condition of the overpass despite numerous signs of deterioration; it also failed to maintain adequate records that could have better guided its inspectors and maintenance workers.

The Commission finds that the overpass inspections were at times deficient, lacking adequate quantification of the deterioration, sometimes incomplete because not enough time was devoted to the inspections, and not thorough because the inspectors failed to look for the reasons behind the deterioration.

More specifically, the Commission finds that the *Ministère* missed at least two opportunities to inspect the structure in detail, first, at the time of the repairs in 1992, and again, when the *direction territoriale* engineer responsible for the structure expressed his concern to the *Direction des structures*. However, in light of the many systemic weaknesses observed, while it reproaches engineer Tiona Sanogo for his management of the repair work in 1992 and deplores the incomplete inspection conducted by engineer Christian Mercier in 2004, the Commission lays most of the blame on the *ministère des Transports du Québec* for tolerating ambiguous accountability, for its lack of rigorous record keeping, and for not developing an adequate inspection and maintenance programme despite knowing about the special characteristics of the de la Concorde overpass.

S.7 Recommendations[2]

The Commission's recommendations are based on evidence presented during the hearings and on the work of experts, as well as on consultations held with various organisations and individuals interested in infrastructures.

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[2] This section summarises Chapter 7.

The following recommendations cover updating codes, standards and manuals, and the legal framework for the design and construction of structures, including supervision. They also cover MTQ management and propose a rehabilitation programme for Québec's bridges.

The Commission's recommendations encompass all the parties involved in design of structures, their construction and its supervision, and their management. They also take into account the daunting task of rehabilitating these structures. The Commission was guided by four major principles: the effective use of public funds, the use of the best expertise available, the accountability of the designers and contractors for the quality of their work, because they all have a role to play in public safety, and lastly, the importance of being rigorous in implementing infrastructure management systems.

S.7.1 Codes, standards, manuals

The Commission concludes, based on the work of its experts, that the requirements for shear reinforcement in thick slabs are insufficient, even in the CSA-S6-2006 version of the Code.

Recommendations of the Commission

1. **Revise CSA-S6-2006 Code**
   The Commission recommends a revision of CSA-S6-2006 in order to require at least minimum shear reinforcement in thick slabs.
2. **Define concrete quality requirements**
   The Commission recommends that as regards bridges, Government require the use of high-quality concrete that meets the updated requirements set out in the CSA-S6-2006 and in CSA-A23.1-2004 and that all related MTQ manuals be modified accordingly.
3. **Improve the knowledge acquisition process**
   The Commission recommends that the MTQ take all useful measures to insure that its personnel in charge of designing bridges and updating codes and manuals have accelerated, timely access to new developments in the field.

   To this end, the Commission recommends that the Government ensure that there be an effective surveillance of scientific intelligence processes and knowledge involving academics and top-level practitioners; this will ensure that persons responsible for designing and maintaining structures, both in private practice and in Government services, be kept constantly informed of new developments and changes in standards and practices.
4. **Update of MTQ manuals**
   The Commission recommends that the inspection and evaluation manuals dealing with the critical load carrying capacity of structures be updated, paying special attention to the recommended timing of interventions, to inspection surveys of cracking and their interpretation, to structural condition assessment, and to the requirements of Chapter 14 of the CSA-S6-2006 Code.

S.7.2 Design, construction and supervision

Bridges are far more complex than freeways and most other types of civil engineering structures. Their design requires a high level of specialised engineering knowledge and expertise. Their construction demands rigour and proficiency in structural engineering and in materials science, as well as impeccable control and supervision. The legal framework must take these elements into account.

Recommendations of the Commission

The Commission recommends that the Government review the legal framework for the design, construction and construction supervision for new structures and for major rehabilitation work, more specifically:

5. **Develop a competency-based policy for granting consulting engineering mandates**
   The Commission recommends that the Government use a transparent process to develop a policy for granting consulting engineering mandates for the design of structures and for the supervision of the construction work. Besides taking into account the competence of firms and of the individuals assigned to projects, this policy should provide for an evaluation of the candidate's past performance on similar contracts. Cost should then come into play only for the selection of a firm among those meeting the competence criteria.

6. **Develop a concept validation policy**
   The Commission recommends that any mandate for structure design should specifically be validated (verification of designer's concept, drawings and calculations). In the case of a consulting engineering firm, the contract should stipulate that the validation be subject to a certificate signed by an engineer, officer of the company. For projects to be executed by MTQ engineers, the departmental procedure should require the signature of a hierarchical superior to whom the design engineer reports and who is himself an engineer. In both cases, the engineer signing the validation certificate should have supervised the work. An alternate option is to have an independent firm perform and certify the validation.

7. **Implement a prequalification system for contractor selection**
   The Commission recommends that contractors be subject to selection criteria that take into account their qualifications for the type of structure to be built. Cost would then come into play among those contractors that fulfilled the competence criteria.

   To this end, the Commission recommends that the Government implement, at least for structures, a transparent prequalification system that takes into account the experience, qualifications, prior performance and quality control systems of the contemplated firm as well as the skills of the individuals proposed for the contract.

8. **Obtain information regarding turnover of key personnel**
   The Commission recommends that the person in charge of prequalifying engineering consulting firms and contractors ensure, when awarding the contract, that the selected

firm still has in its employ key personnel on which its qualification is based and that such personnel will be available for the duration of the work.

9. **Control of sub-contracting**
   The Commission recommends that sub-contracting requirements be rigorously implemented to all structure projects. In their bids, general contractors must always be required to identify the work performed by their own teams. They must also identify their sub-contractors and the work entrusted to them, as well as produce a work quality-control plan for their own employees and those of their sub-contractors.

10. **Implement an inspection process when structures are delivered**
    The Commission recommends that for all structures built in Québec, the supervisor of the work be required, upon delivery of the completed structure, to assemble all the documents associated with the work and the structure, including, without limitation to the foregoing, the "as-built" drawings, specifications, steel reinforcing bar and other lists, jobsite logs, material control reports and any details that might require an adjustment to be made to the inspection and maintenance programmes.

    The Commission recommends moreover that the owner of the structure be given the responsibility of keeping these documents during the entire life of the structure.
    The Commission also recommends that an engineer certify that the structure was built in accordance with drawings and specifications.

11. **Conduct performance evaluations**
    The Commission recommends that all owners of structures evaluate, at the end of the work, the performance of the consulting engineering firms responsible for the design and supervision and also evaluate the performance of the contractors, and that these evaluations be kept on record.

S.7.3 Bridge management by the MTQ

The MTQ prepared a comprehensive report for the Commission describing its organisation, work methods and management. After reading the report, hearing testimonies and analysing the evidence, the Commission finds that the stated ideal of excellence and efficiency is not, in fact, being fully achieved.

During its inquiry into the collapse of de la Concorde overpass, the Commission noted reluctance on the part of the *Ministère*'s professionals to work in a hierarchical structure, with each one more or less left to his own devices when it comes to decision-making and exercising his responsibilities. This reluctance exists both when engineers work together as well as when a *direction territoriale* calls on the *Direction des structures*. This situation results in unclear accountability and adversely affects the *Ministère*'s effectiveness and efficiency.

Although the Commission finds the MTQ's manuals generally adequate, the procedures they set out are not always respected. As a result of poor record keeping, documents lack clarity and after a few years, it becomes difficult to keep track of the structure's condition.

The Commission also finds a systematic reluctance on the part of the *Ministère* to ask itself fundamental questions as to why the de la Concorde overpass was deteriorating, to look for the elements missing from the structure's file, and to seize opportunities to conduct a detailed condition evaluation.

Recommendations of the Commission

12. Improve the MTQ's culture and work methods

The Commission is of the opinion that the *Ministère* must take action to address shortcomings in respect of its work, notably, as regards to poor record keeping, unclear accountability and the apparent difficulty of engineers to impose their professional judgment. The *Ministère* should implement an action plan to rectify this situation.

13. Prepare and maintain complete records

The Commission recommends that the *Ministère* implement an accelerated, comprehensive and easily accessible on-line system containing all records and data relevant to the structure, including reports on inspections and repair activities. The Commission also addresses this recommendation to municipalities with populations of over 100,000.

14. Clarify the relationship between the directions territoriales and the Direction des structures

The Commission recommends that the *Ministère* clarify the responsibilities, functions and roles of the *directions territoriales* and the *Direction des structures* and ensure that these clarifications be communicated to the professionals and personnel concerned. Without recommending that structure inspection and maintenance be centralised at the *Direction des structures*, the Commission recommends that even if the *Direction des structures* does not assume responsibility for administrative management or the direct management of the work, it should be held jointly accountable with the *directions territoriales* for solutions to problems for which its expertise was solicited.

15. Add specific objectives to the structure inspection manuals

The Commission recommends that the MTQ include certain requirements currently missing from its structure inspection manuals but that appear in guides used by other North-American jurisdictions:

- formulate a diagnosis when damage is observed.
- diagnose not only structural but also material-related problems.
- adapt the inspection system to different types of structures under various conditions.

S.7.4 Municipal bridges

The Commission finds inconsistencies in the system used to manage the bridges in the municipal road network ("MUNRN"). These bridges belong to municipalities with populations of less than 100,000 that do not and will never have the necessary resources to manage them. Although these bridges are not owned by the MTQ, it nevertheless handles inspections, establishes repair priorities and subsidises the work.

The nine municipalities with a population over 100,000 manage their own bridges and are presumed to have the resources to adequately assume their responsibilities. The MTQ offers them technical assistance with such matters as inspector training, inspection manuals and work specifications. The Commission did not examine the situation of these municipalities and is not formulating any recommendations in their regard, other than the need to maintain complete records on the structures under their responsibility.

Recommendations of the Commission

16. Clarify accountability with respect to the MUNRN

The Commission is of the opinion that the management framework of MUNRN bridges should be reviewed to better reflect reality. On the one hand, the MTQ evaluates the bridges, determines the priority of rehabilitation work and subsidises the work, while on the other, small municipalities do not and will never have the necessary resources to manage structures of this magnitude.

The MTQ should regain ownership of all the MUNRN bridges or, at the very least, fully assume responsibility for their inspection, maintenance and ultimately, replacement. The Commission is of the opinion that municipalities should remain responsible for street lighting, road signs, sidewalk maintenance and snow removal on structures on their territory.

S.7.5 Rehabilitating Québec's bridges

The need for a broad-based bridge rehabilitation programme gradually became apparent as the Commission performed its work and saw mounting, irrefutable evidence. The Commission itself, as well as the organisations it consulted, are convinced of the urgency to act in this regard.

Ontario, where 68% of bridges are in good condition, wants to see this figure reach 85% by 2021. In the U.S., where 75% of bridges are in good condition, the improvement initiatives undertaken in the mid-1990s continue.

The Commission recommends the implementation of a programme at the end of which the proportion of bridges in good condition will increase from their 2005 level of 53,6% for bridges of the Primary Road Network ("PRN") and 51% for MUNRN bridges to 80% for both networks. In fact, this 80% target should apply to all 12,000 bridges in Québec. The Commission is of the opinion that a ten-year period at the very least will be required to reach this objective.

Although it has only partial data, the Commission can safely say that the Government will need to invest at least $500 million per year for the next 10 years in order to raise the condition indicator of PRN and MUNRN bridges to an acceptable level.

Moreover, while it will not comment on how such a programme should be structured, the Commission is of the opinion that its success is predicated on the following principles:

- Whatever the orientation selected by the Government (management by the MTQ, by an agency to be created, with or without participation from the private sector, including public-private partnerships) the magnitude of the programme dictates that it be managed as a major project, using best governance and management practices, rather than being subjected to the usual constraints of on-going operations.

- Such an initiative must be manned by a dedicated team whose sole and long-term focus is the project. Because it will attract quality human resources, turnover will be minimised, favouring the development of a qualified workforce and the formation of highly competent teams.

- The Commission recommends that independent experts be regularly solicited for advice and recommendations for improvements.

As the Government of Québec commits on a level of investment to rehabilitate Québec's bridges, the following conditions must be met to ensure the smooth operation of the bridge and overpass rehabilitation programme:

- Make a clear, firm commitment to provide, over a 10-year period, a steady, predictable budget dedicated solely to the rehabilitation of bridges and overpasses.

- Establish a clear distinction between the protected $500 million annual budget dedicated exclusively to the rehabilitation of existing structures and amounts allocated for new structure or large projects such as major works on the St. Lawrence River bridges or the reconstruction of the Turcot interchange in Montréal.

- Ensure that the authority responsible for the programme manages it by following clearly established and publicly announced long-term priorities – the first being the safety of the population – and by developing a predictable multi-year plan for the work.

Ensuring the programme's long-term predictability and stability will also allow the consulting engineering firms and the construction industry to develop on solid footing, and make it easier for the MTQ to plan its needs in human resources.

The Commission also suggests exploring funding schemes that can generate predictable revenues, that can be easily identified by taxpayers and that create a "user-payer" relationship. Public-private partnerships should also be contemplated for major projects aimed at ensuring the long-term safety of Québec's infrastructures; such an approach should include performance objectives and call for the structures to be returned in good condition at the end of the term, failing which clearly defined financial penalties should apply.

Recommendations of the Commission

17. The Commission recommends that the Government make bridge rehabilitation a national priority based on the following principles:

- Adopt the principle of a bridge and overpass rehabilitation programme for Québec's PRN and MUNRN networks with the goal of bringing the condition indicator up to a level comparable to that of neighbouring provinces and states.
- Make this programme a Major Project and ensure that it is managed according to best governance and management practices regardless of the organisation and financing methods selected, with or without private sector involvement.
- Dedicate a protected budget of at least $500 million per year for 10 years exclusively to the rehabilitation or reconstruction of existing structures.
- Ensure the programme is managed based on long-term priorities – the first being public safety – that are clearly defined and publicly announced by the appropriate authorities according to a predictable, multi-year work plan.
- Establish sources of financing that will provide stable, predictable revenues which taxpayers can easily identify by establishing the principle of "user-payer".
- Systematically call upon independent experts to recommend measures to improve the framework of management activities and quality control.
- If the Government chooses to involve the private sector, either in terms of financing or management, the participation should be conditional to the achievement of specific performance objectives and to the return of the structure in excellent condition, failing which clearly defined financial sanctions would apply.

S.7.6 Looking to the future

Most of Québec's infrastructures were built in the 30 years following World War II. Like the rest of North America, Québec faces the challenge of rehabilitating them, and in some cases that means rebuilding outright. This is a massive undertaking that will span many years. Meanwhile, Québec must continue to properly manage its aging structures.

At stake is not only public safety but Québec's ability to maintain first-rate infrastructures, which play a role in the quality of life of its residents and in Québec's economic development.

Aging infrastructures pose various challenges to the authorities responsible for their management, particularly in a context of budgetary constraints. The tragedy of the de la Concorde overpass serves as a reminder of the need to exercise the utmost rigour and discipline when designing, building and monitoring bridges. It highlights the importance of having a proper framework with standards, manuals and strictly implemented programmes to help inspectors and maintenance workers; it stresses the importance of encouraging them to always be vigilant and inquisitive when they encounter problems on bridges under their responsibility.

CHAPTER 1

1. THE COMMISSION, ITS MANDATE, ITS RULES OF PRACTICE AND ITS WORK

1.1 Mandate and Members of the Commission

On September 30, 2006, part of the Boulevard de la Concorde overpass[1] above Autoroute 19 in Laval collapsed, resulting in the death of five people and causing injuries to six others. On October 3, 2006, the Government of Québec adopted Order-in-Council 875-2006 establishing the Commission of inquiry into the collapse of part of the Boulevard de la Concorde overpass in Laval (the "Commission").

The Commission was constituted in accordance with Section 1 of the *Act respecting public inquiry commissions.*[2] Its mandate was as follows:

- Inquire into the circumstances of the collapse, on September 30, 2006, of part of the Boulevard de la Concorde overpass on Autoroute 19 in Laval.
- Determine the causes which led to this collapse.
- Make recommendations to the Government on the measures to take in order to avoid a recurrence of such events.[3]

Mr. Pierre Marc Johnson, former Premier of Québec, physician and of counsel with the offices of Heenan Blaikie, a law firm in Montréal, was appointed Commissioner and Chairman of the Commission. Mr. Armand Couture, engineer, President of Société Bédelmar Ltée, and Mr. Roger Nicolet, engineer, President of Nicolet Chartrand Knoll Ltée, were appointed Commissioners.[4]

The original Order-in-Council establishing the Commission stipulated that a detailed report was to be submitted to the Government no later than March 31, 2007. However, in the first week of February 2007, the Commission's mandate was extended to October 15 for reasons related to the execution and drafting of the expert reports ordered by the Commission.[5]

Before the end of October 2006, the Commission had structured its teams charged with the administrative, technical and legal aspects of the inquiry. Heading each of these teams, were, respectively, Mr. Julien Lemieux, an administrator with experience in Government and in various commissions of inquiry,[6] Mr. Michel Lemoine, engineer and attorney, and Mr. Michel Décary, a counsel with an outstanding track record in the area of commissions of inquiry.

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[1] The term "*overpass*" is used in English, and the term "*viaduc*" is used in French. This is not a "viaduc" per se. To designate a structure passing above another road, the *Office québécois de la langue française* recommends the use of the terms *passage supérieur, saut-de-mouton* or *pont d'étagement*. This is what is meant by the term *viaduc* which appears in the French name of the Commission, in this report and in the other documents. For more details, see Chapter 2.

[2] R.S.Q., Chapter C-37 (Appendix 1).

[3] Order-in-Council 875-2006 (Appendix 1).

[4] See the summaries of the Commissioners' curricula vitae (Appendix 16).

[5] Order-in-Council 79-2007 (Appendix 1).

[6] Order-in-Council 916-2006 (Appendix 1).

This embryonic structure allowed for a very rapid launch of the Commission's work. Subsequently, the initial team was expanded to include a coordinator of expert studies, Mr. Paul Croteau, an engineer and Ph.D. in structural engineering, a graduate of the University of California at Berkeley, an assistant counsel, Ms. Marie Cossette, who had recently participated in the Gomery Commission, and a Commission Secretary, Ms. Nicole Trudeau, counsel, with several years of experience in commissions of this nature.[7] The Commission's full organisation is presented in Appendix 16.

1.2 Evidence Preservation Programme

Clearing of the site began in the hours following the collapse, under the supervision of the Sûreté du Québec (the "SQ"), which was then the custodian of the site. The Chairman asked the Government authorities to ensure that no documentation be destroyed and that any dismantling of the north span of the de la Concorde overpass or the east and west abutments be suspended. The purpose of this request was to enable the Commissioners to visit the site and decide on how the operations should continue, in light of the Commission's mandate. Later, the same decision was made with respect to the de Blois overpass.

The Commission undertook a series of meetings with the SQ and with the *ministère des Transports du Québec* (the "MTQ"). The purpose of these meetings was to determine how to gather, preserve and examine the evidence, define the photographic operations to which it had to be subjected, and ensure accessibility of the pieces transported to and stored at the Belgrand site in eastern Laval. The discussions with the MTQ also focused on the list of structures exhibiting certain similarities with the de la Concorde overpass, which the MTQ was already trying to determine with the aim of adopting an action plan designed to locate potentially vulnerable structures.

The Commissioners visited the site of the collapse on October 5. They then developed an evidence preservation programme aimed at protecting all of the evidence considered necessary for the proper conduct of the Commission's work, particularly the work that was to be assigned to experts.[8]

Either alone or jointly with the SQ, the Commission implemented the following measures:

- Complete survey of the de la Concorde and de Blois overpasses.
- Radar surveys of different abutments of these two structures.
- Core sampling in the de la Concorde and de Blois overpasses.
- Examination of the interior of the core holes.
- Opening of observation windows in the de la Concorde and de Blois overpasses.

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[7] Order-in-Council 1008-2006 (Appendix 1).

[8] Appendix 2.

- Collection of two concrete blocks for sampling, one from the southeast abutment and the other from the northeast abutment of the de la Concorde overpass.

The report and the appendices of the Commission's experts, Jacques Marchand and Denis Mitchell, provide a more complete description of the preservation measures.[9]

The physical findings as well as the subsequent analyses flowing from the preservation programme allowed the experts to formulate hypotheses concerning the possible causes of the collapse of the de la Concorde overpass. These findings and results are set out in Chapter 5 of the report.

On October 20, the Commission decided that the evidence preservation programme had been completed to its satisfaction. It informed the SQ, still custodian of the site of the collapse, which immediately turned over responsibility to the MTQ. On the morning of October 21, the MTQ began dismantling the de la Concorde and de Blois overpasses, with a view to the reopening of Autoroute 19 on October 26.

1.3 The Commission's Work Plan

In parallel with the development of the evidence preservation programme, the Commissioners established a work plan for the conduct of the inquiry and the public hearings, and ultimately for the drafting of the report.

For this purpose, they identified three main lines of research. The first two pertain directly to the collapse of the structure. The first line of research concerns the relevant documentation regarding the design, the construction work and its supervision, and the maintenance of the de la Concorde overpass, while the second pertains to the physical causes of its collapse. The third line of research, more general in nature, falls within the context of the recommendations solicited by the Government and led the Commissioners to study various topics related to the design, construction and management of structures, both in Québec and elsewhere.

1.3.1 Searches for and Identification of Documents and Documentary Sources

The Commission quickly drew up a preliminary list of documents relevant to its inquiry. This list was given to the MTQ's representatives, who endeavoured to find these documents both within the MTQ and at the National Archives of Québec. Searches were also conducted among other Government departments and agencies as well as in the private sector.

For reasons related, in particular, to the archiving policies in force at the time of construction of the de la Concorde overpass, which will be discussed in Chapter 4, the MTQ was unable to find many of the documents sought by the Commission. Among them, the bar list, the notes concerning the delivery, sampling and analysis of the concrete, the site log, the vast majority of the minutes of the site meetings and the "as built" plans of the de la Concorde and de Blois structures. Nonetheless, over 3,200 documents, representing approximately 26,000 pages, were given to the Commission.

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[9] Exhibits COM-62, COM-62A, COM-62B, COM-62C, COM-63 and COM-63B (Appendix 10).

The searches conducted among the various interveners responsible for design and construction proved to be fruitless, with one exception. Mr. Gilles Dupaul, at that time an engineer with Desjardins Sauriol & Associés ("DSA") and designer of the de la Concorde and de Blois structures, had kept excerpts from the plans of the de la Concorde overpass, referring to multiple revisions, the last of which was dated August 17, 1970. Mr. Dupaul gave a copy of these plans to the Commission. These were the most up-to-date plans provided to the Commission and its experts for consultation.

1.3.2 Research Concerning the Physical Causes

The Commissioners also undertook to develop a research programme on the physical causes of the collapse with the assistance of the Commission's Technical Unit. They thus identified several technical aspects that would require in-depth expert studies. The main technical aspects are:

- The codes, standards and trade practices in force at the time of design and construction, and their updates up to 2006.
- Applicable trade practices in the inspection, maintenance and repair of structures.
- The properties of the materials, including concrete.
- The overpass structural behaviour as determined through various numerical analysis.
- The dissection of certain pieces of the de la Concorde overpass.

For this purpose, the Commissioners called on two experts, Jacques Marchand, Eng., Ph.D., and Denis Mitchell, Eng., Ph.D. Mr. Marchand is an expert in concrete materials. Mr. Mitchell, for his part, is an expert in the analysis of concrete structures and their behaviour under load. Messrs. Marchand and Mitchell are internationally recognised and have acted as experts in many cases involving bridges and similar concrete structures, as indicated in their respective curricula vitae filed at the public hearings.[10] They also served as experts in the coroner's inquiry following the collapse of the Boulevard du Souvenir overpass in Laval in June 2000.

Originally, Messrs. Marchand and Mitchell had been mandated by the SQ to assist it in its investigation. The Commission quickly found out that their experience would be extremely valuable in helping it to fulfill its mandate. It thus took steps to ensure that Messrs. Marchand and Mitchell would serve as the Commission's experts.

Subsequently, Messrs. Marchand and Mitchell enlisted the services of several other experts with skills to complement their own expertise. These experts supported them in the performance of the various expert mandates assigned to them by the Commission starting in late November 2006. These experts included Messrs. Michel Bédard, land surveyor, Pierre Bélanger, land surveyor, M.Sc., Marc-André Bérubé, Eng., Ph.D., Benoît Bissonnette, Eng., Ph.D., Richard Cantin, Eng., Ph.D., Omar Chaallal, Eng., Ph.D., Michel Chouteau, Eng., Ph.D., William D. Cook, Ph.D., Les Davis, Ron Grieve, Jean Hamaoui,

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[10] Exhibits COM-67, COM-67A and COM-67B (Appendix 10).

Eng., Claude Lelièvre, Ph.D., Éric Ouellet, Eng., M.Sc., Pierre Proulx, Eng. and Alexander M. Vaysburd, Eng., Ph.D.

1.3.3 General Research Related to Management of the Structures

The third line of research concerns the recommendations that the Government seeks to obtain from the Commission regarding the measures to be taken to ensure there are no more collapses such as the one of September 30, 2006. The Commissioners established a research programme to deepen their knowledge of certain subjects relevant to the management of a large network of transportation structures. This research programme mainly focused on the following topics.

Responsibility for bridges, overpasses and other similar structures located in Québec, as well as their management, falls mainly on the MTQ or one of the nine large municipalities that have a population of more than 100,000. The Commissioners examined the applicable legislation, particularly the *Act respecting roads.*[11] They also took an interest in the concept of “shared jurisdiction”, which applies to certain Québec bridges and overpasses. They met with interveners, particularly in the municipal sector, with the aim of better defining certain key issues, such as maintenance of bridges under “shared jurisdiction”.

The Commissioners also looked at other jurisdictions in order to compare practices in Québec with those prevailing elsewhere, particularly in Ontario and the United States of America.

The Commissioners also explored various aspects of the construction of transportation structures, which is far more complex than that of other civil engineering structures. The topics explored include the qualification of contractors, the tendering process, the supervision of professionals as well as contracting methods for the design and construction of structures.

1.4 Legal Aspects of the Inquiry

Under the authority of Mr. Michel Décary, Senior Counsel the Legal Unit undertook to find people and witnesses who could be useful in terms of the first two components of the Commission’s mandate. Numerous efforts were required to contact people whose activities in connection with the development and life of the structure dated back nearly 40 years. Parallel to this, the Commission adopted the *Rules of Procedure and Operation* proposed by the Legal Unit (the “Rules”).[12] These rules mainly governed the status of participant and the status of intervener, the conduct of the hearings, the procedures for formulating requests to the Commission and the process regulating preliminary interviews of witnesses and the conduct of examinations during the hearings. It also set the conditions for the admissibility of the evidence, the procedure for hearing experts and the tabling of their reports, as well as the parameters for the use of documents at the hearings.

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[11] R.S.Q., Chapter V-9.

[12] Appendix 3.

Participant status was granted to all persons[13] who, in the Commission's opinion, had [TRANSLATION] "*a material and direct interest in the subject of the inquiry*".[14] Intervener status was given to all persons who, in the Commission's opinion, had [TRANSLATION] "*a real interest in the questions raised in the mandate of the inquiry, as well as a special view or expertise, which could [...] assist [the Commission]*".[15]

Sections 12 and 13 specified the rights of the participants and interveners, namely:

- To obtain advance notice of the documents which the Commission's counsel propose to file as evidence.
- Whenever possible, to obtain advance communication of the evidence.
- To propose to the Commission's counsel that they call certain witnesses or request an order compelling a specific witness to appear.
- To present a written brief.

1.4.1 Preliminary Hearings and Decisions Rendered

1.4.1.1 Participant and Intervener Status

On March 2, 2007, the Commission issued a public notice[16] inviting any interested person or organisation to send it a request for participant or intervener status, in accordance with Section 10 of the Rules.

The Commission received seven requests: five for participant status and two for intervener status.[17]

On March 12, 2007, the Commission heard the various requests.[18] On the following March 15, it granted[19] participant status to:

- Messrs. René Therrien, Gilles Dupaul and the employees and partners of DSA.
- Inter State Paving inc.
- the *ministère des Transports du Québec.*
- the City of Laval.

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[13] Section 2 g) of the Rules: [TRANSLATION] *"Person means an individual, a group, the governments, the organisations and any other entity".*

[14] Section 8 of the Rules.

[15] Section 9 of the Rules.

[16] Public Notice (Appendix 1).

[17] Request for participant or intervener status (Appendix 4).

[18] Transcripts, March 12, 2007 (Appendix 9).

[19] Decision of the Commission, March 15, 2007 (Appendix 4).

The Commission also granted[20] intervener status to the following organisations:

- *Coalition pour l'entretien et la réfection du réseau routier du Québec.*
- *Ordre des ingénieurs du Québec.*

The *Association professionnelle des ingénieurs du Gouvernement du Québec* ("APIGQ") requested participant status. The Commission granted it intervener status, because it considered that, firstly, while its members had undeniable experience, it was up to the MTQ to answer for its personnel and, secondly, that the APIGQ as an association did not have a direct material interest since it was neither specifically nor directly concerned by the inquiry.[21]

1.4.1.2 Motion for Recusation

On March 27, 2007, the APIGQ served on the Commission a Motion for Recusation against the Chairman of the Commission, Mr. Pierre Marc Johnson, and one of its Commissioners, Mr. Armand Couture.[22]

On March 29, 2007, the Commission heard the APIGQ's Motion,[23] which was dismissed on the following April 4.[24]

1.5 Hearings on the Merits

On March 2, 2007, the Commission issued a public notice setting April 10, 2007, as the beginning of its hearings on the merits.[25]

In addition to the two preliminary procedural sessions, the Commission sat for 30 days and heard 58 witnesses.

The hearings began at 9:30 a.m. on April 10 at the Sheraton Hotel in Laval, and continued on April 11 and 12. They then moved to Montréal to premises made available by the Chair of the *Commission des lésions professionnelles* at 500 Boulevard René-Lévesque Ouest. These hearings ended on July 31 with the presentation of the briefs of the participating and intervening parties.

The hearings were conducted in three distinct segments: the first concerned the factual evidence, the second concerned the expert evidence and the third was devoted to presentation of the briefs of the participants and interveners.

The Commission heard the factual evidence over the course of 17 hearing days, from April 10 to June 19. It heard 49 factual witnesses. The Commission also studied the sworn statements of 17 additional witnesses,[26] mainly people who were injured during the collapse or who witnessed this event.

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[20] *Idem.*
[21] *Idem.*
[22] Motion for Recusation (Appendix 4).
[23] Transcripts, March 29, 2007 (Appendix 9).
[24] Decision of the Commission, April 4, 2007 (Appendix 4).
[25] Appendix 1.
[26] Exhibits COM-12, COM-12k and l, COM-13, COM-13B, COM-14 and COM-55A (Appendix 10).

The presentation of the expert evidence lasted 12 days, from July 4 to 19. During this period, the Commission heard nine expert witnesses, whom it had called itself, or who had been called by the MTQ or by the engineers/designers.

During the hearings, 182 exhibits, including 10 expert reports, were produced as documentary evidence. Furthermore, 8 additional expert reports were filed as evidence.

After hearing the testimony, the Commissioners received the briefs submitted by six participants or interveners. On July 31, five of them presented their observations to the Commissioners and answered their questions.

The hearings were webcast in their entirety in real time via the Commission's website (www.cevc.gouv.qc.ca), for a total of 137 hours of webcasting. The video recordings of the hearings will remain available on that site until March 31, 2008. The audio recordings of the hearings and the transcripts will remain available on the site until March 31, 2009. Thereafter, they can be obtained from the *Service des archives du ministère du Conseil exécutif*. The Commission's website will provide information to that effect until March 31, 2009.

Finally, an official stenographer transcribed the content of the hearings in its entirety. The resulting approximate 7,200 pages of stenographic notes are included in Appendix 9.

CHAPTER 2

2. THE STRUCTURE, AS DESIGNED AND AS BUILT

2.1 General Layout

To clearly understand the causes of the collapse of September 30, 2006, it is essential to acquire knowledge of fundamental characteristics of the design of the de la Concorde overpass and review the concepts and realities which made this structure distinctive. Because of its design, infrequently used in North America, the overpass exhibited several characteristic features that largely determined its behaviour throughout its useful life.

The Commission's work revealed significant differences between the structure described on the design drawings (*as designed*) and the structure actually built (*as built*). These differences will be described.

The drawings and sketches of the *as designed* de la Concorde overpass, appearing in this chapter, were reconstituted from the most recent version of the plans held by Mr. Gilles Dupaul, the design engineer for DSA. The drawings of the *as built* structure were prepared based on experts' reports, concluding that the steel reinforcing bars had been placed incorrectly in the cantilevers of the abutments[1].

Box 2.1 gives a few explanations of both the terminological choices and the term *viaduc*, which the Commission decided to retain (in the French version of the report) even though it constitutes improper usage of French.

Box 2.1 *Viaduc, pont d'étagement, passage supérieur* or *saut-de-mouton?*

The French term "*viaduc*" is commonly used in Québec. It is found, in particular, in the Order-in-Council constituting the Commission of inquiry "*sur l'effondrement d'une partie du viaduc du boulevard de la Concorde*". However, according to the dictionaries, and in standard French, the term viaduc designates a bridge of great height or including multiple spans crossing a valley.

In engineering terms, the type of structure in question in this report is an overpass. As described in the Commission's glossary[2], this is a structure designed to pass over a road or railway artery.

However, the name "*viaduc de la Concorde*" naturally imposed itself throughout the heavy media coverage that followed the collapse and in the vast majority of the documents received by the Commission, which use this term extensively. The Commissioners therefore retained this term, considering that it pertained more to the proper name of the structure covered by this report than to the general category of structures to which it belongs.

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[1] There was a consensus on this point among the various experts: Exhibit COM-72 (point 1.6).

[2] Exhibit COM-2.

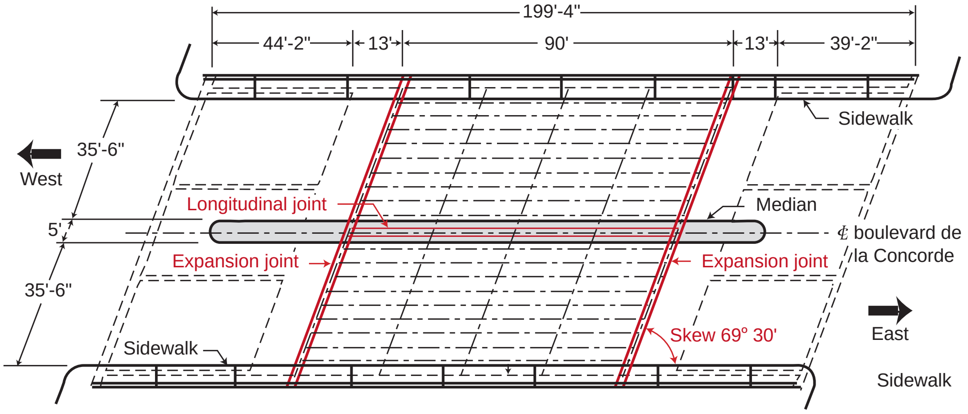

Figure 2.1 Plan View of the de la Concorde overpass

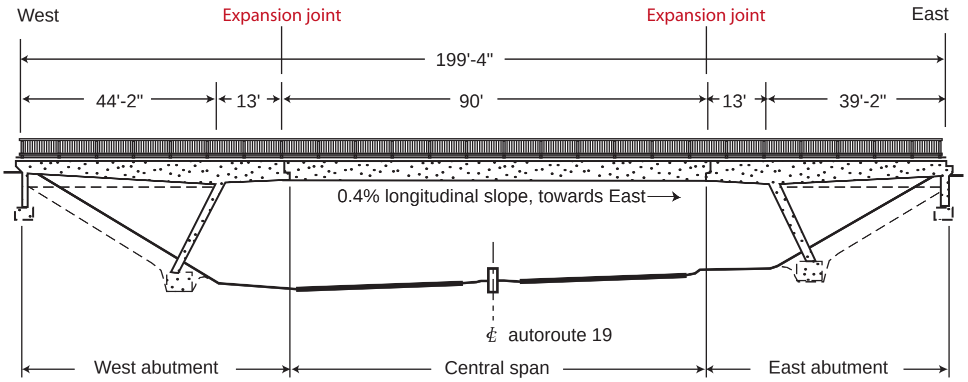

Figure 2.2 Elevation View of the de la Concorde overpass from Autoroute 19

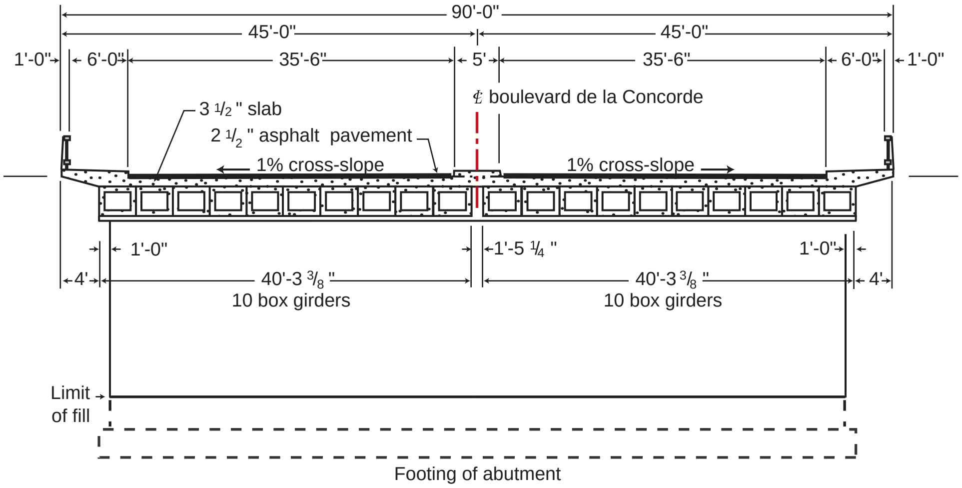

Figure 2.3 Cross-section of the de la Concorde overpass (along the Axis of Boulevard de la Concorde)

The de la Concorde overpass enables the unobstructed crossing of two very busy traffic arteries in the city of Laval: Boulevard de la Concorde, which passes on its surface, and Autoroute 19, which is constructed in a depression at this location. The structure carries six lanes of traffic: three westbound and three eastbound. Figures 2.1, 2.2, 2.3 and 2.4 show a plan view, an elevation view, a cross-section and a general perspective view of this structure respectively[3].

The plan view shows that the overpass has a skew, i.e., an angle different from 90 degrees between the longitudinal axis of the bridge (the axis corresponding to the direction of traffic) and the transverse axis (the axis perpendicular to the direction of traffic). The significance of this skew will be discussed in Chapter 5.

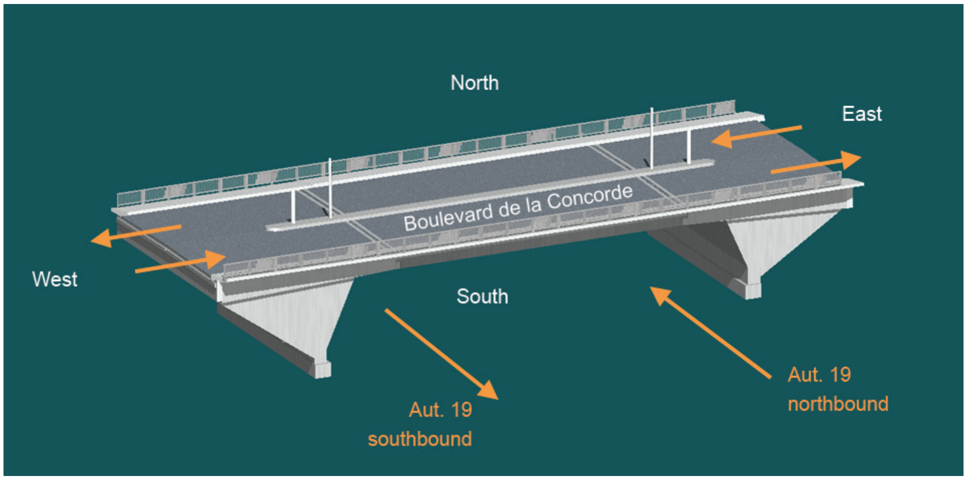

Figure 2.4 General Perspective of the de la Concorde overpass[4]

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[3] Figures 2.1, 2.2 and 2.3 are found in Exhibit COM-62, p. 7.

[4] Exhibit COM-2, p. 10.

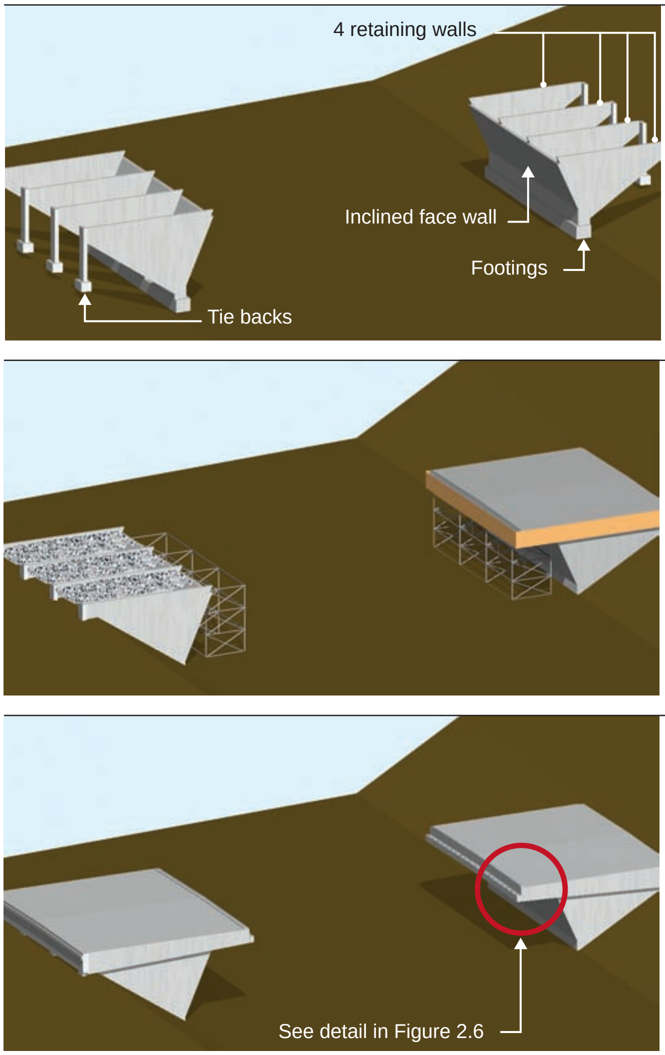

Figure 2.5 Sequence of Construction of the Abutments[5]

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[5] Exhibit COM-2, p. 34, 38 and 39.

2.2 Abutments and Reinforcing Bars, *As Designed*

The overpass has two abutments. These are the supporting structures located at the ends of the overpass. Each abutment is composed of an inclined wall at the front and four longitudinal retaining walls. These retaining walls support a thick reinforced concrete slab, part of which extends over Autoroute 19 forming a cantilever, a structure with only one supported end.

Figure 2.5 illustrates the sequence of construction of the abutments, while Figure 2.6 shows the details of the cantilever.

Stage 1: The footings are resting on the bedrock. Four triangular retaining walls, anchored in the rear to the bedrock by tie backs, support the front wall, which is inclined toward the freeway.

Stage 2: After backfilling of the caissons formed by the walls, the shorings and the formwork are prepared for construction of the thick slabs; the reinforcing bars of each slab are laid and then the concrete slab is cast.

Stage 3: The thick slabs are completed, forming a cantilever over the freeway.

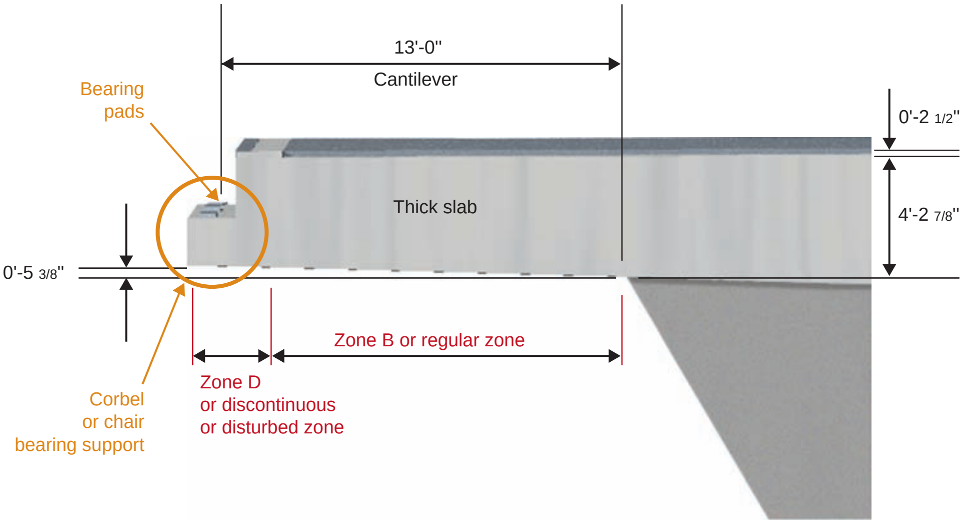

Figure 2.6 Diagram of the Eastern Abutment and Principal Dimensions

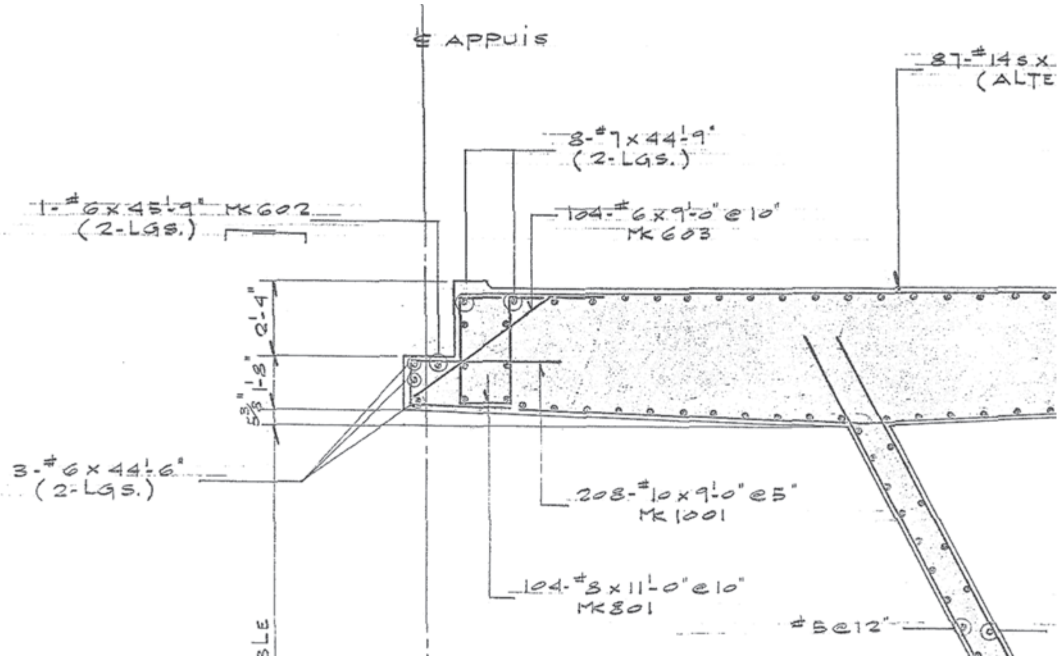

Figure 2.7 Layout of the Reinforcing Bars in the Cantilever of the East Abutment (Excerpted from the As Designed Drawings)

Figure 2.6 illustrates the cantilever which may be divided into two sections: a chair bearing support located at the free end, which supports the box girders of the central span, and a thick slab, which attaches the chair bearing support to the rest of the abutment. The equilibrium of the abutment is achieved by the tie backs into the bedrock at the opposite end from the cantilever.

The chair bearing support (or corbel) is an extension of the cantilever on which the box girders forming the central span of the structure are supported. The horizontal surface of the chair bearing support is called the seat.

Figure 2.6 also indicates the principal dimensions of the east abutment. From the wall of the abutment to the centre of the seat, the east and west cantilevers measure 3.96 m (13’). The total width of the abutments is 27.4 m (90’), including the overhanging sidewalks on each side, or 25.0 m (82’) without the sidewalks. The thickness of the slab varies. Including the thickness of the asphalt pavement, it is roughly 1.36 m (4’-5’ 3/8’’) at the origin of the cantilever at the face of the wall, and becomes slightly thinner, 1.22 m (4’), towards the chair bearing support.[6]

Figure 2.7, extracted from the design drawings, shows the layout *as designed* of the reinforcing bars (or rebars) in the cantilever of the east abutment of the de la Concorde overpass.[7]

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[6] Exhibit COM-62, p. 9.

[7] Exhibit COM-19, p. 15.

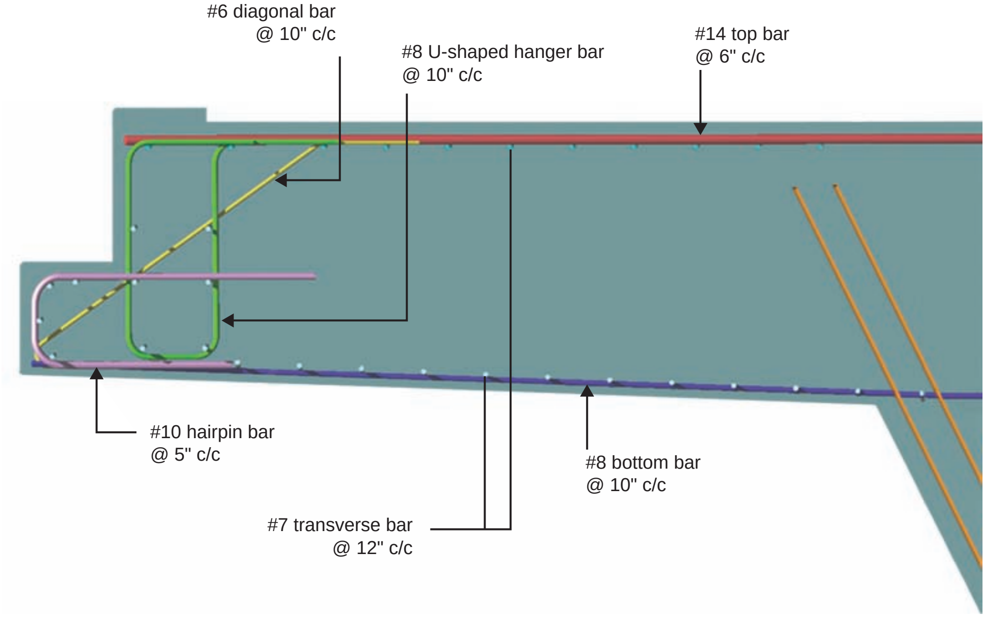

Figure 2.8 Layout of the Reinforcing Bars in the East Abutment Cantilever as Specified On the As Designed Drawings

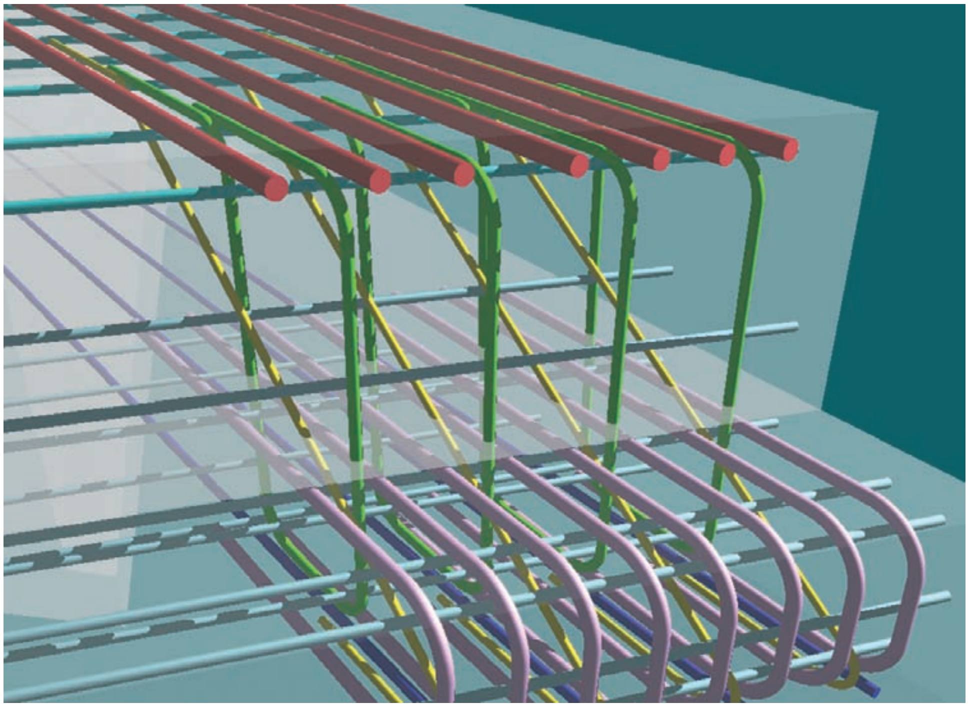

Figure 2.9 Perspective View of the Rebar Layout in the Chair Bearing Support Region as Specified on the As Designed Drawings

Figure 2.8, produced by the Commission's experts,[8] also illustrates the layout of the reinforcing bars *as designed*. In this figure, the colours and textures of the components replace the graphic conventions of the design drawing in Figure 2.7 and therefore each bar is shown in its intended location. On the top row of the reinforcing bars, for example, we note that the main bars (seen here in red and designated as No. 14 or sometimes No. 14 S), the horizontal hooks of the No. 8 U-shaped hanger bars (in green, called No. 8 U-bars in Figure 2.8) and the diagonal No. 6 bars (in yellow) are all placed on the same plane. Also it should be noted that the blue bars, designated transverse No. 7 bars, are placed parallel to the front wall and under the No. 14 bars. To better illustrate the layout of the reinforcing bars, Figure 2.9 provides a perspective view of the reinforcing bar arrangement at the end of the cantilever, in the region of the chair bearing support. Table 2.1 describes the different categories of reinforcing bars used.

Table 2.1 Dimensions of the Reinforcing Bars

Category	Colour in Figures 2.8 and 2.9	Diameter (in eighths of an inch)*	Diameter (mm)
No. 14 S bars (special)	Red	Slightly less than 14/8'' (1.693'')	43.0 mm
No. 10 bars	Pink	Slightly over 10/8'' (1.27'')	32.3 mm
No. 8 bars	Green or purple	8/8''	25.4 mm
No. 7 bars	Blue or pale blue	7/8''	22.2 mm
No. 6 bars	Yellow	6/8''	19.1 mm

* At the time of construction, measurements were reported in the imperial system. The bar sizes were designated by a number corresponding exactly to their diameter in eighths of an inch for No. 8 bars and smaller. For the larger bars, the bar numbers reflect the diameter only approximately.

Here is a description of the reinforcing bars found in the **cantilever** sections[9]:

- No. 14 S main bars (in red), placed longitudinally in the top part of the abutment. In the cantilever section, the spacing between these bars is 152 mm (6''). They are also sometimes called the "No. 14 bars".
- No. 7 transverse bars (in blue), placed under the No. 14 bars and spaced 305 mm (12'') apart.
- No. 8 longitudinal bars (in purple), placed in the bottom part of the abutment and spaced 254 mm (10'') apart.
- No. 7 transverse bars (in pale blue), placed above the No. 8 bars and spaced 305 mm (12'') apart.

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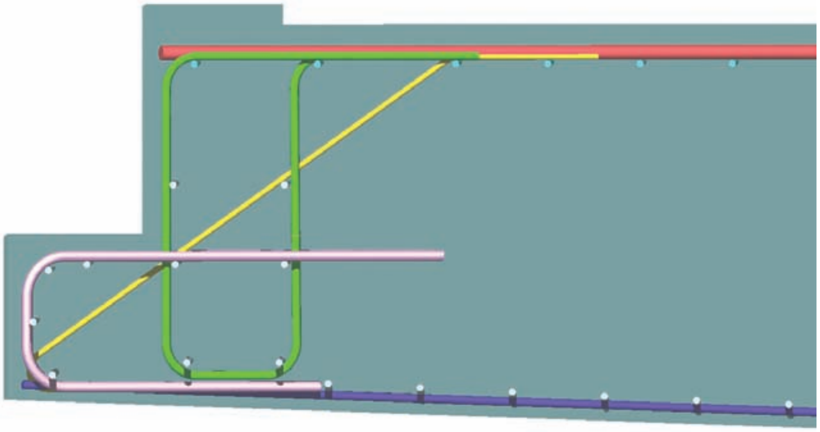
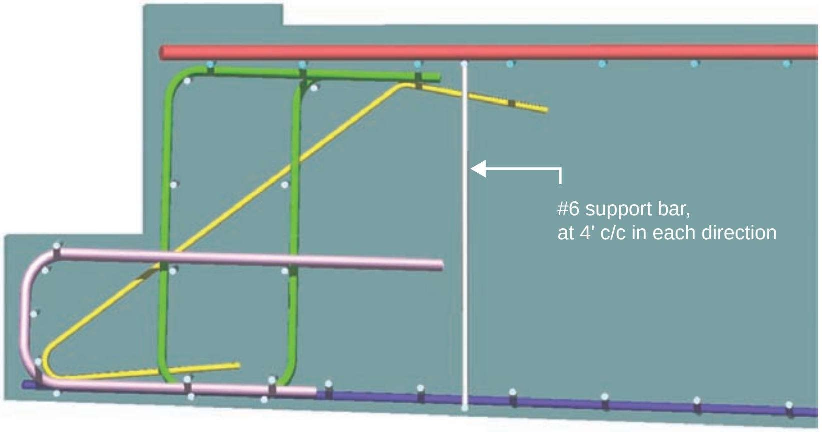
[8] Exhibit COM-2, p. 83.

[9] Exhibit COM-62, p. 8 and 9.



Chair Bearing Support Reinforcement, As-designed



Chair Bearing Support Reinforcement, As-built

Figure 2.10 Layout of the Chair Bearing Support Reinforcements *As Designed* and *As Built* in the Cantiliver of the East Abutment

The reinforcing bars in the chair **bearing support** region of the cantilever include:

- The No. 8 bars (in green), U-shaped hanger bars or ties, spaced 254 mm (10'') apart. The hanger bars are structural and meant to lift the load applied on the bearing seat support towards the top of the cantilever, in order to engage the No. 14 bending bars.[10]
- The No. 6 diagonal reinforcing bars (in yellow), prevent cracks from opening in the corner of the chair bearing support. These bars also serve to transmit the loads from the chair bearing seat to the top of the cantilever and to intercept the tensile stresses in the concrete near the support.
- The No. 10 pin-shaped bars (in pink) form the principal reinforcement of the chair bearing support or corbel and are spaced 127 mm (5'') apart. They transmit the loads exerted on the corbel towards the interior of the thick cantilever slab.

Chapter 5 will also mention another category of reinforcing bars called stirrups. Stirrups are used to resist shear stresses. Placed vertically or inclined, these bars usually end with a bend or a hook engaged on longitudinal bars at the top and bottom. In this way, they can resist tension over their entire height while remaining solidly anchored in the concrete. In the de la Concorde overpass, the thick slab of the cantilever did not contain any stirrups or any other type of shear reinforcement in the regular zone. In most of the cantilever, the shear stress is thus entirely resisted by the concrete alone. This fundamental feature of the de la Concorde overpass is central to the expert opinions discussed in Chapter 5.

2.3 Abutments and Reinforcing Bars, *As Built*

The Commission's work revealed that certain reinforcing bars of the abutments had not been installed in accordance with the plans. Figure 2.10 illustrates the differences between the *as designed* and *as built* structure. In particular, it shows that the U-shaped No. 8 hanger bars, and the diagonal reinforcing bars, did not end at the top in the same plane as the No. 14 bars, but instead *under* these bars. The significance of these differences is discussed in Chapter 5. It will also be noted that the contractor added some extra bars, including some No. 6 vertical bars, installed approximately every 1.2 m × 1.2 m (4' × 4'), and a few horizontal bars, so as to support the bars of the upper layers, which is a common practice.[11] There was no provision in the plans and specifications for the installation of these No. 6 bars.

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[10] In several documents and testimony, these hanger bars are described as "U-shaped stirrups". However, they play a very different role from that of stirrups, which serve as shear reinforcement in the elements subjected to bending.

[11] For more details on the reinforcement as built, see Exhibit COM-62D in Appendix A4 of the report of the Commission's experts.

Figure 2.11 Illustration of Tensile and Compressive Stresses

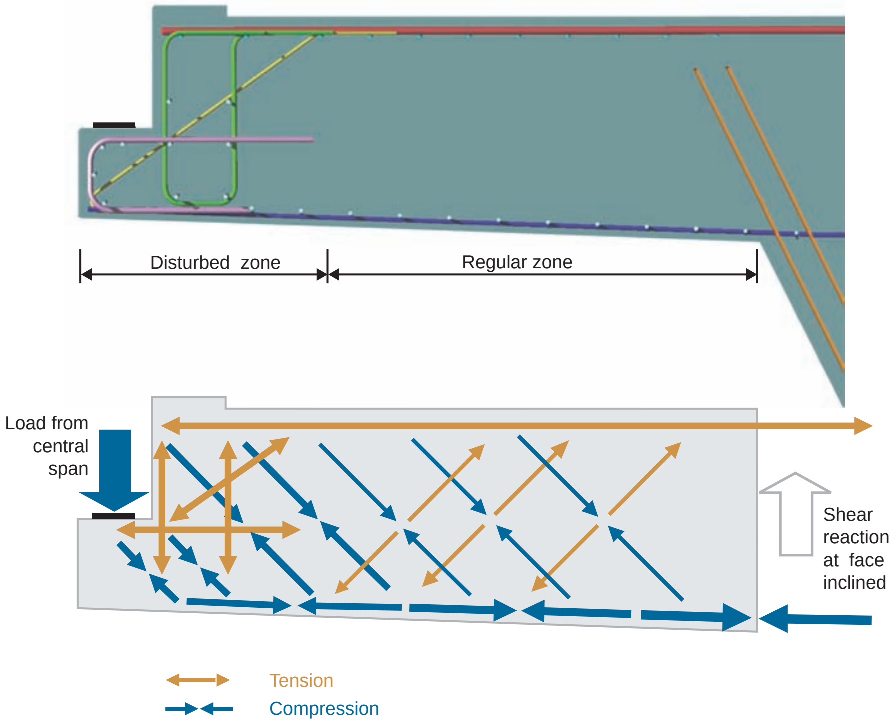

Figure 2.12 Diagram of the Path of the Internal Forces in the Cantilever

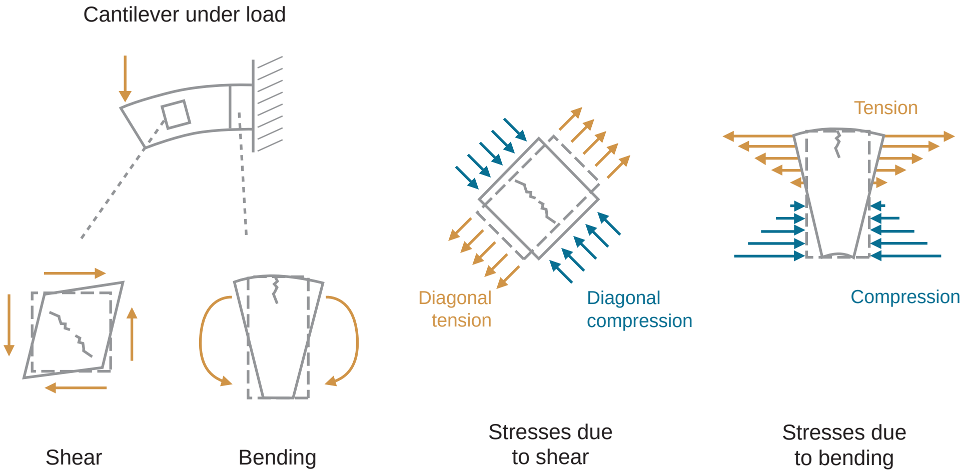

Figure 2.13 Illustration of Bending and Shear Stresses

As the reader will note in Chapters 5 and 6, this installation of reinforcing bars contrary to the plans and specifications had important consequences. To assess its full significance, we must also appreciate the forces and stresses exerted on the concrete, which the reinforcing bars should normally allow it to withstand. This is the subject of the next section.

2.4 Basic Concepts in Strength of Materials

2.4.1 Tension and Compression

All structures support loads. The materials forming the structure transmit these loads to support points, namely to the foundations. The internal forces produce stresses in the materials, causing them to shrink or stretch, or deform or tear. Stress is defined as a force per unit of area. In the Imperial system, stress is measured in pounds per square inch (or psi), or kips per square inch (or ksi). In the International System (SI), stress is expressed in kilopascals (kPa) or megapascals (MPa).[12]

The most elementary stress states are unidirectional. As Figure 2.11 shows, a **tensile** stress stretches the fibres of the material in the direction of the stress; conversely, **compressive** stress causes them to shrink.

2.4.2 Path of Internal Forces in the Cantilever

After presenting the basic concepts of tension and compression, and before entering into the more complex considerations discussed in Chapter 5, which deals with the expert opinions, it is useful to provide a brief description of how the internal forces are distributed in the cantilever. This is indicated by the bottom part of Figure 2.12, which schematically illustrates the path of a force applied to the bearing pad, such as the considerable weight of the central span or the traffic loads.

In simple terms, the force applied to the seat, symbolised by the thick blue arrow on the left, produces a compressive reaction (blue arrow) at the bottom of the slab and a tensile reaction at the top (orange arrow). Note that the distribution of the internal stresses in the region of the chair bearing support is complex, but that it becomes regular to the right, as it approaches the "root" of the cantilever. The tensile forces in the disturbed zone and at the top of the regular zone are mainly transmitted through the reinforcing bars, because the concrete has low tensile strength. As for the compressive forces, they are mainly transmitted through the concrete.

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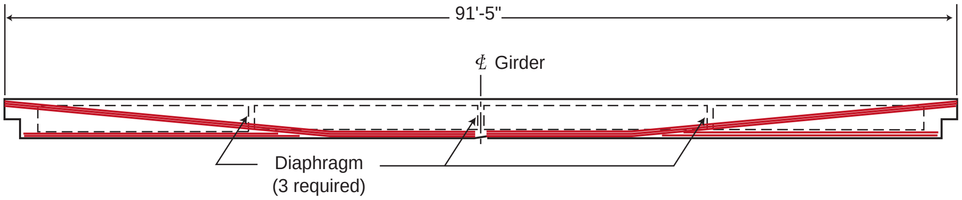
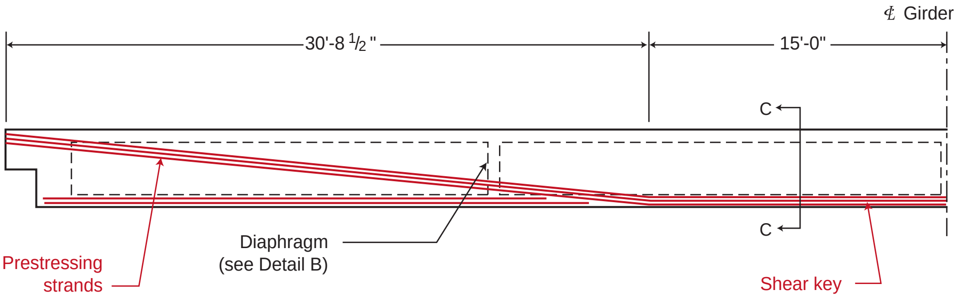
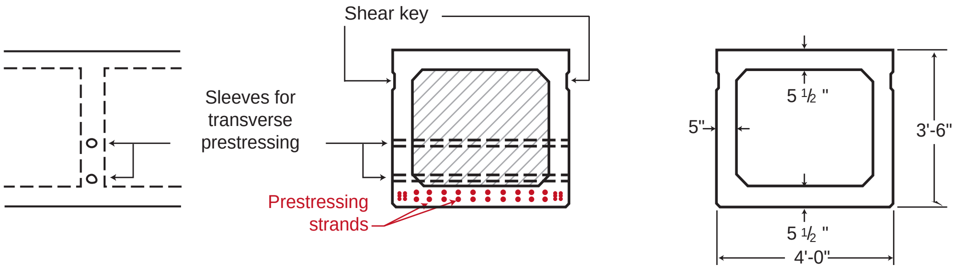
[12] 1,000 psi = 6.892 MPa; for example, the concrete specified for the abutments of the de la Concorde overpass has a strength of 4,000 psi, or 27.6 MPa.



Elevation of complete girder



Half-elevation



Detail B
Diaphragm

C-C section
Prestressing

C-C section
Dimensions of section

Note: Non-prestressed reinforcement not shown

Figure 2.14 Geometry of an Individual Box Girder

2.4.3 Bending and Shear

A structural element, such as a girder, a floor slab or a bridge slab, may bend when a load is applied. The curvature thus imposed on the element simultaneously causes the fibres on the convex side to stretch (due to tension) and the fibres on the concave side to shrink (due to compression).

In some parts of a structure subjected to bending, we also find shear stresses, a cutting effect resulting from simultaneous compression and tension in diagonal directions, which seek to tear (or shear) the concrete. Figure 2.13 illustrates bending and shear stresses.

In a non-reinforced concrete structure, in which the stresses exceed the concrete's tensile strength, shear is necessarily expressed by diagonal cracks. It was a shear failure that caused the de la Concorde overpass to fail.[13] This question is explained in detail in Chapter 5.

2.5 Concrete Used in the Abutments

Concrete is a very strong material in compression but it is relatively weak in tension. Steel reinforcing bars – steel has high tensile strength – are used to provide resistance in tension. Once the concrete hardens, these two materials work together to form a new material called reinforced concrete.

Concrete is composed of a mixture of cement, water, sand and stone. Usually, small air bubbles are incorporated during its production at the batch plant, in order to protect the concrete against the effects of freeze-thaw cycles. The proportions of the mix, especially the water/cement ratio, directly influence the concrete's durability and mechanical strength.

The expert studies filed with the Commission revealed confusion in the specifications for the concrete to be used for the abutments. The Special Specifications described two types of concrete, referred to as "C" and "A". The "C" mixture is produced with a water/cement ratio of 0.45 and an air content of 7%. The "A" mixture, which is not as resistant to freeze-thaw, is manufactured with a water/cement ratio of 0.56 and a lower air content. The latter type of concrete was used in the construction of the abutments. The consequences of this choice are discussed in Chapter 5.

2.6 Box Girders and Central Span

The central span forms the main part of the road, carrying traffic in the east-west direction over the freeway. This part of the structure is supported on the chair bearing supports of the east and west abutments. It consists of two series of ten prefabricated, prestressed concrete box girders.

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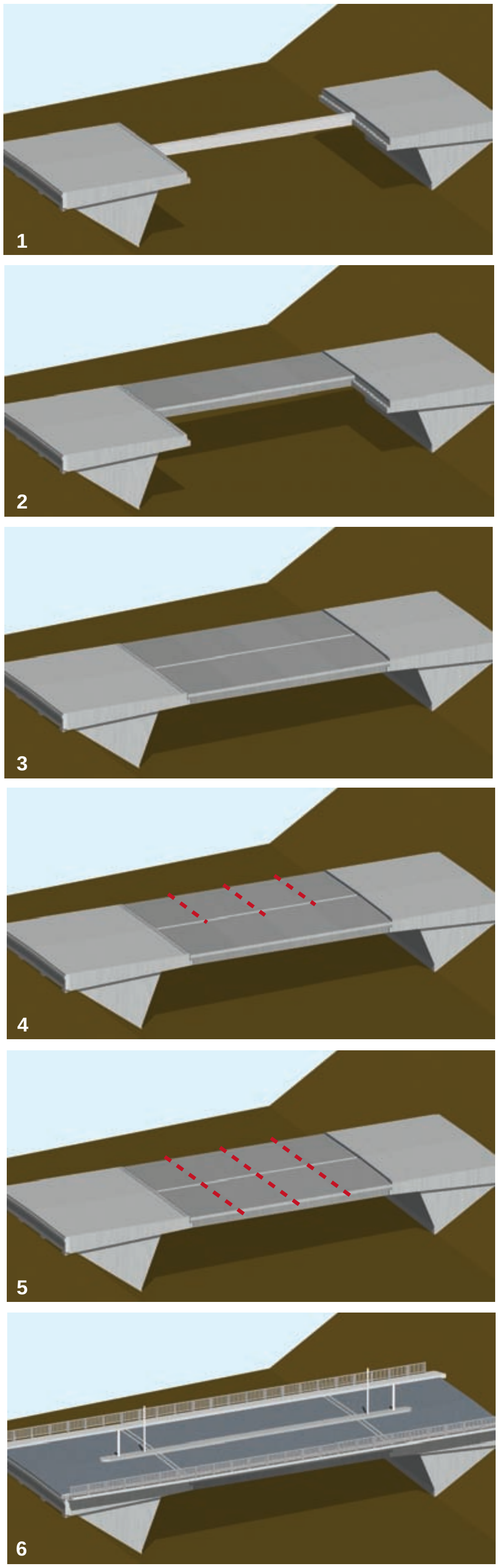
[13] There is consensus on this point among the various experts: Exhibit COM-72 (point 1.7).



Steps 1 and 2:
The 10 box girders forming half of the span are placed on the chair bearing supports.

Step 3:
The 20 box girders of the two halves of the central span are in place.

Steps 4 and 5:
Transverse prestressing of the deck, shown here schematically, is applied by tensioning the strands inserted in the diaphragms. Cement grout is injected around the strands and into the shear keys to bond the girders together.

Step 6:
The thin slab covering the girders is cast and eventually covered with a waterproofing membrane and asphalt pavement. Other components are added, such as the sidewalks, the median, the ramps and the lamp posts.

Figure 2.15 Construction Sequence of the Central Part of the Deck[14]

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[14] Exhibit COM-2, p. 47, 51, 52 and 58

The box girders are hollow, which reduces the weight of the central span. Figure 2.14 illustrates the geometry of an individual box girder.[15]

From centre to centre of the seats, each girder measures 27.9 m long (90'). It is 1.07 m high (3' 6'') and 1.22 m wide (4'). At the centre of the overpass, between the two series of ten girders, there is a spacing of 438 mm (1'-5¼'').

As mentioned above, concrete is a very strong material in compression, but weak in tension. The loads that normally apply on a bridge, including the weight of the deck and the traffic loads, create *tensile* stresses in certain parts of the box girders. To counter this, the concrete box girders are prestressed. High axial compression forces are applied to the concrete by means of steel cables (strands), tensioned to a force of 129 kN (28,900 lbs), incorporated into the concrete. This longitudinal prestressing is applied by *"pre-tensioning"* the steel cables during the manufacturing of the box girders.

Figure 2.15 illustrates the construction sequence of the central part of the deck. The two series of ten girders are held together in the transverse direction by high strength steel strands inserted in sleeves provided in the three diaphragms of the box girders. These strands are inserted and tensioned after the girders are in place on the abutments. The transverse prestressing is thus referred to as *"post-tensioning"*.

The longitudinal grooves of the box girders are filled with cement grout, which forms a shear key between these elements.

Finally, a 90 mm (3½'') concrete slab is installed over the box girders. This slab is protected with a waterproofing membrane and then covered with an asphalt pavement with a nominal thickness of 64 mm (2½'').

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[15] Exhibit COM-62, p. 10.

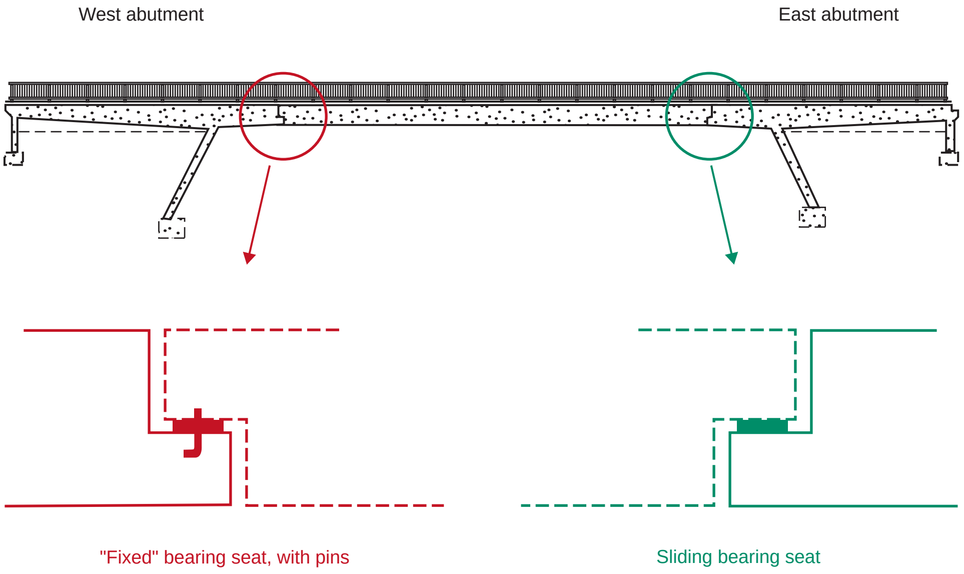

Figure 2.16 Bearings pads of the East and West Abutments

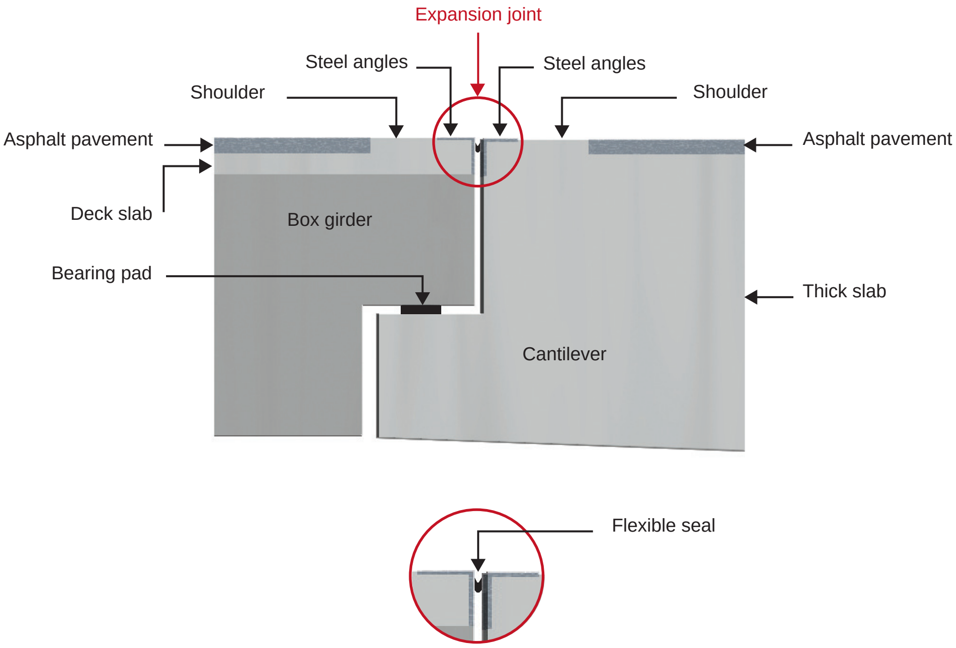

Figure 2.17 Diagram Illustrating the Position of the Expansion Joint Above the Chair Bearing Support

As Figure 2.16 illustrates, each box girder rests on an elastomeric bearing pad sitting on the chair bearing supports. These 152 × 356 × 25 mm (6′′ × 14′′ × 1′′) neoprene pads are reinforced by a 2.4 mm (3/32′′) thick steel plate, cast into the pad. The surface of the seat is slightly inclined to facilitate evacuation of water.

Pins having a diameter of 19 mm (¾′′) are inserted in the centre of the west-side bearing pads, which lock in place the position of the box girders on that side. The expansion movements of the box girders induced by variations in temperature are therefore transferred to the expansion joint of the east abutment[16].

2.7 Membrane

The specifications for the de la Concorde overpass required that a Type 1 membrane, composed of a layer of “asphalt mastic”, be applied to the deck to waterproof the slab. In those days, better quality membranes were rarely installed and the specifications reflected the practice of the time. In its brief prepared for the Commission, MTQ indicated that such a membrane had probably never been installed because the work performed in 1992 revealed no trace of it.[17] During the repairs of 1992, the specifications called for the installation of a Type 3 membrane, which represented best practice at the time. Arising from the demolition work and expert studies on various concrete blocks, it was established that the Type 3 membrane had not been installed and that only a liquid membrane or a liquid asphalt primer had been laid. This question is discussed in more details in Chapters 4 and 5.

2.8 Remarks on the Special Nature of the Structure

In its day, the design of the de la Concorde overpass was innovative, at least in North America. It offered certain advantages, but ultimately it was found to have significant drawbacks as well. The reasons that justified this choice are presented in Chapter 4 and the consequences, in Chapter 5.

A central pier would have required a wider right-of-way and would have restricted visibility on this curved stretch of the freeway. The use of prestressed concrete box girders made it possible to cross the freeway with a single span without any intermediate support. The result was a thin and elegant deck, which minimised the excavation depth required for the open-cut construction of the freeway.

However, the box girders rest on chair bearing supports located at the end of the cantilevers, directly underneath the expansion joints (Figure 2.17). These joints are exposed parts, which lose their ability to seal off water if damaged, thus contributing to the accumulation of water, road salts and debris on the chair bearing support. The vulnerability is even greater because it is impossible to inspect and maintain these seats without lifting the deck. This operation would have necessitated the interruption of traffic both on Boulevard de la Concorde and on Autoroute 19. The expansion joints and the chair bearing supports are therefore a critical area on this type of bridge.

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[16] Exhibit COM-2, p. 42 and 43.

[17] Appendix 15.

CHAPTER 3

3. THE CIRCUMSTANCES OF THE COLLAPSE

3.1 Observations of the Eyewitnesses Before the Collapse[1]

On Saturday, September 30, 2006, around 12:30 p.m., the south deck of the overpass located at the intersection of Boulevard de la Concorde and Autoroute 19 in Laval collapsed. The sudden fall of this overpass caused the deaths of five people and injured six others. The following pages describe the circumstances of the collapse, as presented in evidence by the main witnesses of this event or by the persons who participated in the first response, in securing the site and in the deployment of safety measures. A detailed chronology of the highlights appears in the summary of the police response.[2]

Figure 3.1 Collapsed Portion of the de la Concorde Overpass[3]

The Commission received many comments from citizens claiming to have noticed certain defects or peculiarities, or witnessed various events before the collapse of the de la Concorde overpass. At the hearings, the Commission heard some of these persons. The Commission took into account these testimonies in its evaluation of the condition of the overpass and in establishing the sequence of events.

However, the Commission must remind the readers that the signs brought to its attention by the witnesses did not necessarily constitute typical signs of a risk of collapse. The population should not conclude that the presence of identical signs on other structures means that they could collapse.

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[1] Most of the testimony that will be discussed in subsections 3.1.to 3.5 is consolidated in Appendix 8 and Exhibit COM-15.

[2] Exhibit COM-11, p. 5.

[3] Exhibit COM-1A, p. 6.

3.1.1 Puddle of Water

Mr. Guy Gironne often noticed [TRANSLATION] "*a good-sized puddle*" of water on the southeast side of the overpass, adjacent to the expansion joint, even in winter.[4]

3.1.2 Concrete Chunks

Several citizens reported the presence on Autoroute 19 of concrete chunks which appeared to have fallen from the structure on the day of the collapse. Around 9 a.m., Mr. Patrick Bélanger's vehicle was struck by [TRANSLATION] "*several small rocks*" while he was driving south under the de la Concorde overpass. The loud noise led him to believe that the rocks were fairly big. Around 10:40 a.m., Ms. Annie Deveault, whose vehicle was headed north, experienced the same misadventure. She also noticed [TRANSLATION] "*a fair quantity of small rocks scattered on the road*". In both cases, however, these persons were unable to say whether the "rocks" came from the overpass or whether they were sprayed by a van driving ahead of them.

Between 10:30 and 11 a.m., Mr. Claude Simard was driving south in the right lane of Autoroute 19 when his car hit a concrete chunk at a distance he estimated at [TRANSLATION] "*about 18 feet*" north of the overpass. He stopped, noticed some slight damage to one of his hubcaps and picked up a concrete chunk [TRANSLATION] "*about five or six inches by three-and-a-half inches*" which was crumbling and which he threw away. He could not tell from which part of the structure this fragment originated. However, he noted that the right lane looked abnormally grainy.

Around 11:20 a.m., while Mr. Dave Ferrara was driving north in the centre lane of Autoroute 19 about 50 to 100 metres from the overpass, he saw a concrete chunk, which he estimated as measuring about three feet long by one-and-half foot wide, separate from the deck on the southeast side before crashing down on the shoulder. However, during his testimony, when he studied the photograph of the concrete chunk picked up by the road supervisor[5] at around 11:45 a.m., and which was then handed over to the Sûreté du Québec ("SQ"), he contended that the fragment was different from to the one he had seen fall, as it was much too small and did not have the same shape.

3.1.3 Difference in Level Between the Deck and the Eastern Approach of the Overpass

Several witnesses claimed that they observed a difference in level between the overpass deck and the eastern approach of the overpass.

The week before the collapse, Mr. Claude Marc-Aurèle, a taxi driver, was driving in the right eastbound lane of the de la Concorde overpass when he felt a strong jolt: [TRANSLATION] "*When you were driving, you couldn't see it very clearly, but when I'd drive over it, I could feel the car, the front right wheel suspension bottom out completely, like when you hit a big pothole*". On another occasion, driving north on Autoroute 19, he took the exit leading to Boulevard de la

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[4] G. Gironne, Transcript, April 10, 2007, p. 166 and following.

[5] Exhibit COM-1A, p. 40.

Concorde and, while waiting at the traffic light, he noticed a difference in level of two to three inches in the guardrail.

On September 21, as he was taking the Autoroute 19 North exit ramp, Mr. Jean-François Blanchette, a civil engineering technologist, asserts having noticed on the outer surface of the structure that the expansion joint on the southeast side was unusually dilated, creating a space of about 10 cm. However, he asserts not having observed any subsidence or cracks which might have caught his attention.

On September 29, around 4 p.m., Ms. Patricia Paquette asserts having noticed a difference in level of two to three inches in the expansion joint on the east side, giving her the impression that the deck of the overpass was lower than the road itself. The same day, around 8:30 p.m., Mr. Gérard Branchaud noticed that the deck was two or three inches lower on the western side of the expansion joint.

On the day of the collapse, around 12:30 p.m., Mr. Julien Saint-Pierre was driving east in the right lane of Boulevard de la Concorde when he noticed a [TRANSLATION] *"positive difference in level"* (bulge) in the pavement at the expansion joint. To avoid damaging his vehicle, he practically had to come to a stop, and crossed over at reduced speed. In his deposition to the police on October 2, 2006, he estimated this difference in level at about two to three inches. However, in his testimony before the Commission, he claimed, instead, that it was around four to six inches.

3.1.4 Two Witnesses Contradict the Above Testimonies

Mr. André Rochon and Ms. Dominique Bédard, both public works technicians with the Laval Service Centre of the *ministère des Transports du Québec* ("MTQ"), took the de la Concorde overpass regularly. They were driving east on September 29 – and also, in Ms. Bédard's case, west on September 30 at around 8:45 a.m. – and they did not notice anything abnormal or observe any difference in level.

Findings of the Commission

The Commission found that the main components of the east abutment which pivoted during the collapse separated from a rupture plane passing through the top of the "back" of the bearing support. When rupture occurs, such a movement is necessarily accompanied by a shifting of the expansion joint. However, the Commission cannot confirm whether there was a difference in level in the roadway on both sides of the expansion joint before the final collapse. The road supervisor who was on site from about 11:45 a.m. to 12:00 noon, did not notice any jumping, slowing of traffic, noise or vibration. The evidence shows the presence of a pothole adjacent to the expansion joint on the southeast side[6], causing a localized difference in level in the roadway at that spot, which could explain the testimony heard.

The puddle of water appears in certain inspection photographs of the overpass and was caused by a lack of drainage and a very gentle longitudinal slope of the bridge.

Moreover, after the collapse, the sidewalk guardrail remained in place, overhanging the deck expansion joint, without shifting in relation to the expansion joint, as the photographs show[7]. Consequently, the reported shifting of the guardrail could not be situated next to the southeast expansion joint.

3.2 Reporting System

The Commission studied the operation of the reporting system from two angles: on the one hand, the Laval 9-1-1 emergency reporting service and, on the other hand, the reporting system specific to the MTQ, which is related to its monitoring system.

3.2.1 Laval 9-1-1 System

The Commission studied the recordings of the Laval 9-1-1 system. The first call reporting the collapse was recorded at 12:30:08. Two other calls were received within the next minute and about ten more were recorded within five minutes after the de la Concorde overpass fell. At 12:36:40, Laval 9-1-1 received a call from the SQ, which confirmed the overpass collapse and indicated that police and firefighters were on the way and that four vehicles were trapped under the overpass, where a fire was suspected to have broken out. At 12:38:16, Laval 9-1-1 received a call from Urgences-santé, which wanted to make sure that firefighters were on the way.

3.2.2 Monitoring and Reporting System of the *ministère des Transports du Québec*[8]

The de la Concorde overpass is located within the territory of the *Centre de services Laval* (Laval Service Centre) of the MTQ. This territory includes approximately about one hundred major structures. It is patrolled 24 hours a day, seven days a week, by a team of five road supervisors, led by a crew chief. The team of supervisors reports to a foreman, who on September 30, 2006 was Mr. Jean-Pierre Chabot. It usually takes two to three days for the supervisors to patrol their entire territory.

The supervisors and the foreman are not trained to be aware of the peculiarities of the different types of overpasses. [TRANSLATION] "*For us in maintenance, an overpass is an overpass*", Mr. Chabot says. When he was questioned about the de la Concorde overpass, Mr. Chabot claimed that he had never been informed of its peculiarities or received any special instructions requiring him and his team to be alert to certain things. The supervisors do not receive all the structural inspection reports. Only the aspects affecting their work – such as necessary minor maintenance or the removal of delaminated concrete – are communicated to them.

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[6] Exhibit COM-1A, p. 32.

[7] Exhibit COM-1A, p. 28 and Exhibit COM-1B, p. 5.

[8] J.-P. Chabot. Transcript, April 11, 2007, p. 165 to 197.

When a supervisor observes a minor anomaly, such as an object on the roadway or a pothole needing repair, he carries out the work himself without informing the foreman and then fills out a report. However, if the anomaly is a life-threatening situation or can involve the interruption of the flow of rush hour traffic, the supervisor contacts the foreman, who proceeds to the scene. The foreman is available at all times, even when he is not on duty.

Moreover, the *Guide du surveillant routier* (Road supervisor's guide) contains instructions specifying the person to be contacted in certain emergency situations.[9] According to Mr. Chabot, the supervisors attend a two to three-hour update session twice a year, during which the contents of the guide are reviewed.

A supervisor has the authority to close a road if he considers it necessary. He acts on his own initiative when it comes to ordinary thoroughfares, but in the case of freeways, he must contact the *Centre de télécommunications* (Telecommunications Centre) ("CDT") of the MTQ, which then requests the assistance of the SQ.

Finding of the Commission

The Commission is of the opinion that the Laval 9-1-1 and MTQ reporting systems operated effectively.

3.3 Road Supervisor

The road supervisor inspects the condition of the network, removes any debris found on road right-of-ways, reports any anomalies and fills out the relevant reports.[10] Ideally, the entire territory should be patrolled this way on a daily basis.[11] Given his duties and training, the road supervisor is not qualified to detect structural anomalies; this task is the responsibility of the MTQ engineers and technicians who are assigned to inspect structures within the MTQ's territorial divisions.[12]

On Saturday, September 30, 2006, Mr. Jules Bonin was replacing the normally assigned road supervisor. At 11:26 a.m.,[13] as he was patrolling Autoroute 640, he received a call from the CDT informing him that concrete chunks were falling [TRANSLATION] "*from the overpass before de la Concorde*". [14] From Autoroute 640, he immediately took Highway 335 southbound – which becomes Autoroute 19 – to get to Montreal and then, from Boulevard Henri-Bourassa, he got on to Autoroute 19 North. He first inspected the approaches of the Lévesque overpass, then those of the Rochefort Street pedestrian crossing, before arriving at the de la Concorde overpass around 11:45 a.m.

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[9] Exhibit COM-4, p. 21, 22, 32, 79 and 80.

[10] Exhibit COM-4, p. 3 and 20 to 24.

[11] J. Bonin, Transcript, April 11, 2007, p. 63 and 64.

[12] J. Bonin, Transcript, April 11, 2007, p. 48 to 50 and 121 to 141. See also J.-P. Chabot, Transcript, April 11, 2007, p. 199.

[13] Time indicated in the request report. Exhibit COM-5, p. 40. For the same call, the CDT call recording report indicates 11:28 a.m., Exhibit COM-5, p. 37.

[14] J. Bonin, Transcript, April 11, 2007, p. 70 and 71.

On the white line delimiting the shoulder on the southeast side of the overpass, he noticed a concrete chunk, generally triangular in shape, measuring about 18 inches long by 7 inches wide and 3 inches thick. He also found about twenty fragments the size of golf balls. He placed the concrete chunk in the bed of his truck and picked up the other debris in one shovelful to throw it behind the guardrail. In his testimony, Mr. Bonin recognized the main concrete chunk in the photographs taken by the SQ (Figure 3.2). [15]

Figure 3.2 Concrete Block Picked up by Mr. Bonin

For Mr. Bonin, this concrete chunk constitutes [TRANSLATION] *"ordinary debris"*,[16] similar to those he picks up near various structures, about once a month according to his recollection. Traffic was normal on the overpass. He did not notice any particular jumping, slowing of traffic, noise or vibration during the 15 minutes he spent on the scene, and no other concrete chunk fell. The top of the guardrail was at the same level on both sides of the expansion joint.

He photographed the hole (Figure 3.3) and walked under the northeast side of the overpass to see whether other concrete chunks had fallen. He also performed a visual inspection of the west side of the overpass, but he did not detect anything abnormal. Apart from the visible hole on the outer face of the abutment, he did not suspect anything in particular. He never thought that the overpass could collapse within the next few hours.[17]

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[15] Exhibit COM-1A, p. 37 to 39. See also J. Bonin, Transcript, April 11, 2007, p. 93 to 97.

[16] J. Bonin, Transcript, April 11, 2007, p. 102.

[17] J. Bonin, Transcript, April 1, 2007, p. 103, 104, 109, 124 and 151.

Figure 3.3 Hole and Crack in the East Abutment, photographed by Mr. Bonin between 11:45 a.m. and 12:00 p.m., September 30, 2006.

However, Mr. Bonin filled out an anomaly report in which he wrote [TRANSLATION] *"To be inspected PC"*[18] (a written adaptation of a common French expression meaning a definite emergency). This is the first time that he had asked for an overpass to be inspected and in his testimony before the Commission, he specified that he wanted to be sure that the inspection [TRANSLATION] *"would be done the following Monday"*.[19]

According to Mr. Bonin, the hole left by the fall of the concrete chunk, extended on both sides by a crack, was worth inspecting because of its positioning on the structure. He was worried the concrete had apparently fallen on its own and that another piece adjacent to the hole left in the abutment seemed to be about to detach itself. He was concerned not about the overpass, but about this piece which seemed to be on the verge of falling down onto the shoulder. He did not consider it necessary to advise his foreman, who that day was reachable on his cell phone.[20]

According to the CDT call recording report, at 12:00 noon Mr. Bonin left the scene after picking up the concrete chunks, completed his report, requested an inspection and took a photograph.[21] Around 12:35 p.m., he received another call from the CDT informing him that other concrete chunks had just fallen. At approximately 12:40 p.m., as he was making his way back to the de la Concorde overpass, the CDT informed him that the overpass had collapsed. He arrived on the scene at 12:55 p.m. He confirmed the collapse to the CDT and informed them that Autoroute 19 would have to be closed indefinitely. He then communicated with his foreman, Mr. Jean-Pierre Chabot,

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[18] Exhibit COM-5, p. 35.
[19] J. Bonin, Transcript, April 11, 2007, p. 122.
[20] J. Bonin, Transcript, April 11, 2007, p. 104, 108, 124, 125 and 129 to 131.
[21] Exhibit COM-5, p. 37.

who asked him to bring the concrete chunk to the *Centre de services de Laval*, and also recommended that he draft a statement.[22]

Findings of the Commission

The road supervisor's job description does not call for him to find structural anomalies. At most, he must indicate in his reports the origin of the debris he picks up on the road and photograph the structures which are found to be the source of this debris. In the Commission's opinion, Mr. Bonin reacted appropriately both before and after the collapse. He produced an anomaly report, requesting an inspection as soon as possible, since he was not qualified to assess the structure, despite the damage he observed on the abutment.

3.4 The Collapse Causing Deaths and Injuries[23]

The five people who died were in two vehicles driving south under the overpass at the time of the collapse. In one of the vehicles were Mr. Jean-Pierre Hamel, his spouse Ms. Sylvie Beaudet and his brother, Mr. Gilles Hamel. In the other vehicle were Mr. Mathieu Goyette and his spouse, Ms. Véronique Binette, who was then pregnant at the time. As for the injured persons, they were all driving east on the overpass at the time of the collapse.

Mr. Paul Cousineau and his spouse, Ms. Louise Bédard, were driving east in their Toyota Corolla on Boulevard de la Concorde. As he entered the overpass, Mr. Cousineau noticed no difference in level. He was driving on the deck in the left lane and was preparing to take the access ramp to Autoroute 19 North. This is when he heard a [TRANSLATION] "*loud crash*" and was overcome by a [TRANSLATION] "*feeling of void*". Ms. Bédard, for her part, was rummaging through her handbag at the time of the event and felt the car begin to plummet and hit the concrete wall under the east side of the overpass. A concrete block crashed through the windshield and landed 30 centimetres from the passenger's head. Mr. Cousineau felt such a pain in his back that he could not get out of the vehicle, while Ms. Bédard was trapped in the cab. Citizens helped get them out of the car and took them a safe distance away.

Ms. Anne-Marie Leblanc was a passenger in a Honda Civic driven by her spouse, Mr. Robert Hotte. She said that their car was heading east at about 60 km/h. At first she thought that the road in front of them was rising, before realising that their car was falling as the deck collapsed. Mr. Hotte did not notice any vibration or have any forewarning of the impending sudden collapse. He said that the overpass broke cleanly, in a single block. Since the vehicle was tilting forward, without deviating to the left or the right, he inferred that the east abutment gave way first, but he also stated that the entire deck fell at the same time. Their car struck the concrete wall under the overpass and overturned on its right side. Two young men helped them get out through the door on the driver's side and led them to safety.

Mr. Mohamed Ashraff Umerthambi was driving east in his van on Boulevard de la Concorde at about 40 km/h when the deck collapsed. He felt himself falling, believing at first that it was an

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[22] Exhibit COM-5, p. 38. Mr. Bonin's statement to the SQ is found in Exhibit COM-5, p. 33. See also J. Bonin, Transcript, April 11, 2007, p. 110 to 112 and 148 to 149, as well as J.-P. Chabot, Transcript, April 11, 2007, p. 181.

[23] All the testimony related to subsection 3.4 is taken from Exhibits COM-16 and COM-12 e) to j).

earthquake. There was a lot of dust and smoke. He said he heard the overpass fall, which made a loud noise, but he did not see it collapse. He was trapped in his vehicle for three minutes until citizens helped him get out.

Mr. Claude Bastien was riding east on his motorcycle on Boulevard de la Concorde. He woke up in the hospital without any memory of the collapse. He had been trapped in the rubble by his helmet until he was rescued.

3.5 The Eyewitness Accounts of the Collapse

Several eyewitnesses recounted what they saw and heard at the time of the collapse. These accounts reveal some confusion as to the exact sequence of the event, the only common denominator being the obvious speed with which it occurred. Everyone says that it happened in a split second.

Mr. Michel Beaupré was driving north on Autoroute 19. According to him, the west side came off first, followed by the east side a fraction of a second later. Mr. Claude Girard, who was driving in the same direction, twice noticed a vibration on the upper part of the west guardrail, giving the impression that the parapet was moving west. He saw the west side fall first, while the centre and the east side remained suspended for a fraction of a second before also collapsing.

Driving south on Autoroute 19, Mr. Menasse Cameus saw the southeast side fall a fraction of a second before the southwest side. According to Mr. Denis Leboeuf, who was also driving south on Autoroute 19, the east side started to fall first, followed by the west side, and the two sides then collapsed in a single block. Mr. Pasqualino Simeone was also driving south on Autoroute 19. He said that he saw the east side of the deck fall, while the west part remained suspended for a fraction of a second before also collapsing.

Findings of the Commission

The Commission concludes that the deck of the de la Concorde overpass fell to the ground in a fraction of a second, as soon as the central span lost its support on the abutment which had just fractured. The expert reports reveal that the deck hit the ground on the east side first, leaving a mark in the roadway of the freeway. The fracture stopped at the centre of the east abutment, near the axis of the overpass, and the bearing support was twisted at this location, allowing the south deck to collapse, as shown in various photographs taken after the collapse. The fall of the southern half of the deck, therefore, did not bring down the northern half. After falling in a single block, the south deck fractured at mid-span, hitting the concrete guardrail separating the north and south lanes of the freeway.[24] The west abutment remained practically intact.

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[24] Exhibit COM-1A, p. 10 and 14.

3.6 First Response and Securing the Perimeter

Initial assistance was provided by citizens who were on the scene or who arrived immediately after the collapse. The Commission underscores the exemplary civic-mindedness and courage displayed by these individuals. Several victims spoke of their own and their rescuers' fear that the collapse would continue. It was precisely this concern that led rescuers to extract the victims from their vehicles and move them a safe distance away without waiting for the arrival of the rescue services.

3.6.1 Laval Fire Department[25]

The Laval Fire Department mobilised about twenty firefighters, three tanker trucks and two firefighting vehicles. The response was coordinated by Mr. Guy Archambault, Chief of Operations.

Upon his arrival, Mr. Archambault noted that several Urgences-santé vehicles were on the scene. He established a command post on Autoroute 19, north of the overpass. He saw two cars crushed under the structure, from which smoke was rising. At the east end of the collapsed deck, on the structure, he noticed three damaged cars and the motorcyclist, who was unconscious. Having gone through a similar experience during the collapse of the du Souvenir overpass, he ordered powerful cranes and called in the Montréal "moles" – specialists who work in enclosed or confined spaces – to obtain an assessment of the structure before venturing into it. He waited for the arrival of a Laval public works engineer, who would determine whether the remaining structure was stable. For the time being, however, he decided, together with a colleague who was on the scene, that he should rescue the victims who were still trapped in the cars as quickly as possible.

Mr. Daniel Hillman of the Laval Fire Department, took charge of the perimeter and set up the operations structure required to free the victims. The Laval and SQ police officers and the firefighters worked together to rescue the victims. When the cranes arrived, firefighters and crane operators looped steel cables around the girders to lift them and free the trapped cars, which were sent to the Cunard municipal garage.

3.6.2 Sûreté du Québec[26]

Around 12:31 p.m., the SQ received an emergency call and two officers proceeded to the scene along with a sergeant supervisor. The scene of the collapse was secured by the SQ. It encompassed the two access ramps east and west of Boulevard de la Concorde, the collapsed overpass structure and the affected section of Autoroute 19, which was closed to all traffic in both directions as of 1:10 p.m.

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[25] G. Archambault, Transcript, April 11, 2007, p. 214 to 222; mention of the work performed by Mr. Daniel Hillman, Head of the Fire Operations Division, officer responsible, during the testimony of Mr. P. St-Onge, Transcript, April 11, 2007, p. 236. See also Exhibit COM-10 describing all of the interventions of the Laval Fire Department concerning this event.

[26] P. St-Onge, Transcript, April 11, 2007, p. 222 to 249. See also Exhibits COM-11 and COM-11A describing all of the SQ interventions concerning this event.

Mr. Bernard Ouellet, a SQ traffic accident reconstructionist, arrived on the scene around 3:25 p.m. He found that the security system was in place and that the police officers, the ambulance crews and the cranes had arrived.[27] While awaiting his superiors' instructions, he took photographs of the scene. The *Service des enquêtes des collisions* (Collision Investigation Service) took more than 1,299 photographs and the *Service d'identité judiciaire* (Legal ID Unit) took a few hundreds.

Mr. Pierre St-Onge, a sergeant investigator, arrived on the scene between 3 and 3:30 p.m. and became the investigator in charge of the event.[28] Around 5 p.m., Dr. Michel Trudeau was appointed Coroner in the case.[29] The ranking officers summoned SQ response teams to assist the firefighters. One of these teams had a optic fibre camera which allowed them to look under the structures. The *Service d'identité judiciaire* worked in tandem with Sergeant Detective Martin Cossette.

The first day, 15 or 16 girder pieces were removed to free the trapped vehicles. At the request of Mr. Jacques Marchand, an expert engineer acting under an SQ mandate at the time, each girder was photographed, numbered, weighed and marked before removal. The girders were transported under police escort to the Belgrand Street storage site in Laval. Other smaller blocks were processed according to the same protocol. They were all marked on the ground so that they could be repositioned according to a plan incorporated in the police response summary.[30]

SQ officers interviewed about fifty witnesses in the 24 hours following the collapse, including eyewitnesses, people who assisted the victims and individuals who saw things that seemed unusual to them in the days preceding the collapse. Some of these individuals would testify before the Commission. The SQ investigated a rumour, which proved to be unfounded, that a truck had collided with the de la Concorde overpass the day before the collapse. In fact, the truck had run into a road sign at the intersection of freeways 19 and 440. The SQ also investigated, with the help of Natural Resources Canada, the absence of seismic shocks in the days preceding the collapse, and the fact there was no blasting at the Saint-Martin quarry, located about 2.8 kilometres from the de la Concorde overpass.

3.7 Ministère des Transports du Québec[31]

3.7.1 Emergency Response and Detection of Structures at Risk

The MTQ's general procedure in the event of a major incident is to dispatch two engineers to the scene. They are assisted by a technical team established by the *Direction des structures* (Structures Division) of the MTQ, which performs the necessary expert studies and calculations.

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[27] B. Ouellet, Transcript, April 11, 2007, p. 251 to 266.

[28] The organisation chart of the structure of responsibilities in connection with the investigation is reproduced in Exhibit COM-11, p. 4.

[29] The Coroner filed his report on the causes of the deaths on March 11, 2007, Exhibit COM-11. (the pages have been removed from Exhibit COM-11).

[30] Exhibit COM-11, p. 29.

[31] This section is essentially based on the testimony of Ms. A.-M. Leclerc and Mr. G. Richard, Transcript, April 12, 2007, p. 129 and following.

A team of three MTQ specialists was dispatched to the scene in the late afternoon of September 30. It had three major concerns: secure the site, institute traffic mitigation measures and open an emergency response centre.

In Québec City, the Assistant Deputy Minister, Ms. Anne-Marie Leclerc, was informed of the collapse around 12:45 p.m. on September 30. She immediately mobilised a team from the *Direction des structures*, including the director, engineer Guy Richard. The team reviewed the file on the de la Concorde overpass, which includes a reference to the special inspection performed by engineer Christian Mercier of the *Direction des structures* on July 15, 2004. This inspection was conducted following a request for technical assistance formulated by inspector Gilbert Bossé, also an engineer, employed by the *Direction territoriale de Laval-Mille-Îles* (Laval-Mille-Îles Territorial Division).

Anxious to ensure that no other structure might suffer such a sudden rupture, or represent any risk in this regard, the team endeavoured to identify the other structures exhibiting similar design details. The MTQ's immediate reaction then served as the core of what was to become a response plan, designated as the MTQ Action Plan, which will be discussed in Chapter 5.

The team analysed the plans and files concerning all of the structures under the MTQ's responsibility, spontaneously paying attention to structures including span bearing supports (see Figure 2.6). This structural inventory was then studied according to the following criteria:

- Structures built before 1986 (since Mr. Richard, who joined the MTQ in 1986, knew that no structure with a bearing support had been built since at least that year)
- Bridges including at least three spans (within the meaning of the inspection system inventory used by the MTQ) in order to locate structures comprising cantilevers
- Bridges with thick concrete slabs (reinforced or prestressed, solid or hollow slab)
- Bridges with concrete box girders (reinforced or prestressed)
- Bridges with solid concrete girders (reinforced or prefabricated prestressed, or cast in place)
- Portal frame bridges
- Trusses.

The team thus referenced and studied some 1,066 bridges files. Starting the day after the collapse, the MTQ engineers identified 16 bridges and overpasses having points in common with the de la Concorde overpass, including the de Blois overpass. The MTQ instructed its territorial divisions to inspect these structures immediately and to verify whether other bridges involved similar details. The territorial divisions identified two additional structures which also exhibited the characteristics sought. The inspections performed on these 18 structures on October 1 and 2, 2006, allowed the MTQ to conclude, at a press conference held on

October 2, that only the de Blois overpass had [TRANSLATION] *"identical features, including certain specific damaged elements"* and that the other 17 structures posed no danger to motorists.[32]

In the weeks that followed, as a safety measure and based on a better understanding of the role played in the collapse both by the bearing support and cantilever, the MTQ evaluated the bearing capacity of each of the 17 structures. It also recommended to its territorial divisions that they inspect these structures annually instead of every three years, paying special attention to the evolution of the cracks, and that they [TRANSLATION] *"modify their structural systems, and even replace them within five years"*.

3.7.2 The rue de Blois, Joliette and Saint-Alphonse-de-Granby Overpasses

The de Blois overpass crosses Autoroute 19 about half a kilometre north of the de la Concorde overpass, to which it is virtually identical. As a precautionary measure, around 2 p.m. on the day of the accident, its closing was ordered, effective as of 3:20 p.m. The abutments of the de Blois overpass would be demolished at the same time as those of the de la Concorde overpass, i.e., between October 21 to 25, 2006.[33]

Later, realising that the problem which led to the collapse may have involved the cantilever thick slab rather than the bearing support, the MTQ began paying special attention to an overpass located at the intersection of Highway 158 and Autoroute 31, in Joliette, as well as a similar structure spanning Autoroute 10 in Saint-Alphonse-de-Granby. These two structures appeared on the list of the 18 structures inspected on October 1 and 2.

In the case of the Joliette overpass, despite the satisfactory result of an evaluation of its load bearing capacity and of the reinforcement details according to standard CSA-S6-2006, the MTQ undertook a core sampling operation in October 2006. The result of the analysis led it to reduce the capacity of the overpass to 12 tonnes, to reinforce the structure by adding steel piles under the bearing supports, and to request the territorial division to replace it within five years.[34]

The posted capacity of the structure located in Saint-Alphonse-de-Granby was reduced to five tonnes until the evaluation of the load bearing capacity and the reinforcement details could be completed. Since these were found to be satisfactory, the restriction was lifted, then reinstituted soon afterwards when the core sampling showed the existence of a crack at the end of the cantilever, near the sidewalk.[35] The MTQ recommended to the territorial division that it replace the overpass by 2008 to allow traffic at legal loads. This recommendation will be implemented ahead of schedule, as the new overpass will likely be completed by the end of 2007. While awaiting the erection of the new overpass, the old one was demolished in the night of May 22nd to May 23rd 2007.

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[32] Exhibit COM-6, p. 1. The 18 structures are listed in Exhibit COM-6, p. 5.

[33] Exhibit COM-6C, p. 7.

[34] Exhibit COM-6B reports on the result of the observations and tests performed on the core samples taken on this overpass.

[35] Exhibit COM-6A reports on the result of the observations and tests performed on the core samples taken on this overpass.

3.7.3 Bridges Under Municipal Responsibility

The MTQ owns 4,900 of the approximately 12,000 Québec road structures. Through its territorial divisions, it also assumes responsibility for the inspection and maintenance of bridges owned by municipalities with less than 100,000 population, for a total of some 9,200 bridges and overpasses. At the MTQ's request, the territorial divisions performed the required inspections, based on the parameters identified, for all of the bridges of these municipalities. It was found that none of these structures exhibited such characteristics.

Moreover, the municipalities with a population of 100,000 or more, which are responsible for bridges located on their territory, were invited to a conference call on October 23, 2007. They then received a memo confirming the technical elements that needed to be monitored. In June 2007, the MTQ communicated with these municipalities again after the Commission informed it of the problem posed by bridges with a thick slab with no shear reinforcement. This question will be discussed in detail in Chapter 5.

3.7.4 Documents search, recovery and archiving[36]

As soon as it was established, the Commission asked the MTQ to make every effort to locate all existing information concerning the de la Concorde and de Blois overpasses. The MTQ then proceeded with an exhaustive examination of the Transport Archive Group of the National Archives of Québec, as well as all the active and semi-active files in its possession.

Several relevant documents were thus located, including contract documentation pertaining to the interveners concerned, the claim file and most of the inspection reports for these two structures. A version of the plans was turned over by the MTQ, although this was not the most recent, as explained in Chapter 2. The MTQ also provided the Commission with other normative documents, such as the numerous manuals that guide the work of its inspectors and engineers.[37]

Other documents could never be located such as the bar list, almost all the minutes of the construction site meetings (only a few were found[38]) and the construction site log. There is every reason to believe that these documents were not retained, because the contract in question at the time did not require it, or that they were destroyed, in accordance with the requirements of the MTQ retention schedule.[39]

Moreover, during the hearings, it appeared that certain documents might have been mislaid or misfiled when the territorial divisions were created during the 1993 reform, which redivided Québec into 18 territories.[40] The witnesses heard assumed the essential documents had been

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[36] A description of the possible filing locations and the composition of the structural files is found in Chapter 4, paragraph 4.7.2.

[37] Exhibits COM-30A to COM-30N, MTQ Manuals.

[38] Exhibit COM-25 lists the minutes of the site meetings found.

[39] On these questions see the testimony of A.-M. Leclerc and G. Richard, Transcript, April 12, 2007, p. 203 to 239 and Exhibit COM-7, p. 1 to 58. The documentary research steps taken by the MTQ are described in Exhibit COM-7, p. 59 to 70, and Exhibit COM-61.

[40] G. Bossé, Transcript, May 3, 2007, p. 174. See also G. Bossé, Transcript, May 14, 2007, p. 32. The steps taken by the MTQ to exhaust all the filing sources and the chronology of the research performed to ensure the transfer of the files in 1993 are related in Exhibit COM-61.

collected when the new territories were established.[41] For the purposes of the Commission, however, this means that a whole chapter in the life of the de la Concorde and de Blois overpasses was not documented in the Laval-Mille-Îles Territorial Division's structural file. Indeed, the major repairs performed in 1992 were barely mentioned. It was only by a stroke of luck that one of the boxes containing certain information relevant to this repair was found, thus shedding conclusive light on questions crucial to the understanding of the nature and scope of the major work performed by the MTQ in 1992.[42]

3.8 First Actions Taken by the Commission[43]

The Government of Québec established the Commission on October 3, 2006. On October 5, the three Commissioners performed a thorough inspection of the site and held their first formal meeting. During the next two weeks, the Commission held nine meetings to discuss what actions should be taken to dismantle the remainder of the de la Concorde overpass while preserving the evidence necessary for its inquiry.

Thus, various measures were ordered, such as the collection of core samples and concrete pieces, the examination of the box girders, a meticulous gathering of the fracture plane, the opening of observation windows in the remaining structure, a complete survey of the site and radar measurements.

The Commission dispatched various experts to the scene to ensure proper implementation of the evidence preservation programme.[44]

On October 20, 2006, the Commission decided that the evidence preservation programme had been carried out to its satisfaction. The SQ, which was still the custodian of the site, was informed of this and immediately handed over responsibility to the MTQ. The reports prepared by Messrs. Jacques Marchand and Denis Mitchell provide more details on the various preservation measures taken.[45]

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[41] G. Bossé, Transcript, May 3, 2007, p. 174 and 182. See also G. Bossé, Transcript, May 14, 2007, p. 12 to 14.

[42] It seems that the notes and documents relating to these repairs should have been destroyed in 2005 according to the MTQ retention schedule in force (Exhibit COM-54B). However, it is impossible to certify whether additional relevant information may have existed in this regard.

[43] Appendix 19 additional note No. 1, and Appendix 2.

[44] The complete list of experts whose services were retained by the Commission is found in Chapter 1, paragraph 1.3.2.

[45] Exhibits COM-62, COM-62A, COM-62B, COM-62C, COM-63 and COM-63B.

CHAPITRE 4

4. DESIGN, CONSTRUCTION AND MAINTENANCE OF THE DE LA CONCORDE OVERPASS

Facts put forth before the Commission

4.1 Introduction

In addition to the physical causes of the collapse, human factors also contributed, namely the actions of people concerned, or their inability to make up for the shortcomings of standards which today would be considered inadequate in calculating shear strength. The testimony heard by the Commission, as well as the material proof collected, clearly shows that the construction and the management of the de la Concorde overpass during its useful life were marred with non- or ill-fulfilled obligations on the part of many parties. As for the design itself, it did not contravene any critical provision of Code CSA-S6-1966.

The general lack of accountability regarding the quality control of the work and the materials represents the greatest weakness noted during the construction phase of the overpass. Despite the clear legal and contractual obligations to which they were bound, the contractor and associated sub-contractors passed on all of their responsibilities with respect to the quality of the work and its compliance with the drawings and specifications to the workers and the engineering consulting firm responsible for the complete supervision of all of the construction work.

Desjardins Sauriol & Associés ("DSA"), an engineering consulting firm, was responsible for all aspects regarding engineering, which included planning the work, design, preparation of drawings and specifications, the complete supervision of the work and the control of materials.[1] With regard to work supervision, DSA failed to live up to its responsibilities. While it has been established that its teams supervised the road work, the Commission was unable to determine with certainty who was in charge and which mechanisms were put in place to ensure proper supervision of the construction of the overpass. At best, DSA would only have exercised partial or very incomplete supervision of the overpass construction.

Inter State Paving inc. ("ISP") entered into a contract with the *ministère de la Voirie* for the construction of the overpass. It carried out the construction work of Autoroute 19, but sub-contracted most of the overpass construction work, without having set up mechanisms to ensure that work executed by sub-contractors was in accordance with the drawings and specifications. These sub-contractors, including the one responsible for manufacturing and installing the steel reinforcement, in turn hired their own sub-contractors who also passed on their responsibilities regarding work quality.

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[1] In chapter five, the Commission will analyse the design with regard to codes and standards as well as best practice at the time.

This general lack of accountability resulted in the improper installation of the steel reinforcement and the use of low-quality concrete.

The organisation chart shown in Figure 4.1 establishes the relationships between the *ministère de la Voirie*, Desjardins Sauriol & Associés and Inter State Paving inc., as well as the responsibilities of their respective sub-contractors.

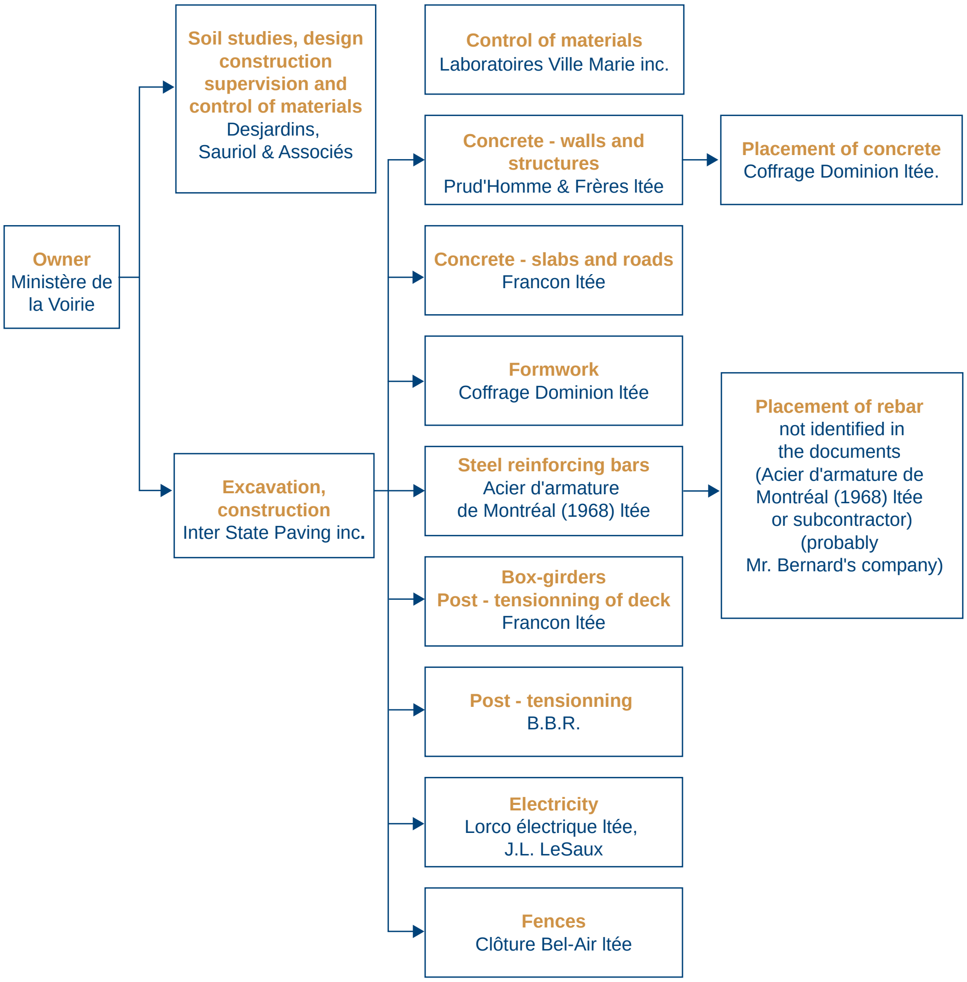

Figure 4.1 Organisation chart of stakeholders who participated in the design and construction of the de la Concorde overpass

Furthermore, while the de la Concorde overpass was under the responsibility of the MTQ, it was never subjected to an inspection and maintenance programme which would have taken into account its particular features, most notably the importance of the beam seats (corbels) located at the extremities of the cantilevers. The delays in the maintenance operations are an obvious demonstration of this shortcoming. Indeed, during the 1992 repairs, despite the clear evidence of serious degradation of the concrete and improper installation of the steel reinforcement, no corrective action was undertaken.

4.2 Preliminary studies – origin of the design

On August 14, 1968, DSA was granted a contract for professional services by the *ministère de la Voirie* to carry out preliminary engineering work.[2] On November 27, 1968, by decree of the *Conseil du trésor*, the government retained the services of DSA and authorised it to proceed with the engineering work on the de la Concorde overpass.[3]

The location of the freeway presented particular difficulties regarding the design of the de la Concorde overpass, notably the elevation of the rock and the curving of the road at this location. Taking into account these factors, engineers Gilles Dupaul and René Therrien suggested to the *Ministère* two architectural designs offering two solutions, one with prefabricated beams for the de la Concorde overpass and the other with steel beams for the de Blois overpass.[4]

Mr. Therrien explained to the Commission that the design chosen for the de la Concorde overpass was a concrete bridge with a "drop-in span" supported by a beam seat at the end of a cantilever.[5] He had used a similar design in 1965 for the Notre-Dame Street overpass in the Turcot Interchange;[6] however, for that bridge, the cantilever abutments were constructed with beams rather than with a thick slab. Mr. Therrien did not see any disadvantages to this design but rather many advantages including:[7]

- reduced beam span, therefore a decreased depth
- better exterior finish, with a flat underside of the overpass rather than separate beams and a thin superstructure
- elimination of the central pier
- reduced expropriation costs since the right-of-way would be narrower
- the ease of construction of the overpass

For his part, Mr. Dupaul stated to the Commission that, before the Autoroute 19 project, he had participated in the design of a few bridges with thick slabs, namely for the Turcot Interchange.[8] Furthermore, he added that rock excavation being very expensive, he preferred a design that would not require deep excavation, adding that it was easy to add anchors to stabilise the abutments[9] and that the elimination of the central pier would improve visibility for drivers (Figure 4.2).

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[2] Exhibit COM-21, p. 19.
[3] Exhibit COM-21, p. 21.
[4] G. Dupaul, Transcript, April 18, 2007, p. 173 and 174.
[5] R. Therrien, Transcript, April 17, 2007, p. 119.
[6] R. Therrien, Transcript, April 17, 2007, p. 122.
[7] R. Therrien, Transcript, April 17, 2007, p. 119, 122 to 124 and 141.
[8] G. Dupaul, Transcript, April 18, 2007, p. 162 to 165.
[9] G. Dupaul, Transcript, April 18, 2007, p. 172 and 173.

Figure 4.2 The de la Concorde overpass, north-bound

According to Messrs. Therrien and Dupaul, considerations related to the difficulties of inspection, maintenance and repair of the structure were not discussed at the time.[10] Mr. Raymond Francoeur, assistant director of bridge projects for the *Direction générale des ponts* at the time, confirms their testimony.[11]

It seems that the critical importance of the expansion joint had been taken into account however, Mr. Francoeur pointed out to the Commission that a note in the preliminary studies called for the installation of a watertight joint and that the type of joint proposed by the designers was supposed to meet this requirement, in compliance with practice at the time.[12] Moreover, much less de-icing salt was used at that time, according to Mr. Raymond Désy, at the time *directeur général* of bridge project, and Mr. Francoeur's superior.[13]

The *Ministère* approved the option of a concrete bridge and had, at the time of the opening of tenders, decided to build the de Blois overpass as a replica of the de la Concorde overpass. The preliminary studies were approved based on preliminary drawings prepared by draftsmen, based on the sketches of the designer; these comprised one or two sheets showing elevations of the structure and its main cross-sections.[14] The department summarily verified if certain criteria were respected, such as vertical and horizontal clearances and geometry.[15] The approval of a preliminary design provided an authorisation to go ahead based on the reputation and

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[10] R. Therrien, Transcript, April 17, 2007, p. 131 ; G. Dupaul, Transcript, April 18, p. 178.
[11] R. Francoeur, Transcript, April 19, 2007, p. 237, 238, 248 and 249.
[12] R. Francoeur, Transcript, April 19, 2007, p. 239 and 240.
[13] R. Désy, Transcript, April 19, 2007, p. 184.
[14] G. Dupaul, Transcript, April 18, 2007, p. 182.
[15] R. Désy, Transcript, April 19, 2007, p. 173 to 175 and 186 to 187 ; R. Francoeur, Transcript, April 19, 2007, p. 217 to 220.

competency of the engineering firm that had been retained to carry out the project.[16] This approval was an informal consent rather than a formal agreement.

At the end of discussions on the preliminary design, the *Ministère* and the engineering firm were generally in agreement with the changes to be made to the drawings. Based on the records kept by the *Ministère*, the final version of the drawings and specifications did not need to be reviewed by the *Ministère*.

During their testimony before the Commission, Messrs. Dupaul and Therrien indicated that numerous problems that had not been anticipated occurred once the structure was put into service:

1. **Drainage**: The small slope of the pavement and the absence of drains on the overpass lead to an accumulation of water between the sidewalk and the pavement.[17]

2. **Expansion joint**: In principle, these joints must always be watertight, but it is not uncommon to see some leakage. However, the design of the de la Concorde overpass is such that the joints are located directly above the beam seats, which can lead to the penetration of water and salt through the joints and onto the beam seats. At the time, Mr. Therrien[18] assumed that the leaking water would simply run off the beam seat and that a pressure wash would be able to remove the accumulated salt at this location.

3. **Inspection**: Inspection of the beam seat is very difficult due to limited access. The section of the structure located under the joint is inaccessible and it is impossible to inspect the interior of the box girders. Mr. Therrien pointed out, however, that many structures, e.g. in France, are similar, and that this has not proven to be a problem for their entire lifespan.[19]

4. **Maintenance**: Maintenance of the beam seat is difficult due to its inaccessibility, with the concrete, steel and neoprene pads located under the joint on which the vehicles travel. Maintenance work would mean lane closures on the overpass and, for major repairs, closure of the freeway.

After the Autoroute 19 project, Mr. Dupaul never again designed structures similar to the de la Concorde and de Blois overpasses. The last structure of this type dates back to 1972.[20]

Findings of the Commission

The Commission notes that the *Ministère* approved the preliminary design submitted by DSA for the de la Concorde overpass without anticipating the considerable difficulties that would result from this decision, particularly if the expansion joint were to lose its watertightness. Furthermore, it did not assess the inspection problems that such a structure might involve. In the *Ministère's* defence, however, the Commission

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[16] R. Désy, Transcript, April 19, 2007, p. 185 and 186.
[17] G. Dupaul, Transcript, April 18, 2007, p. 200 to 204.
[18] R. Therrien, Transcript, April 17, 2007, p. 127 and 128.
[19] R. Therrien, Transcript, April 17, 2007, p. 132.
[20] Exhibit COM-6, p. 4 and 5 ; R. Francoeur, Transcript, April 19, 2007, p. 246 ; G. Richard, Transcript, July 13, 2007, p. 170.

acknowledges that the use of de-icing salts was relatively new at the time and that little was known concerning the problems related to their use.

Since 1972, the *Ministère* stopped approving similar structures. However, the Commission has found no evidence to show that, afterwards, measures were taken to incorporate appropriate actions into the inspection and intervention programme regarding this particular type of structure.

4.3 Professional service contract – design related duties[21]

In April 1970, after the beginning of the construction phase, the *ministère de la Voirie* confirmed the mandate and ultimately awarded a contract for professional services to DSA for all engineering work required by the extension of the Papineau-Leblanc Autoroute.[22] The mandate included the following phases:

- further preliminary studies
- preliminary and final drawings, specifications and estimates
- drilling, surveys and soil tests
- complete work supervision
- control and supervision of infrastructure and foundation materials
- control and regular testing of cement and concrete
- control of production and placing of asphalt pavement
- control of reinforcing and structural steel
- slope protection against erosion and improvement
- lighting systems in designated areas
- road signal systems
- government, public or private agency contribution opportunity studies
- any other work that may be required by this mandate, upon written request of the owner

This contract also defined the main phases of the mandate and administrative aspects, such as insurance and remuneration. The appendixes of the contract, signed on April 27, 1970, included the following:[23]

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[21] DSA's contractual obligations for supervision are discussed in detail in section 4.7.2.

[22] Exhibit COM-18, p. 76.

[23] Exhibit COM-18, p.106 to 222.

- Appendix A: Soil study
- Appendix B: Control of soil and installation of infrastructure materials and foundation
- Appendix C: Quality control of concrete used for constructing the structures
- Appendix D: Control of reinforcement and structural steel used for building the structures
- Appendix E: Control of asphalt pavement and related materials used for building the structures

4.3.1 Drawings and specifications

The drawings of the de la Concorde overpass were prepared by Mr. Michel Bertrand, draftsman. Another draftsman, Mr. Gilles Demers, made some revisions.[24] The work was then verified by the head draftsman.[25] Throughout the whole process, the drawings were verified by the design engineer, Mr. Gilles DuPaul.[26]

The drawings of the de la Concorde overpass are part of a larger set of design drawings describing the extension of Autoroute 19. Table 4.1 gives the list of these drawings.[27]

Table 4.1 List of design drawings

Public works	
Public works	Location plan
Sheet Nos. 1 and 2	Existing conditions
Sheet Nos. 3, 4, 5 and 6	Public services
Sheet Nos. 7 and 8	Saint-Martin Boulevard
Sheet No. 9	de la Concorde Boulevard
Sheet No. 10	Collector sewer
Sheet Nos. 11, 12 and 13	Geometry
Sheet Nos. 14 and 15	Signage
Sheet Nos. 16 to 22	Cross-sections
Sheet Nos. 23, 24 and 25	Typical drawings
Sheet No. 26	Drawings and profiles – Saint-Martin in Laval
Framework	
Sheets Nos. 27 to 30	de la Concorde overpass
Sheets Nos. 31 to 34	de Blois overpass
Sheets Nos. 35 to 37	Rochefort Street footbridge
Sheets Nos. 38 to 40	Retaining walls
Sheets Nos. 41 to 45	Saint-Martin overpasses

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[24] G. Demers, Transcript, April 19, 2007, p. 109.
[25] G. Demers, Transcript, April 19, 2007, p. 108 and 109.
[26] G. Dupaul, Transcript, April 18, 2007, p. 182.
[27] Exhibits COM-19 and COM-20A, p. 77.

DSA had to prepare the drawings and specifications used by the *Ministère* in the tender process leading to the selection of a contractor. It therefore drafted Special Specifications, adding or modifying the general specifications according to the particular character of the structures in the contract.[28] These Special Specifications were signed by Messrs. Marcel Dubois, Eng. and René Therrien, Eng., both with DSA. They were approved on July 30, 1969, by Mr. Arthur Branchaud, chief engineer of the *ministère de la Voirie*.[29] These specifications clarify certain technical aspects, namely the requirements related to fresh concrete properties, prestressing details and bearing pads, as well as administrative aspects such as terms and conditions of payment. Three other addenda, prepared by Mr. Dubois[30] but not dated,[31] also add some modifications or precisions to the contract.

The Special Specifications also included sections on general conditions, public, lighting and structural work. Structural work included the following:[32]

- Construction of a pretensioned concrete overpass at de la Concorde Boulevard
- Construction of a pretensioned concrete footbridge at the corner of Rochefort Street
- Construction of a steel overpass at de Blois Boulevard
- Construction of two reinforced concrete overpasses for the freeway at Saint-Martin Boulevard
- Construction of two reinforced concrete overpasses for the east and west service roads at Saint-Martin Boulevard
- Construction of all retaining walls

Analysis of the bid documents have shown that it would be more expensive to build an overpass at de Blois in steel rather than a replica of the de la Concorde overpass in concrete. For economical reasons, related to the [TRANSLATION] "*difficult and expensive steel market*" the *Ministère* decided, upon the recommendation of DSA, to build the de Blois overpass according to the similar design details as the de la Concorde Boulevard overpass.[33]

In addition to the drawings, the draftsmen also had to prepare the bar list. Along with the drawings and specifications, this document is used by the contractor to fabricate the reinforcement. It shows the size and length of the bars and the required bend details. At the time, according to Mr. Dupaul, the design engineer was not required to review this list.[34] The bar list was never found.

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[28] Exhibits COM-20B and COM-20C. The contract signed by DSA lists the government's general specifications, which apply the following.

[29] Exhibit COM-20A, p. 74.

[30] Two of the three addenda bearing Mr. Dubois's name; one bears his signature.

[31] Exhibit COM-20A, p. 55 to 58.

[32] Exhibit COM-20A, p. 103.

[33] Exhibit COM-20A, p. 47 and 48.

[34] G. Dupaul, Transcript, April 19, 2007, p. 10.

4.4 Design of the overpass and detailed calculations

Mr. Dupaul was in charge of the design and the detailed calculations. He produced the preliminary and final drawings, cost estimates and specifications.[35] He states that he complied with the following codes and standards, in effect at the time:[36]

- *Standard Specifications for Highway Bridges*, 8th Edition (American Association of State Highway Officials, AASHO 1961)[37]
- *Design of Highway Bridges* (Canadian Standards Association, CAN/CSA-S6-1966)[38]
- *Design Handbook* (Concrete Reinforcing Steel Institute, CRSI 1952)[39]

To calculate the live loading on the de la Concorde overpass, Mr. Dupaul used the H20-S16 truck loading, as specified by CSA Standard S6-1966, the heaviest truckload at the time, at the most critical position on the structure. He assumed the load was uniformly distributed on the neoprene bearing pads, given that transverse prestressing stiffened the superstructure.[40] He did not consider the additional live load from the sidewalk, but he claims that the live load on the sidewalk is not as high as elsewhere.[41]

The cantilevers of the de la Concorde overpass are designed to resist the most critical bending moments, which include the dead load (the self-weight of the structure) and the live load (the weight of the moving vehicles). Mr. Dupaul explained in his own words that tensile stresses have to be resisted by the steel because the concrete has a limited ability to resist tensile stresses and is subject to "fatigue".[42]

Mr. Dupaul states that the code allowed for a shear stress of up to 70 psi before any shear reinforcement was required.[43] The maximum shear stress calculated for the thick slab of the de la Concorde overpass abutments was 60 psi. However, the presence of a skew in the geometry of the abutment slabs creates stresses in the south corner of the east abutment and the north corner of the west abutment that exceed the average stresses calculated by Mr. Dupaul[44] (see Figure 2.1). In his calculations, he accounted for the effect of the skew by considering the total length of the cantilever measured along the axis of the bridge, and not perpendicular to the supporting wall. However, the finite element analysis tools that are commonly used today, but were not available in 1969, show that the forces are more concentrated than was indicated by Mr. Dupaul's calculations and that these calculated stresses exceed the stresses allowed by CSA-S6-1966.[45]

U-shaped No. 8 hanger reinforcement was placed at the end of the cantilever to transfer loads in tension from the beam seat to the top of the cantilever.

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[35] G. Dupaul, Transcript, April 18, 2007, p. 164.
[36] G. Dupaul, Transcript, April 18, 2007, p. 199 and 200.
[37] Exhibit COM-29D.
[38] Exhibit COM-29A.
[39] Exhibit COM-29E.
[40] G. Dupaul, Transcript, April 19, 2007, p. 29.
[41] G. Dupaul, Transcript, April 19, 2007, p. 29.
[42] G. Dupaul, Transcript, April 18, 2007, p. 233.
[43] G. Dupaul, Transcript, April 19, 2007, p. 45.
[44] G. Dupaul, Transcript, April 19, 2007, p. 45.
[45] Exhibit COM-62, p. 110 and 111. As described in more detail in Chapter 5.

4.4.1 Design of the U-shaped hangers

The hooks at the top of the U-shaped hanger reinforcement were intended to anchor the tension forces in the hanger reinforcement near the top of the cantilever. According to the drawings, these hooks were intended to be placed on the same horizontal plane as the No. 14 bars. The length of the hooks were chosen to be 18 times the diameter of the bars to provide anchorage. According to Mr. Dupaul, the overlap of the hooks of the U-shaped hangers with the No. 14 bars was a very important concept in the design.[46]

According to Mr. Dupaul, if the hangers had been hooked around the main No. 14 bars, the effective depth of the slab would have been less because the main bars would have been lower. As a result, the thickness of the structure would have had to be increased.

While there were no specific provisions for the anchorage of hanger reinforcement in the standard, Section 8.6.10.4.3 of CSA-S6-1966 requires that stirrups be anchored as follows:[47]

> "*Stirrups shall be anchored at both ends by one of the following methods, or by a combination thereof:*
>
> *a) Bending around closely in contact with a bar of the longitudinal reinforcement, in the form of a U-stirrup or hook;*
>
> *b) Embedment above or below the mid-depth, 1/2, of the beam on the compression side a distance sufficient to develop by bond the stress to which the beam will be subjected at the bond stress permitted by Clause 8.3.3c) but in any case a minimum of 24 bar diameters.*"

In defence of his design, Mr. Dupaul stated that this section of the Code applies to beams and that the cantilever portion of the abutments should not be considered as a beam, but as a thick slab.[48] He therefore did not take this section into consideration when designing the overpass. According to Mr. Dupaul, in a thick slab, it is possible to join the hangers to the longitudinal reinforcement by placing the hooks of the hangers parallel to the longitudinal reinforcement on the same horizontal plane.

For the same reason, Mr. Dupaul considers that Section 8.6.10, and more particularly Section 8.6.10.3, of CSA-S6-1966 does not apply in this case:[49]

> "*Stirrups: Where stirrups are required to carry shear, the maximum spacing of stirrups shall be limited to 1/2 the depth of the beam, and where not required to carry shear, the maximum spacing shall be limited to 3/4 the depth of the beam. The first stirrup shall be placed at a distance from the face of the support not greater than one fourth of the effective depth of the beam.*"

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[46] G. Dupaul, Transcript, April 18, 2007, p. 230 and 231.

[47] Exhibit COM-29A, p. 43.

[48] G. Dupaul, Transcript, April 19, 2007, p. 36 and 37.

[49] Exhibit COM-29A, p. 42.

Findings of the Commission

The steel reinforcement design complies with the code in force at the time; Code CSA-S6-1966 did not require the use of stirrups in slabs if the maximum shear stress in the concrete did not exceed the limiting shear stress. Code CSA-S6-2006 does not require stirrups in slabs provided that the factored shear resistance exceeds the factored shear force.

The loads in the abutment created by the skew effect were very difficult to calculate at the time. Without today's computerised methods, thorough analysis of this geometrical particularity had to be made by means of calculation methods that most engineering designers did not master at the time. The skew effect introduced an additional risk factor.

Moreover, the reinforcement detail on the drawings should have been more precise in accordance with the best practice and adapted to the specific character of the structure at the extremity of the cantilevers.

4.4.2 Manufacture and installation of the U-shaped hangers

According to Mr. Dupaul, the U-shaped hangers must have a total length of 11 ft. and when they are manufactured at a plant, the bends must be taken into account and the hangers increased in length accordingly.[50]

According to Mr. Dupaul, the hanger should have been made with right angle bends (90°).[51] However, it seems that when installed on site, the lower part of the hanger was resting on the No. 7 bars, resulting in a slope of about 4% (see Figure 2.10). The drawings do not specify that it was necessary to support the reinforcing bars to provide proper angles. Rather, the contractor must use construction techniques to achieve this. According to Mr. Dupaul, a competent contractor should have deduced that "chairs" (spacers) were required.[52]

Mr. Dupaul states that the placement of the steel was "unacceptable".[53] Looking at photos of the northwest observation window of the de la Concorde overpass, he clearly noted that the U-shaped hanger bars were not placed properly. These hanger bars were placed under No. 7 crossbars and, consequently, under the No. 14 main bars.[54] The fact that the hanger bars were below the No. 14 bars created a zone where no reinforcement was present in the slab.[55] Mr. Dupaul came to the same conclusion by looking at photographs and sketches made after the dissection operations carried out by the Commission's experts.[56] For Mr. Dupaul, someone in charge of supervising the construction would have seen that the reinforcing bars were placed improperly.

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[50] G. Dupaul, Transcript, April 19, 2007, p. 12.

[51] G. Dupaul, Transcripts, April 18, 2007, p. 232 and April 19, 2007, p. 14 and 15.

[52] G. Dupaul, Transcript, April 19, 2007, p. 15.

[53] G. Dupaul, Transcript, April 18, 2007, p. 244.

[54] Exhibit COM-35C ; G. Dupaul, Transcript, April 19, 2007, p. 20 to 25.

[55] G. Dupaul, Transcript, April 19, 2007, p. 24.

[56] Exhibit COM-1B, p. 16.

Looking at the photograph taken by highway patrolman Jules Bonin,[57] less than an hour before the collapse, Mr. Dupaul said that the crack was very visible and that the bridge should have been closed. However, he considers that the photograph was not a warning of what happened.[58]

Mr. Dupaul said that the cantilever collapsed in shear and not in bending, and that there was no failure of the beam seat proper. He explained that the cantilever collapsed because a crack had formed between the reinforcing bars.[59] This crack would have grown slowly inside the structure with time. According to him, had there been stirrups along the length of the cantilever, they would have supported the loads or at least delayed the collapse.[60] Throughout his testimony, Mr. Dupaul stated that there would not have been a collapse had the hanger bars been anchored to the No. 14 and No. 7 bars. The design did not provide for direct anchorage, by hooking the No. 8 U-bars around the No. 14 bars, but rather aligning the hooks of the hanger bars on the same horizontal plane as the No. 14 bars, without necessarily anchoring the U-shaped hangers to the No. 7 or No. 14 bars.

Findings of the Commission

It is the Commission's opinion that during construction, the steel reinforcement next to the cantilever beam seat was misplaced. This opinion is shared by the witnesses involved in the construction as well as all of the experts. This is especially the case for the No. 8 U-shaped hanger bars and the No. 6 diagonal bars, in all cantilevers of the de la Concorde and de Blois overpasses. These bars were not anchored to the No. 14 bars since it was not specified on the drawings. The hooks, which were intended to go alongside the No. 14 bars on the same horizontal plane, were instead placed under them, thus defining a zone of weakness without reinforcement between the hooks and the No. 14 bars.

4.4.3 Other considerations

The No. 7 transverse bars shown on the drawings are intended as minimum temperature and shrinkage reinforcement in the transverse direction of the cantilever (see Figures 2.8 and 2.9 in Section 2.2.). Since there was a risk of cracking at the corner of the beam seat, the designer provided steel reinforcement at this location.

No drainage system was shown on the drawings. According to Mr. Dupaul, water was drained at the ends of the structure. There was a longitudinal slope on the overpass towards the abutments and transverse slopes towards the sidewalks.[61] The slope is usually 1 to 2%. Although the slope on the de la Concorde overpass was small, Mr. Dupaul considers it sufficient.[62] He made the point that the slope of the structure shown on the drawings does not necessarily correspond to the actual road surface slope. The possible difference depends on the thickness of the asphalt

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[57] Exhibit COM-1A, p. 40. (repeated in the report at Figure 3.3)

[58] G. Dupaul, Transcript, April 19, 2007, p. 67 and 68.

[59] G. Dupaul, Transcript, April 19, 2007, p. 76 and 77.

[60] G. Dupaul, Transcript, April 19, 2007, p. 51 to 53.

[61] G. Dupaul, Transcript, April 18, 2007, p. 200 to 203.

[62] G. Dupaul, Transcript, April 18, 2007, p. 202 and 203.

and, because of the low slope of the overpass small defects in the asphalt may result in the formation of puddles.[63]

Mr. Dupaul never went to the job site of the de la Concorde and de Blois overpasses.[64] He does not recall being notified of any construction problems.[65] Moreover, he states that he had never been consulted throughout the useful life of the bridges nor during the course of inspection or maintenance work, regarding specific difficulties related to the particular design of these structures.[66]

4.4.4 Properties of concrete

The concrete used in the construction is specified in the Special Specifications,[67] in which Table E-4.1 amends Table 4.1 of the General Specifications.[68]

Four concrete types are described in this table (A, exposed to air; B, exposed to water; C, exposed to salt water and de-icing salts; and D, cast underwater). Under the table, a note specifies:

> [TRANSLATION] "*In this project, only type A concrete applies to all structures.*"

Regarding the air content, Table E-4.1 mentions that for type A concrete, the entrained air may vary from 5 to 7% when 3/4 in. aggregate is used. However, in Section 203-3, additional specifications are introduced for the different elements of the structures. For example, the concrete used for the abutments was supposed to have an air content of 4 to 6% with a slump of 4 in., while the concrete used to build the deck, the sidewalk and the central median had a specified air content of 6 to 7% with a 3 in. slump.

In other words, the specifications are confusing with respect to the required framework concrete characteristics. Furthermore, the concrete properties required by the A-type exposure conditions did not comply with Canadian Standard *A23.1-67 – Concrete Materials and Methods for Concrete Construction* in force at the time.

4.4.5 De Blois overpass

Mr. Gilles Demers prepared the drawings for the de Blois overpass, as evidenced by his initials in the insert at the lower right corner and the table of revisions at the upper right corner of the drawings.[69]

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[63] G. Dupaul, Transcript, April 18, 2007, p. 204.
[64] G. Dupaul, Transcript, April 18, 2007, p. 185.
[65] G. Dupaul, Transcript, April 18, 2007, p 185 and 186.
[66] G. Dupaul, Transcript, April 19, 2007, p. 65.
[67] Exhibit COM-20A, p. 105.
[68] Exhibit COM- 20C, p. 41.
[69] G. Demers, Transcript, April 19, 2007, p. 109 ; Exhibit COM-19, p. 63 to 66.

According to Mr. Demers, the hangers are 11 ft. long on the drawings for the cantilevers of both structures, but with the following differences:[70]

- The slope under the cantilever is slightly different because the de la Concorde overpass has a skew and the de Blois overpass is at 90° [71]
- There are only two lengths of bar that overlap on the de Blois overpass (MK701 and MK702) while there are three on the de la Concorde overpass (one on each side that is bent and one in the middle that is straight) since the latter structure is wider [72]

According to Mr. Demers, it is evident that the U-shaped hanger reinforcement is vertical and should not be aligned with the sloping bottom bars.[73] When shown photographs taken during the dissection pointing out the position of stirrups in the north-west section of the abutment of the de la Concorde overpass,[74] he stated that it was nonsense.[75]

4.4.6 The "as-built" drawings

At the end of the construction, DSA's contract for professional services specified in Section II.10 that the firm had to submit one or more "as-built" drawings of the structure in a form that was easy to reproduce. Mr. Dupaul explained that this version of "as-built" drawings is prepared by updating the original drawings with information added on the job site.[76]

Unfortunately, the MTQ did not have a copy in its archives of these drawings. Mr. Dupaul does not recall if DSA sent "as-built" drawings of the de la Concorde overpass to the *Ministère* at the end of the construction and it was impossible to determine from the evidence if they were ever sent.[77]

The drawings submitted to the Commission by the MTQ correspond to the preliminary drawings discussed by DSA and the *Ministère* during the design approval phase.[78]

TEL QUE CONSTRUIT

Cette mention ne signifie pas que le plan a été annoté comme tel. Son contenu peut donc être différent de l'ouvrage existant.

Date ____________ par : ___________

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[70] G. Demers, Transcript, April 19, 2007, p. 111 to 113.

[71] G. Demers, Transcript, April 19, 2007, p. 111.

[72] G. Demers, Transcript, April 19, 2007, p. 113.

[73] G. Demers, Transcript, April 19, 2007, p. 114 and 115.

[74] Exhibit COM-1B, p. 16.

[75] G. Demers, Transcript, April 19, 2007, p. 127.

[76] G. Dupaul, Transcript, April 18, 2007, p. 196.

[77] G. Dupaul, Transcript, April 18, 2007, p. 189 and 190.

[78] Exhibit COM-19 [TRANSLATION] "*AS BUILT — This expression does not mean that the drawing was annotated as such. Thus its content may differ from the actual structure.*"

It appeared that these drawings, dated July 31, 1969, did not incorporated later revisions and were not the true “as-built” drawings.

It is during his testimony before the Commission that Mr. Dupaul produced the drawings that he had on hand. These drawings are also dated July 31, 1969, but also include a number of revisions, the last one dated August 17, 1970. The drawings submitted by Mr. Dupaul appear to be those used in the construction.[79]

Regarding the note mentioning that the drawings were “as-built,” Mr. Guy Richard, director of the MTQ’s *Direction des structures*, explained that typically when drawings were microfilmed, two different types of stamps were used. One indicated “as-built” with no notes, which was the true “as-built” drawings. The other stamp, which is reproduced above, was used when no true “as-built” drawings were found. This stamp reflected that the drawings were the only ones that could be found.[80]

Findings of the Commission

It is surprising that the MTQ was not able to find the true “as-built” drawings of the de la Concorde and de Blois overpasses. If DSA did not send them, then MTQ should have asked for them.

4.5 Construction of the structure

On October 30, 1969, following a public call for tenders, the *ministère de la Voirie* awarded to the lowest bidder, ISP, contract No. 4210-69 to build a six-lane highway north of the new Papineau-Leblanc bridge. The terms of this contract specified that the new highway was to be completed on July 1, 1971,[81] and open to traffic on November 11, 1971.[82]

The pertinent documents are listed in the [TRANSLATION] “*list of documents*” prepared by DSA. This list is part of the Special Specifications.[83] In addition to the drawings of the structure listed in the general conditions of the Special Specifications entitled [TRANSLATION] “*Location and scope of the work*”, the following documents listed below were also included.

1- General Specification documents:

- *Cahier des charges et devis généraux pour la construction, la réfection et l’entretien des routes* (" CCDG ") (last edition) published by the *ministère de la Voirie*
- *Devis de construction des ouvrages d’art majeurs* published by the *ministère de la Voirie* (Bridge Department), May 1968
- Amendments to the *Cahier des charges et devis généraux, pour la construction, la réfection et l’entretien des routes.* (June 4th 1968)

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[79] Exhibit COM-19, p. 13 to 16.

[80] G. Richard, Transcript, April 12, 2007, p. 230 and 231.

[81] Exhibit COM-20A, p. 81 and 115.

[82] Exhibit COM-20A, p. 51.

[83] Exhibit COM-20A, p. 2 to 5.

- Compaction Specifications

2- Special Specifications intended for the contractor

3- Price schedule

The main work mentioned in the contract and the cost allocations were indicated on a price schedule that accompanied the proposal and that was prepared according to the specifications dated July 30, 1969.[84] It was a fixed unit price contract. In this type of contract, the contractor bids on quantities assessed by the engineering firm and entered on the quantity schedule accompanying the invitation to tender. The contractor completes its proposal entering fixed unit prices for each element of the schedule. If quantities change during the course of construction, the payments are adjusted accordingly.

The total cost allocations of the proposal were as follows:

Road system and lighting	**$ 2,692,838.80**
Structures	
- De la Concorde overpass	$227,519.50
- Twinned Saint-Martin overpasses (over the freeway)	$278,558.45
- Twinned Saint-Martin overpasses (over the service roads)	$178,044.50
- De Blois overpass	$208,232.80
- Rochefort Street pedestrian bridge	$20,417.00
- Retaining walls	$151,150.50
Grand total	**$ 3,756,761.55**

NOTE: The de Blois overpass was not built with a steel structure, at the cost estimated in the table, but with reinforced concrete at a cost of $163,533.94.

For the de la Concorde overpass, the price schedule included the cost allocation of the structure. The main elements consisted of the 20 prestressed beams ($84,900), 1,600 cubic yards of concrete to build the abutments ($56,000) and 300,500 lb. of reinforcing steel ($35,459).[85]

The Decree of October 29, 1969, allowed an amount totalling $4,160,000 to carry out the work included in document 4210-69 by ISP.[86] This sum was detailed as follows:

Contract	$3,756,761.55
Materials	$30,000.00
Contingency and variations in quantities	$373,238.45

The final price of the contract, according to final payment request No. 27 dated March 31, 1973, was $3,713,191.76, to which was added an amount of $86,415.09 for the settlement of an extra claim.[87]

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[84] Exhibit COM-20A, p. 69.
[85] Exhibit COM-20A, p. 63.
[86] Exhibit COM-21, p. 41.
[87] Exhibit COM-23, p. 326.

4.5.1 Contractor's obligations[88]

The contractor had to carry out the work according to the drawings and specifications, in compliance with the rules of the art and to the satisfaction of the engineer acting as the designated representative of DSA. The contractor had to produce a construction programme for each weekly meeting, update it and review it depending on the progress of the job. Neither the approval of this programme by the engineer, nor the presence on site of inspectors and supervisors, relieved the contractor from any duties and obligations.[89, 90]

According to the CCDG (1945) published by the *ministère de la Voirie,*[91] the contractor was [TRANSLATION] "*to employ supervisors and foremen that were competent, experienced in carrying out road work and able to easily understand specifications and read drawings*". The same document also mentions that [TRANSLATION] "*these individuals should have recognised integrity and be disposed to managing operations in order to obtain the best possible results, in compliance with the contract*". Moreover, the document also specified that obligations in terms of skill also applied to the engineers employed by the contractor to manage the work.

As indicated in the Special Specification document ("SSD"), the contractor[92] was not to order the reinforcing steel before verifying and receiving approval from the engineer, especially if the footing level was modified. According to the construction specifications for major civil engineering works in 1968,[93] the contractor had to verify, upon reception, that the quantity and dimensions of the reinforcing steel conformed to the required specifications.

In addition, before pouring concrete, the contractor was required by the SSD to submit the mix proportions it intended to use for approval.[94] It also had to make sure that all accessories required to be inserted into the concrete (rebar, expansion joints, bearing pads, drains, etc.) were properly placed before pouring.[95] The contractor also had to notify the engineer at least 48 hours in advance when it planned to pour concrete and was not allowed to proceed before the engineer had inspected and approved the forms and the reinforcement.

The 1945 edition of the CCDG mentions that the contractor was responsible for the structures until final approval was given by the engineer.[96] If, during the five years that followed this final approval, defects were found with the structures, the contractor had to repair them at its own expense regardless of whether these defects were caused by construction defects, external elements or acts of sabotage.

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[88] The contractor's obligations for supervision are discussed in Section 4.6.4.
[89] Exhibit COM-20A, p. 80.
[90] Exhibit COM-20B, p. 29.
[91] Exhibit COM-20B, p. 40.
[92] Exhibit COM-20A, p. 106.
[93] Exhibit COM-20C, p. 47.
[94] Exhibit COM-20C, p. 37.
[95] Exhibit COM-20C, p. 40.
[96] Exhibit COM-20B, p. 36 and 37.

4.5.2 Internal organisation of Inter State Paving inc.

The Autouroute 19 construction contract was the largest contract for ISP at the time.[97] The company specialised in such works as paving, aqueducts, sewers and retaining walls. According to Mr. Raymond Désy, a contractor did not have to be specialised in bridge construction, provided proper supervision was carried out. Nevertheless, ISP had already built an overpass over the Papineau-Leblanc bridge approach in Montréal.[98]

ISP hired specialised sub-contractors for the construction of forms as well as the concrete supply and placement while it controlled the overall job site conditions and excavated the foundations. The sub-contractors took over once the footings were in place.[99]

In 1969, Mr. Philippe Rizzuto of ISP was in charge of all the construction regarding the extension of Autoroute 19. Bertrand Lampron worked for ISP as an engineer, responsible for the coordination and proper execution of the work. He considered that his mandate did not include ensuring the work complied with the drawings and specifications because, in his opinion, this responsibility was incumbent on DSA's engineers who were mandated by the client to supervise. Guillaume de Paoli worked as an engineer at ISP's offices; he prepared tenders and contracts for the ISP's sub-contractors.

Meetings were held at the job site once a week or every two weeks. The names of Messrs. Bertrand Lampron, Guillaume de Paoli, Philippe Rizzuto and Pietro Rizzuto, of ISP, appear in the minutes of these meetings submitted to the Commission.[100] Before these meetings, Mr. Lampron prepared the list of both the executed and projected work.[101] Mr. Pietro Rizzuto, President of ISP, attended the meetings but was not present on the job site on a daily basis. Mr. de Paoli states that he personally was not involved in the actual execution of the construction contract.[102] He does not recall why his name appears in the minutes of the meeting No. 27.

As for quality control, Messrs. Lampron and de Paoli left the responsibility to the consulting engineers and to the sub-contractors' workers. The evidence gathered has shown that Mr. Lampron did not verify if the work was executed in conformity with the drawings.

4.5.3 Sub-contracted work

4.5.3.1 Reinforcing steel supplier

On January 29, 1970, Mr. Claude Robert, President of Acier d'armature de Montréal (1968) ltée ("AAM"), informed the *ministère de la Voirie* that his company was awarded by ISP a contract to fabricate, supply and install all the reinforcing steel required for the extension of Papineau-Leblanc Autoroute in the City of Laval.[103]

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[97] B. Lampron, Transcript, April 26, 2007, p. 8.
[98] R. Désy, Transcript, April 19, 2007, p. 193 and 194.
[99] B. Lampron, Transcript, April 25, 2007, p. 227 and 228.
[100] Exhibit COM-25, p. 1 and 3 to 12.
[101] B. Lampron, Transcript, April 25, 2007, p. 221.
[102] G. de Paoli, Transcript, April 25, 2007, p. 178 and 179.
[103] Exhibit COM-26, p. 35.

AAM was originally a steel reinforcement fabricator. However, in order to be more competitive in the market, the enterprise also offered the placement services for the reinforcing steel. To do this, it hired its own sub-contractors. During the hearings, opposing testimonies were given about which sub-contractor placed the steel on the de la Concorde overpass.

Among the sub-contractors that might have installed the reinforcing steel on the de la Concorde overpass are the companies owned by Messrs. Raymond Bernard, Raymond Lessard and Réal Desrochers.[104]

4.5.3.1.1 Mr. Raymond Bernard's company

Mr. Raymond Bernard claims that he installed the steel bars for the Saint-Martin overpasses.[105] He is also certain that he was not involved in the contracts for the de la Concorde and de Blois overpasses. He is certain that "Desrochers Steel" was responsible for this contract. However, Messrs. Jean-Claude Lessard and Régis Saint-Laurent, who both were employed by Raymond Bernard at the time the overpass was built, contradicted Mr. Bernard.

Mr. Jean-Claude Lessard states that he installed the reinforcing bars on the deck of the de la Concorde overpass while he was working for Mr. Bernard. Back then, he was employed by a company named Durno and while out of work between two contracts, he worked three or four days for Mr. Bernard. He remembers that he worked in the summer because it was very hot and that the overpass curved over part of Autoroute 19.[106] Later, he had to return to Mr. Bernard's office because he had been paid with a "non sufficient funds" cheque.[107] During the hearings, Mr. Bernard did not recognise Mr. Jean-Claude Lessard and he did not recall issuing any NSF cheque.[108]

Mr. Régis Saint-Laurent was a reinforcing steel worker employed by Mr. Raymond Bernard in 1969 and 1970.[109] He recalls having worked for him as a foreman on the construction for the four overpasses over Saint-Martin Boulevard. His work on the de la Concorde overpass was limited to the placement of the reinforcing steel in the east abutment.[110]

4.5.3.1.2 Mr. Raymond Lessard's company

Mr. Raymond Lessard's company was started in 1964 or 1965. Mr. Lessard admits he did some work for AAM, but claims he was not involved in the Autoroute 19 project.[111]

Findings of the Commission

The Commission has noted that the reinforcing steel was improperly placed, as shown at many locations through the use of ground penetrating radar as well as through the dissection. Regardless of which company was in charge of placing the steel

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[104] C. Robert, Transcript, May 17, 2007, p. 26.
[105] R. Bernard, Transcript, May 17, 2007, p. 146 and 147.
[106] J.-C. Lessard, Transcript, May 17, 2007, p. 128 and 133.
[107] J.-C. Lessard, Transcript, May 17, 2007, p. 10.
[108] R. Bernard, Transcript, May 17, 2007, p. 148.
[109] R. Saint-Laurent, Transcript, June 19, 2007, p. 24 and 27.
[110] R. Saint-Laurent, Transcript, June 19, 2007, p. 28.
[111] R. Lessard, Transcript, June 19, 2007, p. 37 and 38.

reinforcement, it was an AAM sub-contractor. The latter should have ensured that the reinforcing steel was installed in accordance with the drawings and specifications, or at least should have obtained an approval from the supervising engineer for any modifications to the drawings and specifications, or for any work, which did not comply to specifications.

4.5.3.2 Comments pertaining to the steel reinforcement placement

The Commission interviewed witnesses about the fabrication and placement of the steel reinforcement on the de la Concorde overpass.

The reinforcing bars were cut and bent according to the specifications of the bar list that was prepared by the engineering firm. The reinforcing steel placer also used the drawings and the bar list which indicated the size of each reinforcing bar to place.

The reinforcing steel placer's foreman did not have the authority to deviate from the drawings. He had to communicate with Mr. Jean Ménard, draftsman with AAM, who communicated directly with the DSA supervisor in case of any change. Before placing steel that was different from what was shown on the drawings, the foreman and the supervisor had to notify the designer, unless the supervisor on site was an engineer.[112]

4.5.3.2.1 No. 14 main reinforcement bars

According to Mr. Claude Robert, No. 14 bars for the top of the abutment were cut according to the drawings, i.e. without being bent downwards at their ends.[113] It would have been impossible to bend the bars towards the end of the cantilever because this would have required extra space which was simply not available. The Commission disregarded this testimony because it noted on drawings of similar structures, such bends of No. 14 bars at the end of cantilevers. Such a hook would have allowed for better load transfer.

4.5.3.2.2 No. 6 additional reinforcing bars

Some additional vertical bars, not shown on the drawings, were added during construction to support the reinforcing steel at the top of the abutment, to which they were welded (see Figure 2.10). According to Mr. Robert,[114] these No. 6 bars supported the top reinforcing layer.[115] They were not structural because of their limited number, their wide spacing and the absence of adequate anchoring and therefore could only provide a limited role in resisting shear. They were added to the overpass on the job site although the drawings did not make provision for them. The welding of these bars is the only issue of which Mr. Robert was aware of on the de la Concorde overpass job site.[116] He discussed it with Mr. Guillaume de Paoli who provided AAM with a welder to perform the operation.

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[112] J. Ménard, Transcript, May 17, 2007, p. 78.

[113] C. Robert, Transcript, May 17, 2007, p. 60 to 62.

[114] Exhibit COM-35B, p. 5.

[115] C. Robert, Transcript, May 17, 2007, p. 74 and 75.

[116] C. Robert, Transcript, May 17, 2007, p. 96 and 97.

The results of the laboratory load tests ordered by the Commission have shown that these vertical No. 6 bars played a role in the interception of the rupture plane by slightly increasing the shear resistance of the cantilevers.[117]

It is noteworthy to mention that according to Mr. Dupaul, since each abutment contains about 40 tons of reinforcing steel, the installation likely took four to five days of work per abutment.[118] Similarly, Mr. Lampron estimated that it would take about one week to install the reinforcing steel in one abutment.[119]

4.5.3.3 Concrete supplier for the walls and structures

On October 30, 1969, ISP hired Prud'Homme & Frères ltée ("Prud'Homme") to supply all the required materials for the concrete work, including the concrete pavement (contract price of $175,800), the middle strip (contract price of $23,600), and the structures (contract price of $152,900).[120] The structures in question were as follows:

De la Concorde overpass (drawing Nos. 27 to 30)	2,040 cu. yd.
De Blois overpass (drawing Nos. 31 to 34)	1,225 cu. yd.
Rochefort Street pedestrian bridge (drawing Nos. 35 to 37)	252 cu. yd.
Retaining walls (drawing Nos. 38 to 40)	2,285 cu. yd.
Saint-Martin overpasses (4) (drawing Nos. 41 to 47)	4,068 cu. yd.

Overall, the contract involved 9,870 cu. yd. of concrete. The contract price included the following:

- concrete supply
- placing concrete in compliance with the specifications
- finishing the concrete in the unformed exposed areas, such as sidewalks, top of the walls, top of the parapets, top of the deck, etc.

The specifications did not require any finishing of the formed concrete, except for honeycombs defects or bad joints.

Prud'Homme, of which Mr. Camille Deschamps was the Vice-President at the time, specialised in the production of ready-mix concrete. This company was practically ISP's sole concrete supplier and was involved in the construction of the de la Concorde, de Blois and Saint-Martin overpasses.[121]

Prud'Homme sub-contracted to Coffrage Dominion ltée the placing placing and finishing the concrete, for a total amount of $29,610 (9,870 cu. yd.).[122] Prud'Homme worked with Coffrage Dominion ltée for this contract only.

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[117] Exhibit COM-62, p. 164.
[118] G. Dupaul, Transcript, April 19, 2007, p. 60.
[119] B. Lampron, Transcript, April 26, 2007, p. 6.
[120] Exhibit COM-26, p. 3 to 6.
[121] C. Deschamps, Transcript, May 1, 2007, p. 9 and 14.
[122] C. Deschamps, Transcript, May 1, 2007, p. 11 and 12; Exhibit COM-26, p. 13 and 21.

Furthermore, the concreting of the slabs and the roadways was sub-contracted to Francon ltée.[123]

The contract between ISP and Prud'Homme[124] specifically mentions in the General Conditions that the sub-contractor is fully responsible for the quality and the quantity of the materials supplied on the job site.

Prud'Homme had to submit a copy of the mix design to the site's material control laboratory for approval.[125] The common practice was for the concrete to have a resistance 20% higher than that required to ensure it met the requirements of the quality control of samples.[126]

Quality control of the concrete on the job site was performed by both the laboratory and Prud'Homme.[127] Normally, both parties would agree to sample concrete from the same trucks. Neither Prud'Homme nor ISP asked for clarifications as to the properties of the concrete to be produced.

Findings of the Commission

As discussed in further detail in Chapter 5, the concrete supplied did not have the required properties to sustain freeze-thaw cycles in the presence of de-icing salts. Thus, as discussed in Section 4.4.4, the Special Specifications regarding the properties of the concrete to be delivered to the job site were confusing and did not comply with Canadian Standard *A23.1-67 – Concrete Materials and Methods for Concrete Construction* in force at the time.

4.6 Work supervision

4.6.1 Role of the *Ministère* during supervision

It was the responsibility of each district to follow up on projects that were in progress in their territory.[128] However, except for an administrative follow-up which was intended to manage payments and bond requests, the *Ministère* left the supervision of work and material control[129] entirely in the hands of the engineering firm. The *Ministère* did not have a policy that required the supervision of engineers.[130]

Mr. Claude Bertin, the engineer responsible for district No. 4 where the project was being carried out, did not appoint a coordinator from the *Ministère* to work on the job sites. In any case, he would not have had enough personnel to do so, given the large number of on-going projects.[131] At most, he may have asked Mr. Marcel Parent, Division Chief for Division 4 in

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[123] Exhibit COM-26, p. 22.

[124] Exhibit COM-26, p. 6.

[125] C. Deschamps, Transcript, May 1, 2007, p. 16.

[126] C. Deschamps, Transcript, May 1, 2007, p. 19.

[127] C. Deschamps, Transcript, May 1, 2007, p. 22 and 23.

[128] R. Désy, Transcript, April 19, 2007, p. 200.

[129] R. Désy, Transcript, April 19, 2007, p. 190; C. Bertin, Transcript, April 25, 2007, p. 73 and 74.

[130] R. Désy, Transcript, April 19, 2007, p. 190; C. Bertin, Transcript, April 25, 2007, p. 87 to 90.

[131] C. Bertin, Transcript, April 25, 2007, p. 79 and 83 to 87.

Montréal, to attend one or two meetings at the start of the project in order to explain the procedure regarding payment requests.[132]

Mr. Parent, however, has no recollection of having attended any of those meetings, even though his name appears in the minutes of a number of them.[133] In his own words, he acted mainly as a [TRANSLATION] "*transmission belt*", forwarding unchecked estimates of the work progress to Mr. Bertin, who was in charge of the budget.[134] At best, Mr. Bertin would only supervise the progress status of the project.[135]

4.6.2 Obligations of Desjardins Sauriol & Associés

Under the terms of the contract for professional services awarded by the *ministère de la Voirie*, work supervision was the responsibility of DSA.[136]

The contract provided that DSA engineers were to perform their tasks according to the *ministère de la Voirie*'s *CCDG* in force at that time,[137] as well as the construction specifications for major civil engineering works.[138] Certain aspects regarding on site supervision, among others, were also described in the Special Specifications issued by DSA and approved by the *ministère de la Voirie.*[139]

More precisely, the contract for professional services described in detail the mandate, which called for complete work supervision to be carried out by DSA. It provided that the resident engineer had responsibilities of an administrative nature. The supervising engineer was in charge of issuing, in the course of construction, the certificates needed for progressive payments. As such, DSA was to provide a written report at least once a month on the nature and scope of the work performed.[140] DSA also had to prepare cumulative and detailed estimates of the cost of work performed up to that point.

In order to better follow the programme and work progress, weekly meetings were held.[141] These meetings brought together the authorised representatives of the contractors and of the *ministère de la Voirie* – in this case DSA – and those from the contractor. At each meeting, the contractor had to produce its construction programme, in accordance with the Critical Path Method ("CPM"), which was continually revised and updated as work progressed. DSA had to make sure that the contractor and its sub-contractors fulfilled their obligations and that any delays with respect to the schedule be reported.

This mandate for complete supervision included a technical section dedicated to the compliance of the work with the drawings and specifications, verification of shop drawings, as well as

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[132] C. Bertin, Transcript, April 25, 2007, p. 82.
[133] M. Parent, Transcript, April 25, 2007, p. 123 to 126.
[134] M. Parent, Transcript, April 25, 2007, p. 119 to 121.
[135] C. Bertin, Transcript, April 25, 2007, p. 88. Messrs. Bertin and Parent also specialised in pavement and knew little about structures: C. Bertin, Transcript, April 25, 2007, p. 83 and 84.
[136] Exhibit COM-18, p. 76.
[137] Exhibit COM-20B.
[138] Exhibit COM-20C, p. 1 to 196.
[139] Exhibit COM-20A, p. 74 to 116.
[140] Exhibit COM-18, p. 81 and 89.
[141] Exhibit COM-20A, p. 80.

establishing rules and procedures to control the construction process.[142] DSA had to ensure the permanent presence on site in sufficient numbers of competent supervision personnel.[143] DSA's engineers and technicians were also required to be at the disposal of the *ministère de la Voirie* and its authorised representatives to provide any information as needed. Furthermore, DSA also had to provide to the contractors the necessary information regarding work execution to ensure conformity with the drawings and specifications.

The contract for professional services stated that DSA could not, without the written approval of the *ministère de la Voirie*, modify, limit or cancel any provision of said contract, give instructions contrary to the content of the specifications or modify the drawings or sketches approved by the *Ministère*. The final approval of the work was left to the *ministère de la Voirie*.

4.6.3 Construction site organisation by Desjardins Sauriol & Associés

Supervision of the construction site for the de la Concorde and de Blois overpasses was the subject of contradictory testimony during the Commission hearings.

Mr. Claude Roberge, a structural engineer at DSA, acknowledges that the firm was in charge of work supervision for the roadway, but does not recall who was in charge for supervision of the overpasses.[144] According to Messrs. Therrien[145] and Dupaul,[146] construction of the overpasses would have been under the supervision of Mr. Marcel Dubois, engineer, assisted by Mr. Normand Plouffe, technician.

According to Mr. Claude Bertin, from the *Ministère*,[147] Mr. Dubois, engineer at DSA, was the individual in charge of the supervision on the project site. According to Mr. Camille Deschamps,[148] of Prud'Homme, Mr. Plouffe was the quality control supervisor on the Autoroute 19 project, including overpasses.

During their testimony, Messrs. Dubois and Plouffe admitted that they acted as roadwork supervisors and as residents on the site.[149] They began, however, by denying any involvement in the supervision of construction of the overpasses. They stated that they did not have the necessary qualifications. Yet, Mr. Dubois, subsequently recognised that he had supervised many such projects.[150]

Mr. Dubois claimed that he did not possess the knowledge to inspect the formwork of the overpasses and to verify the position of the reinforcing bars in the cantilevers.[151] He was contradicted on that point by Mr. de Paoli, who worked as an engineer for ISP on the Autoroute 19 project, prior to the construction of the de la Concorde overpass, in particular on the construction of the Gouin Boulevard overpass. Mr. de Paoli stated that Mr. Dubois was the engineer in charge

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[142] Exhibit COM-18, p. 88 and 90.
[143] Exhibit COM-18, p. 88.
[144] C. Roberge, Transcript, April 17, 2007, p. 47.
[145] R. Therrien, Transcript, April 17, 2007, p. 192.
[146] G. Dupaul, Transcript, April 18, 2007, p. 63.
[147] C. Bertin, Transcript, April 25, 2007, p. 76.
[148] C. Deschamps, Transcript, May 1, 2007, p. 29 and 30.
[149] M. Dubois, Transcript, April 24, 2007, p. 39 to 41; N. Plouffe. Transcript, April 24, 2007, p. 228 and 229.
[150] M. Dubois, Transcript, April 24, 2007, p. 18 and 19.
[151] M. Dubois, Transcript, April 24, 2007, p. 107.

of the supervision of all work, including the overpass. Mr. Dubois admitted having been, atmost responsible for administrative aspects for the construction of the overpasses.[152] However, both he and Mr. Plouffe insisted on the fact that they were not in charge of the supervision of construction work on the overpasses. According to them, this task belonged to DSA's structural department.

According to Mr. Dubois, Mr. Therrien sent an internal memo to DSA personnel requiring that all overpasses or structures designed by the structural department at DSA be supervised by a representative of that department before any concrete was placed.[153] However, neither Messrs. Dubois nor Plouffe nor Mr. Therrien were able to identify the person in the structural department who would have assumed that role, if it were assumed at all.

Mr. Plouffe claims to have monitored the roadwork of the Autoroute 19 contract and work on the retaining walls. He also prepared progressive estimates and met with Mr. Lampron on that matter once a month, but does not recall having been involved in the supervision of the construction of the overpasses.[154] He also does not recall nor does he believe having been involved in the progressive estimates concerning the overpasses.[155] Mr. Plouffe does recall having been in charge of siting the foundations for the abutments of the overpasses, but does not remember having made other surveying work for the abutments.[156] However, Mr. Plouffe recalls having contacted Mr. Dupaul on one occasion regarding water that had accumulated after the concrete was placed on one of the overpasses on Autoroute 19.[157]

In addition to Mr. Plouffe, one other DSA technician in charge of job site supervision, Mr. Zoël McGrath, remembers having worked on Autoroute 19. He believes he was present on the site for about a month during Mr. Plouffe's holidays.[158] Mr. McGrath also performed a small number of inspections at the Francon ltée plant during the manufacture of the prestressed concrete beams in order to verify the position of the prestressing strands and the tension applied to them.[159]

Mr. McGrath does not recall having supervised the de Blois and de la Concorde overpasses, nor does he recall who could have performed supervising work for DSA.[160] He remembers having done some supervision on one of the Saint-Martin Boulevard overpasses, where he saw the drawings of the falsework and examined them with Mr. Gilles Dupaul. Mr. McGrath went regularly to the site, because his role consisted of verifying the dimensions of formwork and the placement of the reinforcing bars. Mr. McGrath remembers one problem in particular regarding the vibration of the concrete because the reinforcing bars were placed too closely to one another.[161] Mr. Dupaul then came on the site and decided to reduce the number of main bars, but to use ones of a larger diameter.[162]

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[152] M. Dubois, Transcript, April 24, 2007, p. 138.
[153] M. Dubois, Transcript, April 24, 2007, p. 22.
[154] N. Plouffe, Transcript, April 24, 2007, p. 228, 229, 238 and 239.
[155] N. Plouffe, Transcript, April 24, 2007, p. 239.
[156] N. Plouffe, Transcript, April 24, 2007, p. 249.
[157] N. Plouffe, Transcript, April 24, 2007, p. 231.
[158] Z. McGrath, Transcript, April 24, 2007, p. 277 and 278.
[159] Z. McGrath, Transcript, April 24, 2007, p. 279.
[160] Z. McGrath, Transcript, April 24, 2007, p. 285.
[161] Z. McGrath, Transcript, April 24, 2007, p. 281 and 282.
[162] Z. McGrath, Transcript, April 24, 2007, p. 282.

4.6.3.1 Time of supervision

Called upon to comment on the manner in which he usually performed the supervision of the installation of reinforcing steel bars,[163] Mr. Dubois stated that it is possible to wait until just before the concrete is placed to perform this task. He admitted, however, that this approach involves significant risk. Indeed, it can take longer and turn out to be more costly to correct mistakes than to provide proper supervision during the placement of the reinforcing steel bars. Mr. Plouffe stated that inspections of the placement of the steel reinforcing bars took place just before the concrete was placed.[164]

This type of inspection would be performed by an individual experienced in the placement of reinforcing steel or, ideally, by someone who had taken part in the actual design of the overpass. Afterwards, this individual reported directly to the contractor or to Mr. Plouffe,[165] who does not remember having called someone from the structural department to come and verify the placement of the reinforcing steel bars.[166]

Upon examining the photographs of an observation window in the east abutment on the north side of the de la Concorde overpass, Mr. McGrath noted that the “stirrups” run under the No. 7 bars, something he would not have accepted on a work site.[167] In such a situation, he would have reported that fact immediately without waiting for the installation of the reinforcement steel bars to be completed. In his opinion, the supervisor who notes this problem, once all the reinforcing bars are installed, should require that the work be redone. Mr. McGrath believes that this error occurred on both abutments of the de Blois and de la Concorde overpasses, given that the supervisors were not present or that they misinterpreted the way in which these bars were to be installed.[168]

Findings of the Commission

The contract for professional services awarded to DSA complied with the best practices in force at the time of the construction of the de la Concorde overpass, if not those in force today.

DSA personnel present on site – Mr. Marcel Dubois, engineer, present part-time, and Mr. Normand Plouffe, technician, present full-time – both stated in their testimony that their responsibilities mainly consisted of supervising construction work of the freeway only. As for the overpasses, they are of the view that it was the role of the contractor’s personnel to ask for the intervention of individuals at DSA specialised in the supervision of structures, either directly, or through DSA personnel present on the site. In that regard, they describe a situation that can, at best, correspond to partial supervision for both overpasses. Yet, the contract between DSA and the *Ministère* entrusted the firm with the responsibility for all of the supervision of the work, including the overpasses. It follows that DSA did not carry out the supervision of the structures in accordance with its contract.

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[163] M. Dubois, Transcript, April 24, 2007, p. 136, and May 1, 2007, p. 58.
[164] N. Plouffe, Transcript, May 1, 2007, p. 118 to 120.
[165] M. Dubois, Transcript, May 1, 2007, p. 59 and 60.
[166] N. Plouffe, Transcript, May 1, 2007, p. 125.
[167] Exhibit COM-35C.
[168] Z. McGrath, Transcript, April 25, 2007, p. 13.

As the evidence shows, the lack of supervision during construction of the overpasses resulted in the failure to notice the improper placement of the reinforcing steel bars in the cantilevers of the de la Concorde and de Blois overpasses.

The Commission is of the opinion that it is impossible to determine who, at DSA's head office, was involved in the supervision of the construction of the overpasses. The same applies to the roles effectively played by Messrs. Dubois and Plouffe. Their testimony was ambiguous on both counts. As for Mr. Dupaul, the head designer of the de la Concorde overpass, he testified that he was not in charge of that aspect. Mr. Therrien stated that the supervision of the construction of the overpasses was the responsibility of DSA, but he was not able to specify who was involved and whether or not such an intervention from the head office ever took place.

Furthermore, the Commission is of the opinion that the best supervision practice was the one provided for in DSA's contract for professional services, namely the full-time presence of supervisors on the site and not, as Mr. Dubois stated, a single inspection just before concrete is placed.

The testimony of all those related to the construction established the necessity of an inspection prior to each placing of concrete and that the supervision had to specifically authorise that concrete be cast. They also admitted that contrary to the requirements of the contract and good practice, these authorisations were not given in writing and that they may have been given verbally.

The Commission blames DSA, their engineer Marcel Dubois, who was in charge of the supervision, and its managers responsible for the site for not respecting the obligations set out in their contract with respect to the supervision of all construction work of the overpass, and thus for not having prevented the misplacement of the steel reinforcing bars that resulted in a structure that was not compliant with the drawings and specifications

4.6.4 Obligations of Inter State Paving inc.

The obligations of the contractor were given in Section 4.5.1 of ISP's construction contract. The contractor had the obligation to perform the work according to the drawings and specifications, in compliance with good practice and to the satisfaction of the engineer acting as DSA's authorised representative. The contractor could not be relieved of its contractual responsibilities by reason of adequate supervision by the engineer, or by its absence. This absence cannot be invoked to justify the non-compliance of the construction work with the drawings and specifications.[169]

The construction specifications for major civil engineering works of the *ministère de la Voirie* (Bridge Department), May 1968 edition, are more stringent when referring to concrete:

- The contractor was required to notify the engineer at least 48 hours in advance prior to placing concrete[170]

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[169] Exhibit COM-20B, p. 28 and 29.

[170] Exhibit COM-20C, p. 37.

- The contractor was not allowed to place concrete without the engineer having inspected and approved the formwork[171]

- The contractor was required to verify the quantities and sizes of the reinforcing bars specified in the bar list[172]

Furthermore, the CCDG 1945 specified that competency requirements for the personnel employed on the project also applied to the engineers employed by the contractor to manage the work.

4.6.5 Site organisation of Inter State Paving inc.

According to Mr. Lampron, Mr. Normand Plouffe, of DSA, was in charge of work supervision on the freeway as well as on the overpasses, and that Mr. Plouffe, in his view, would never have authorised the placement of concrete without first having made sure that the placement of the steel reinforcement had been verified.[173]

Mr. Lampron used to give a 24-hour notice before placing concrete and the authorisation to proceed would be issued during that period.[174] Mr. Lampron cannot confirm that, in the case of the de la Concorde overpass, someone came and gave an authorisation, but claims that Mr. Plouffe gave him verbal authorisation to proceed. Mr. McGrath also confirms that authorisation to place concrete was given verbally and/or in writing at the site.[175] At the time of the placement, Mr. Lampron personally verified certain elements such as drains, joints and pipes.[176]

However, the evidence shows that ISP did not verify that the construction of the overpasses complied with the drawings and specifications. The evidence also clearly demonstrates the total lack of accountability of the sub-contractors and their own sub-contractors, all of them having failed to verify that the reinforcing steel bars were installed in compliance with the drawings and specifications. The supervision by the engineering firm was not performed in such a way as to adequately ensure that the reinforcing steel bars had been placed in compliance with the drawings and specifications.

Indeed, it appears that at the site, the superintendent and the foreman for the reinforcing steel bar placers only verified the number of bundles of steel, to make sure that they would not run out.[177] Mr. Ménard also stated that probably no verification was carried out after the bending of the bars.[178]

Nobody at AAM monitored the work performed by the reinforcing steel bar placers.[179] According to Mr. Claude Robert, former President of the company, the engineering firm's supervisor was the only person on the site responsible for ensuring that all work was performed correctly.[180]

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[171] Exhibit COM-20C, p. 40.
[172] Exhibit COM-20C, p. 47.
[173] B. Lampron, Transcript, April 25, 2007, p. 216, 223, 224 and 262.
[174] B. Lampron, Transcript, April 26, 2007, p. 15.
[175] Z. McGrath, Transcript, April 25, 2007, p. 15 and 16.
[176] B. Lampron, Transcript, April 25, 2007, p. 256 and 257.
[177] C. Robert, Transcript, May 17, 2007, p. 34.
[178] J. Ménard, Transcript, May 17, 2007, p. 177.
[179] C. Robert, Transcript, May 17, 2007, p. 98.
[180] C. Robert, Transcript, May 17, 2007, p. 100.

According to him, AAM's sub-contractors did not bear any responsibility in that regard, even though the reinforcing steel bar placers could notify the supervisor directly about the presence of certain problems in order to minimise lost time.[181]

Mr. Robert stated that neither he, nor anyone from his personnel, visited the ISP work site.[182] He maintains that it is everyone's responsibility to know what they have to do: [TRANSLATION] "*I cannot have an installer watch another installer.*"[183]

Therefore, even if the reinforcing steel bar placer was present when the authorisation to place concrete was issued, there was no chain of supervision between the contractor and its sub-contractors at the site.[184]

Findings of the Commission

The Commission hearings have shown that the reinforcing steel bars were misplaced, which would later lead to major consequences, as further discussed in Chapter 5.

The Commission finds that ISP did not assume the responsibility of ensuring the compliance of the work with the drawings and specifications and did not assume the primary quality control responsibility of the contractor, leaving it to the sub-contractors and the engineering firm.

The Commission also finds that, as in the case of ISP, AAM relied upon either the supervision or its own sub-contractors, and that the company did not take measures to ensure that the reinforcing steel bars were placed in compliance with the drawings and specifications.

Therefore, the Commission blames ISP and its managers responsible for the site as well as AAM and its president, Mr. Claude Robert, for not having adequately controlled the quality of the work.

4.6.6 Laboratoires Ville-Marie inc. and material control

According to the contract for professional services, DSA was responsible for quality control of the soil, concrete, reinforcing steel bars and structural steel, as well as asphalt. This responsibility was sub-contracted to its affiliate, Laboratoires Ville-Marie inc. (" LVM ").

Activities related to material control were defined and governed by different documents. Thus, appendixes to the DSA contract for professional services with the *ministère de la Voirie* specified that material control work had to be executed in compliance with the drawings,[185] the requirements of the Special Specifications[186] and the *ministère de la Voirie*'s CCDG of 1945,[187] as well as the amendments included in the CCDG in 1961.

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[181] C. Robert, Transcript, May 17, 2007, p. 83.
[182] C. Robert, Transcript, May 17, 2007, p .36 to 38.
[183] C. Robert, Transcript, May 17, 2007, p. 101.
[184] C. Robert, Transcript, May 17, 2007, p. 82, 83 and 97 to 100.
[185] Exhibit COM-19.
[186] Exhibit COM-20A, p. 74 to 116.
[187] Exhibit COM-20B.

The *Devis de construction des ouvrages d'art majeurs* (1968),[188] in addition to appendixes C and D of the DSA contract for professional services with the *ministère de la Voirie*,[189] provided further information relative to the obligations of the parties and the specificities or requirements for work to be performed with regard to quality control of the concrete and the reinforcing steel bars.

The contract for professional services provided that DSA, or the associate laboratory to which DSA could sub-contract certain responsibilities concerning quality control, had to sample all the materials used for the fabrication of concrete and conduct all laboratory tests on aggregates in order to verify their quality. It also was responsible for the approval of concrete mix designs. During the execution of concrete placement, DSA or the laboratory were to verify the production of the concrete, its transport, its placement and finish as well as its consolidation and protection. Its representatives were in charge of measuring temperature, workability and air content in the fresh concrete. Any concrete that did not meet the specifications following verifications performed at the site, either with the slump or air content test, should be rejected, so was any concrete that was beginning to set before being put in place.

The contract required DSA, or its associate laboratory, to collect cylinders and perform the required tests, in compliance with the methods in force at the *ministère de la Voirie*'s *Laboratoire des Essais et Expertises*. For all concrete structures, three cylinders of concrete had to be collected for every 100 cubic yards placed. In the case of mass concrete, this proportion decreased to three cylinders for every 250 cubic yards of concrete.[190] In no situation were the sampling and tests to be less than a series of three cylinders per concrete placement, per work day, per section of the structure and per work team. The contractor was to store these concrete cylinders under adequate curing conditions.[191]

DSA was also required to make sure that the falsework under the reinforced concrete structure was not removed before the concrete reached a minimal resistance of 70% of its nominal compression resistance, and while no live load was present on the structure.[192] The verification of this capacity was to be carried out using control cylinders cured under the same conditions as the concrete in the structure.

Concerning the reinforcing steel, Appendix D of the contract for professional services[193] provided, in section IV, Bf), that the firm [TRANSLATION] "*had to ensure that the elements had the correct geometry indicated by the drawings when formwork was constructed.*"[194] This is a distinct and additional obligation to the supervision mandate described in Section IX of the contract for professional services. This obligation should have been fulfilled by DSA or LVM, the material control sub-contractor.[195]

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[188] Exhibit COM-20C, p. 1 to 196.

[189] Exhibit COM-18, p. 76 to 222.

[190] Exhibit COM-18, p. 160 and 161.

[191] Exhibit COM-18, p. 160.

[192] The compressive strength (f'_c) is the compressive strength after 28 days, as determined according to the requirements of Standard CSA – A 23.1.

[193] Exhibit COM-18, p. 175.

[194] Exhibit COM-18, p. 183.

[195] Exhibit COM-18, p. 88.

One must also remember that the contract for professional services provided that the engineering consulting firm DSA remained [TRANSLATION] "*fully responsible for all or any work assigned by it to associate laboratories.*"[196]

At the beginning of his testimony, Mr. Dubois stated that DSA did not provide the laboratory services for the overpasses on Autoroute 19, which was under his supervision. He later corrected his testimony and admitted that LVM indeed provided those services which was also confirmed by Mr. André Dion, materials manager for LVM in 1969.[197]

According to Mr. Dion, LVM was in charge of material control for the roads and overpasses of the Autoroute 19 project.[198] On site, LVM was under the authority of DSA.[199] According to the few minutes of job site meetings that the Commission had the opportunity to review, two LVM employees were present at the work site meetings: Mr. André Dion or René Isabelle.[200]

Findings of the Commission

None of the laboratory reports or memos issued by Laboratoires Ville-Marie inc. to the resident engineer was found or brought forth as evidence before the Commission. Furthermore, the witnesses had no recollection of any particular fact concerning the quality of the concrete, except for one case of possible freezing.

In the absence of pertinent evidence, the Commission cannot express an opinion regarding the laboratory services. At most, the Commission concludes that the concrete of the abutments was generally in compliance with type A, which is the lower quality of the two types indicated in the specifications, as further discussed in Chapter 5.

4.6.7 Final acceptance of the work

On November 8, 1971, the *ministère de la Voirie* officially took possession of the de la Concorde overpass. Mr. Claude Bertin stated to the Commission that he was under the impression that the final acceptance did not concern the structures because the overpass had been open to traffic for some time already.[201] However, he and Mr. Marcel Parent conceded that there was no structural engineer among the representatives of the *Ministère* as they took possession.[202] It therefore appears that this formality did not include any verification of the files or a detailed inspection of the structure itself.

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[196] Exhibit COM-18, p. 87 and 92.

[197] A. Dion, Transcript, April 25, 2007, p. 32 to 34.

[198] A. Dion, Transcript, April 25, 2007, p. 32 and 33.

[199] A. Dion, Transcript, April 25, 2007, p. 24 and 25.

[200] Exhibit COM-27. M. Isabelle has since passed away.

[201] C. Bertin, Transcript, April 25, 2007, p. 93 to 97.

[202] M. Parent, Transcript, April 25, 2007, p.127 to 130; C. Bertin, Transcript, April 25, 2007, p. 91 to 97.

4.7 Inspection, maintenance and repair during the lifespan of the structure

4.7.1 Administrative structure of the *Ministère*[203]

According to the administrative structure of the *Ministère* in 1971, the de la Concorde overpass was under the management of District No. 4, which covered the island of Montréal, the island of Laval and the Regional County Municipality of Vaudreuil-Soulanges. In 1993, an administrative reorganisation occurred in which the territory of Québec was subdivided differently and *directions territoriales* were created. Since then, the de la Concorde overpass has been under the management of the *Direction territoriale de Laval–Mille-Îles*.[204]

The *Direction territoriale de Laval–Mille-Îles* and the City of Laval are jointly responsible for the de la Concorde overpass. In practice, this means that the MTQ carries out all inspections and maintenance work required on structural elements. Thus, for all issues pertaining to the structure, the de la Concorde overpass has been under the jurisdiction of the MTQ since it was built. The City of Laval is responsible for the maintenance of the roadway, sidewalks, safety guard rails, drains and lighting. This sharing of responsibilities was still effective when the overpass collapsed.[205]

As for every *direction territoriale, the Direction territoriale de Laval–Mille-Îles* office is responsible for all of the following services regarding structures:

- Partner and User Liaison
- Projects (structure repair and maintenance work)
- Inventory and Planning (responsible for inspections of structures)
- Management Support

The *directions territoriales* are assisted in their mandates by the bridge experts of the *Direction des structures*. The latter plays a prescriptive role by developing manuals and reference documents, and overseeing the growth and improvement of the MTQ personnel's knowledge. It also conducts research programmes and follows up on advances in technology. It answers requests for assistance from the *directions territoriales* and provides state-of-the-art expertise in the area of structures, both within and outside the MTQ. Last, it supports the *directions territoriales* in managing structures under their responsibility and sees to the implementation of

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[203] In 1972, the *ministère de la Voirie* became the *ministère des Transports et des Travaux publics* and, in 1973, *ministère des Transports*.

[204] The organisation chart of the *Direction Territoriale de Laval–Mille-Îles* is found in Exhibit COM-3, p. 20.

[205] In 1993, Government of Québec revised the management of the road network to transfer to the local municipalities the property of the local road system. The *Act to amend the Roads Act and other legislative provisions* (L.Q., 1992, c. 54) prescribes the terms for applying this decentralisation. Pursuant to this Act, the MTQ maintains responsibility for the management of roads identified by decree. It must also inspect the structures under shared responsibility and maintain their structural elements. The municipalities continue to be responsible for maintaining the roadway, sidewalks, safety guard rails, drains and lighting. Interpretation issues exist for certain elements, e.g. for extension joints, which can be considered as being part of the structure or part of the roadway. The MTQ generally accepts to bear the repair costs for these elements that are not clearly the responsibility of the municipalities: Exhibit COM-60, p. 58 to 61. This issue of shared responsibility is explained in detail in Appendix 19, Additional Note No. 2.

adequate management systems.[206] Consequently, the *directions territoriales* will spontaneously turn towards the *Direction des structures* when additional expertise is needed.[207]

4.7.2 Structure file

The structure file is essential in ensuring follow-up on a structure throughout its life and identifying the problems and weaknesses requiring particular attention. The works of the Commission have brought to light numerous file-keeping flaws in the case of the de la Concorde overpass.

The documents for a structure are kept at three different places:[208] the *direction territoriale*, the *Direction des structures* in the City of Québec and in the archives, which include the semi-active documentation centre[209] and the *Archives nationales du Québec*. All of these files must include, on paper or in electronic form, the "as-built" drawings, inspection reports, photographs, correspondence pertaining to the structure, inventory file, the summary of interventions performed and general remarks, etc.[210]

In the particular case of the de la Concorde overpass, the Commission noted the following:

- The files kept at the *direction territoriale* and at the *Direction des structures* were incomplete. Some documents were lost during the territorial reorganisation in 1993

- Drawings were kept in the files of the *direction territoriale* and the *Direction des structures*, but not the final "as-built" version.[211] The drawings submitted by the MTQ are dated July 31, 1969, while those submitted by the designer, Mr. Gilles Dupaul, are dated August 17, 1970, and are more representative of the structure and include some additional revisions [212]

- The bar list detailing the reinforcing steel did not appear on the drawings and was not found in any of the files,[213] or elsewhere. It is worthy of note that the job site's document retention procedures in force at the time contained no provision for this type of document [214]

- The file kept at the *direction territoriale* only contained fragmented information regarding the repairs made in 1992,[215] as explained in more detail in the Section *Recherche et conservation de documents* in Chapter 3. The file kept at the *Direction des structures* did not contain any information about these repairs.[216] It should be kept in mind that the notes taken by Mr. Tiona Sanogo, the engineer in charge of the repairs, and the photographs

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[206] Exhibit COM-8, p. 4.

[207] A more detailed description of the role of the *Direction des structures* and its three departments is found in Appendix 19, Additional Note No. 3.

[208] G. Richard, Transcript, May 16, 2007, p. 168.

[209] This center stores what Mr. Christian Mercier called the *Dalton file*: C. Mercier, Transcript, May 14, 2007, p. 220.

[210] For a more complete description of the content of various files, see Appendix 19, Additional Note No. 4.

[211] G. Bossé, Transcript, May 3, 2007, p. 178 and A.-M. Leclerc, Transcript, April 12, 2007, p. 225 and 226.

[212] However, the MTQ thinks that the changes made between the two versions were [TRANSLATION]"*details, electrical conduit were added to the bridge, things like that,*" which did not change the bridge's load carrying capacity calculations: G. Richard and A.-M. Leclerc, Transcript, April 12, p. 225 and 229 to 231.

[213] G. Bossé, Transcript, May 3, 2007, p. 178 and A.-M. Leclerc, Transcript, April 12, 2007, p. 227.

[214] A.-M. Leclerc, Transcript, April 12, 2007, p. 227 to 229.

[215] G. Bossé, Transcript, May 3, 2007, p. 236 to 238.

[216] C. Mercier, Transcript, May 14, 2007, p. 223.

taken during this work were only recovered during the hearings. These documents were stored in a box at the semi-active documentation centre and should have been destroyed in 2005 according to the document retention procedures of the MTQ. It was thus through a fortunate combination of circumstances that these documents of paramount importance were preserved.

Findings of the Commission

The Commission noted that some important information was either not available or easily accessible for those in charge of inspections and repair of structures. The Commission blames the MTQ for its lack of discipline in keeping the de la Concorde overpass files. The Commission is of the opinion that special efforts must be made to regroup the files and maintain them more thoroughly (according to witnesses from the MTQ, this is already under way). They must be complete and made easily accessible to all stakeholders in the inspection, maintenance, structural assessment or repair of structures.

4.7.3 Inspections, maintenance and repairs made before 1992

Inspections have a direct impact on the lifespan of a structure; they allow an assessment of the structure and the determination of the interventions required to maintain it.[217]

The Commission could find little information regarding the inspections made before 1985. The documents related to the 1977 and 1978 inspections do not mention any serious abnormality. In 1980, an inspection report indicates a leaking expansion joint and includes a cost estimate to repair it. This report bears the following mention: [TRANSLATION] "*Forgotten. We have too much to do.*" Reports from 1982 and 1984 include a barely legible note indicating the overpass is in good condition, without further detail.[218]

In 1985, engineer Mr. Drasko Simic joined the maintenance division of *Direction Régionale* 6-3. He was in charge of inspections for this region in 1987 or 1988.[219] Mr. Simic mentions that he has training in structures and materials. His résumé indicates a Bachelor of Civil Engineering.[220] He has also undergone training provided by MTQ. He personally carried out the various inspections from 1985 to 1991 or verified the reports completed by the appointed inspector.[221]

From 1985 to 1991, the general description indicates that the de la Concorde overpass was still in good condition, but there are more signs of deterioration. The signs of concrete degradation and spalling had increased. However, they are mentioned in the inspection reports without precise details and do not always appear in photographs.

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[217] Appendix 19, Additional Note No. 5 provides a complete description of the Ministère's inspection program, including various inspection types, qualification of inspectors, manuals and tools at their disposal.

[218] Exhibit COM-31B, p. 4 to 12.

[219] Exhibit COM-53, p. 5: D. Simic, Transcript, May 1, 2007, p. 162 to 164.

[220] Exhibit COM-53.

[221] D. Simic, Transcript, May 1, 2007, p. 165, 173, 182 and 191. It should be noted that Mr. Simic did not feel the need to examine the drawings before performing inspections, even in the case of designs such as that for the de la Concorde overpass, a structure type seen more often in Europe, where he studied. For him, even if the manual in use at the time stipulated that the inspector was to acquire as much knowledge as possible on the structure to inspect and ask for the required documentation (Exhibit COM-30C, p. 56), it was not a requirement to consult the drawings.

All the inspection reports produced during these years indicate that the expansion joints continued to leak. Moreover, they were not repaired even though Mr. Simic had first noted the problem in 1985[222] and indicated that they required intervention before 1988. Questioned on this subject, Mr. Simic explained that his first diagnosis was maybe a little premature, due to his inexperience.[223]

Moreover, a first photograph of the beam seats taken in 1985 show concrete degradation at the beam seat level, the appearance of cracks and the first signs of efflorescence (although the 1985 report itself mentions only slight concrete spalling).[224]

During these years, no in-depth inspection was conducted by a design and construction expert from the *Direction des structures*, even if the manual in use for inspections stated that complex structures, such as the de la Concorde overpass, had to be the subject of such inspection.[225] For Mr. Simic, the de la Concorde and de Blois overpasses were structures that did not require special measures during inspections, even if access to the bearing pads was limited. It was enough, according to him, to find [TRANSLATION] "*the means of putting the finger on the bruise.*"[226] However, he conceded the particular characteristics of the structure, particularly in the cantilever portions, could make it necessary to support it when repairs are required.[227]

4.7.4 1992 Repairs

In 1992, Mr. Simic decided to replace the expansion joints on the de la Concorde overpass as part of a larger repair programme that also included the repair of concrete surfaces and the replacement of asphalt.[228] Regarded at first as a routine and relatively minor intervention, the repair became increasingly large in scope as the work progressed.

Mr. Simic delegated the preparation and supervision of the work to Mr. Tiona Sanogo, a project manager on his team.[229] Mr. Sanogo was assisted by a technician, Mr. Benoît Archambault.

Apart from the notebook and annotated photographic documentation gathered by the project manager that provided information about the reported damage level and work progress,[230] the main information sources about this work came from the testimony of

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[222] Exhibit COM-31B, p. 13 to 16.

[223] D. Simic, Transcript, May 1, 2007, p. 230 to 232.

[224] Exhibit COM-31B, p. 19. The same photos are repeated in colour in Exhibit COM-1C, p. 10.

[225] Until 1987, the *Guide de l'entretien des structures* (version published in 1978, revised in 1984) (Exhibit COM-30A, p. 163) stipulates that complex structures, likely including the de la Concorde overpass (the Guide does not provide a definition), should be subject to an in-depth inspection every 10 years. After 1987, the de la Concorde overpass structure type became qualified as a "concrete box girder bridge" complex structure. This type of structure should be subject to a special inspection by the *Direction des structures*, upon request of what was then known as the *Direction de l'entretien*, which was in charge of scheduling these special inspections. The new Guide published in 1987 no longer provided a specific deadline: Exhibit COM-30C, p. 49 and 50 (from the *Guide de l'entretien des structures,* revised in March 1987). This 1987 provision was applied until 1993. Also see D. Simic, Transcript, May 1, 2007, p. 180 and 181. Mr. Guy Richard explained that this provision was abolished since the inspectors in the *directions territoriales* henceforth responsible for conducting general inspections had specialised knowledge that enabled them to perform the same inspection as before when inspecting a complex structures: G. Richard, Transcript, May 16, 2007, p. 118 to 120 and 225 to 228.

[226] D. Simic, Transcript, May 1, 2007, p. 178 and 179.

[227] D. Simic, Transcript, May 1, 2007, p. 246.

[228] D. Simic, Transcript, May 1, 2007, p. 237 and 238.

[229] D. Simic, Transcript, May 1, 2007, p. 237; T. Sanogo, May 2, 2007, p. 14 and 15.

[230] Exhibits COM-54, p. 12 and following, COM-1C, p. 15 to 103 and COM-1C amended.

Messrs. Tiona Sanogo,[231] Primo Scapin (representing the general contractor who carried out the work)[232] and Drasko Simic.[233]

4.7.4.1 Damage report

As part of the mandate given to him for the repair of the de la Concorde overpass and three other structures, Mr. Sanogo previously had to consult the drawings of the structure and perform an inspection leading to a damage report. This was necessary to prepare drawings and specifications for the work required.

According to the file submitted to the Commission by the MTQ on April 12, 2007,[234] which included notes and pictures, Mr. Sanogo and technician Benoît Archambault inspected the de la Concorde and de Blois overpasses at the end of February 1992. The pictures and notes taken then indicate that the de la Concorde overpass was showing significant signs of damage. The notes mention that the east and west expansion joints were not watertight, were defective and patched, and that the pavement was cracked in several places. The notes also indicate that the concrete scaling had occurred in the beam seat area on the east abutment.

Throughout his damage report, Mr. Sanogo recalls noticing mostly superficial damage, but no cracking, on the structural elements.[235] He said the observations he made were consistent with those he saw on the inspection reports and therefore he did not have any particular worries about the deck.[236] He did not order an evaluation of the load-bearing capacity because, to him, nothing suggested that the structure would become unsafe during or after the repairs.[237] He did not deem it necessary either to take a core sample or to characterise the concrete of the structure.[238] As a result, no thorough assessment of the structure's condition was carried out before the repair work was done.

Still, as evidenced by the photographs in Figure 4.3, the concrete showed clear signs of deterioration near the joints, particularly some major degradation in the beam seat area. On the northeast lateral face, reinforcing bars were exposed while on the lateral face of the southeast abutment, a shear crack (circled in red on the picture) was visible. It is noted that for a few years already, the inspection reports mentioned degradation of the beams and abutment cantilever on both sides of the joints and pointed out potential degradation of the beam seats, which were for the most part impossible to inspect except for the extremities.

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[231] T. Sanogo, Transcript, May 2 and 3, 2007.
[232] P. Scapin, Transcript, May 3, 2007.
[233] D. Simic, Transcript, May 1, 2007.
[234] Exhibits COM-1C, p.15 to 103 and COM-1C amended.
[235] T. Sanogo, Transcript, May 2, 2007, p. 31, 32, 167 and 226 to 228.
[236] T. Sanogo, Transcript, May 2, 2007, p. 33.
[237] T. Sanogo, Transcript, May 2, 2007, p. 53.
[238] T. Sanogo, Transcript, May 2, 2007, p. 54, 56 and 57.

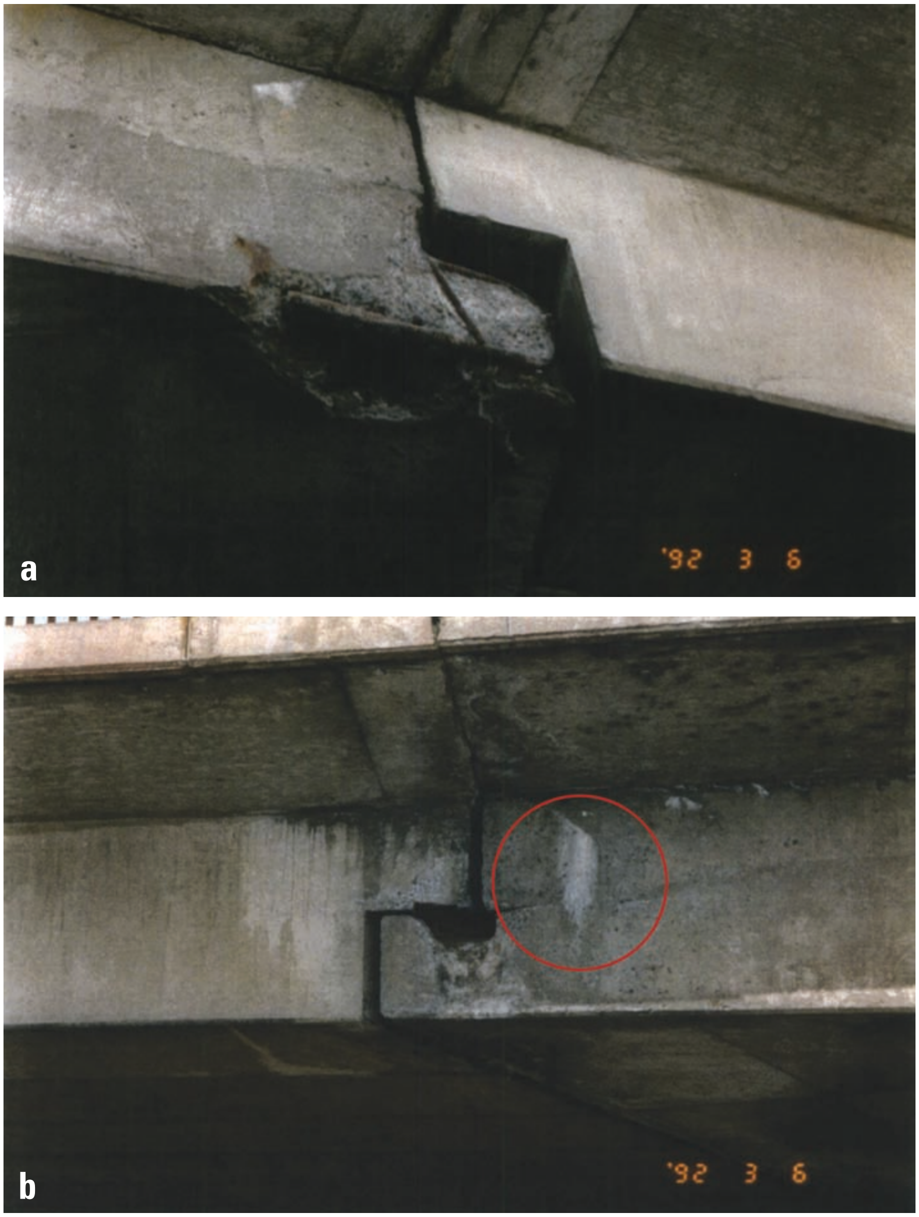

Figure 4.3 Concrete degradation on the east abutment of the de la Concorde overpass in 1992
a) North lateral face[239]
b) South lateral face[240]

4.7.4.2 Preparation of drawings and specifications

The testimony gathered during the hearings confirms that drawings and specifications were prepared in due form by Mr. Sanogo and approved by Mr. Simic.[241] These documents had to be prepared in accordance with the current standards. The recommended procedure for joint replacement is given in Standard N-2141.[242] Also, the work to be done by the

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[239] Pièce COM-1C, p. 45.

[240] Pièce COM-1C, p. 46.

[241] T. Sanogo, Transcript, May 2, 2007, p. 65; D. Simic, Transcript, May 1, 2007, p. 259.

[242] Exhibit COM-30B, p. 45 to 50.

contractor is described in the "Standard" Special Specifications.[243] Finally, the repair work is also subject to the requirements of the *Code de sécurité pour les travaux de construction.*[244] Section 3.3.4 of the Code stipulates that:

> [TRANSLATION] "*No change which might affect the structure of a building shall be undertaken before ensuring that the constituent elements will not be submitted to stresses higher than those prescribed.*"

The drawings and specifications could not be found in any of the files kept by the MTQ. It seems that these documents were destroyed in 2005, after expiry of the period stipulated by the document retention procedures.[245]

According to Mr. Sanogo, these documents provided detailed information about the demolition required during repair (regions to be repaired, surfaces and depth to demolish, equipment to be used, etc.), repair methods and sequence, materials specifications (concrete mix designs and other requirements), joint specifications, etc.[246] Mr. Sanogo did not consider that shoring would be necessary for the structure because the damage report only required that the concrete be removed up to a few centimetres deep near the expansion joint.[247] Moreover, he did not deem it necessary to completely interrupt the traffic on the overpass during the repair work and he only closed two lanes to reduce the loads on the structure.[248]

A contract (5100-92-0223/6365-92-0223) was awarded on the basis of these drawings and specifications to repair four bridges, including the de la Concorde overpass.[249] In the administrative summary sheet that could be retrieved, the works are described as such:

Types of works:	Repair of the approach slab; Repair of the top and bottom surface of the deck slab; Repair of the sidewalks, parapets, wheel guards, bridge piers and abutments; Leak-proofing of the longitudinal joint of the central strip of the de la Concorde overpass; Repair of the fixed and expansion joints of the structures; Leak-proofing of the concrete deck slabs; Asphalt supply and placement; Sealing of concrete surfaces against salt.

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[243] Exhibits COM-30C, Suppl. 1, p. 3 to 30 and COM-30B, p. 188 and 195.

[244] Exhibit COM-30B, p. 334 and following.

[245] T. Sanogo, Transcript, May 2, 2007, p. 65 and 66.

[246] T. Sanogo, Transcript, May 2, 2007, p. 41 to 51.

[247] T. Sanogo, Transcript, May 2, 2007, p. 76 to 81.

[248] T. Sanogo, Transcript, May 2, 2007, p. 39.

[249] Exhibit COM-31B, p. 237.

DIMS Construction was the contractor to carry out the work and the expansion joints were supplied by Z-Tech. The shop drawings of the replacement joints were found.[250] The information on these drawings corresponds to those of the part recuperated during the dissection operations.

The MTQ laboratory was in charge of the quality control for the joints while Laboratoires Ville-Marie was in charge for the concreting.[251]

As per the timetable, the work was planned to begin on October 19, 1992, and be completed on May 3, 1993, including a four-month winter interruption.

Mr. Simic approved the drawings and specifications documents and the call for tenders prepared by Mr. Sanogo.[252] However, he does not exactly remember what Mr. Sanogo discussed with him. He said it is likely that they discussed this contract, but added that MTQ engineers seldom consult each other, even in delicate situations.[253] Although he was Mr. Sanogo's technical superior, he would not have questioned him about the choice of methods used to repair the overpass.[254] Mr. Simic felt that he could not impose particular repair procedures on engineers under his responsibility and mentioned that they were members of the same union. He was, however, willing and available to answer questions from his colleagues if requested.

Findings of the Commission

The Commission has noticed ambiguity in the accountability within the MTQ, an issue that will also be brought to light when discussing the special inspection in 2004. Mr. Simic, an engineer in charge of structures, does not feel free to challenge Mr. Sanogo. He claims he cannot impose a particular way of doing things on engineers under his responsibility. Even more troubling, this restraint is voiced not by a professional, member of a recognised professional association, who hesitates questioning the competency of a work colleague, but by a hierarchical superior who does not feel comfortable questioning an employee on the basis that they belong to the same union. This is incompatible with the sense of duty of a professional who has a specialised knowledge and must act according to good practice and in the interest of the public safety above all.

The Commission noticed a lack of a clear affirmation of hierarchical responsibilities and related obligations and duties.

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[250] Exhibit COM-19, p. 92.
[251] T. Sanogo, Transcript, May 2, 2007, p. 44 to 47.
[252] D. Simic, Transcript, May 1, 2007, p. 256 to 259.
[253] D. Simic, Transcript, May 1, 2007, p. 240 and 257.
[254] D. Simic, Transcript, May 1, 2007, p. 252 to 254.

4.7.4.3 Work execution and remarks[255]

4.7.4.3.1 Heavy equipment

Photographs found show that heavy equipment was used on the de la Concorde overpass during repair operations.[256] According to Mr. Sanogo's field notes,[257] the asphalt was removed with a Caterpillar 235 hydraulic shovel. The weight of this equipment varies from 85,000 to 92,000 lb., according to the experts. This is heavier than the reference truck, H20-S16, used for the design of the overpass (32,659 kg or 72,000 lb.). At certain points during the work, photographs show that the hydraulic shovel was directly over the joints where the concrete was being removed.

The photographs also show that in addition to the hydraulic shovel, two backhoes are also in operation on the overpass deck, one with a bucket and the other with a jackhammer. The latter is set up at the end of a hydraulic arm to remove the concrete near the joints.[258] Nevertheless, Standard 2141 recommends removing the concrete around the joint with a pneumatic hammer, which causes less damage to adjacent sound concrete and reinforcing bars crossing it. The MTQ's standards and "Typical Specifications" in use at this time stated that the contractor should take the necessary precautions to avoid damaging the existing longitudinal reinforcing bars or any other element not part of the demolition. As discussed in Chapter 5, examination of the sections dissected after the collapse show the presence of marks and damage to the reinforcing bars near the joint, notably on No. 8 U-shaped hangers.[259]

In addition to the weight of the above-mentioned equipment, other vehicles were also present in the photographs and driving on the deck during the concreting of the new joint (two of six lanes), i.e. when the reinforcing bars near the joint were exposed.[260]

4.7.4.3.2 Removal of concrete to a depth greater than expected

Once the asphalt was removed, Mr. Sanogo confirmed that it soon became evident that the concrete near the expansion joints was heavily damaged at some places.[261] The deteriorated concrete was removed under the No. 14 bars in certain areas, not only on the width of the joint shoulder, but beyond the hooks of the U-shaped hangers and to a depth much greater than was anticipated. Accordingly, the longitudinal bars were exposed to a greater depth and width than initially planned.

4.7.4.3.3 Lack of shoring and structural calculations

Although the thickness of the concrete removed at the end of the cantilevers was greater than expected and the longitudinal bars and hooks were exposed and heavy loads were present on the overpass, Mr. Sanogo did not undertake any precautionary measures to support the structure during the work. During his testimony, Mr. Sanogo mentioned that once he noticed the damage behind the joints was greater than expected, he discussed with Mr. Simic the

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[255] Photographs and notes on asphalt and concrete removal operations: Exhibits COM-1C, p. 15 to 103, COM-1C amended and COM-54.

[256] Exhibit COM-1C, p. 80 and 81.

[257] Exhibit COM-54, p. 15 to 49.

[258] Exhibit COM-1C, p. 102.

[259] Exhibit COM-1D, p. 5 and 6.

[260] Exhibit COM-1C, p. 56.

[261] T. Sanogo, Transcript, May 2, 2007, p. 72 to 74, 142 and 143.

possibility of shoring the overpass. However, they both came to the conclusion that it was not necessary.[262] Mr. Simic stated that he did not recall this discussion with Mr. Sanogo about shoring the structure; in any case, he claims it was Mr. Sanogo's responsibility.[263]

In light of the testimony and available files, it seems that the stresses applied by the repair work on different parts of the structure were not verified or calculated, before or during the repair work.[264]

4.7.4.3.4 Improper placement of reinforcing steel

Upon inspection of the elements after the concrete was demolished, Mr. Sanogo noticed that some stirrups (U-shaped hangers) were installed lower than shown on the drawings. Some of these stirrups were [TRANSLATION] "*misplaced*" and "*different from the drawing*"[265] The work was interrupted and Mr. Sanogo talked with his superior and engineer Mr. Simic about possible corrective measures to solve these abnormalities.[266] He told the Commission that [TRANSLATION] *"upon seeing some stirrups that were below and several opposite, we restored the part to its original state."*[267] He claims having an L-shaped bar installed that was attached to the stirrup and connected to the main reinforcing steel.[268] DIMS (the contractor responsible for the repair) would have been requested to add this to the contract, and would have been paid the extra cost by the kilogram.[269]

As for DIMS representative Mr. Primo Scapin, he does not recall this abnormality, the job being stopped because of it, or being asked by Mr. Sanogo to add bars.[270] A former DIMS engineer, Mr. Raffaele Petruzzo, corroborated Mr Scapin's testimony.[271]

Moreover, neither Mr. Sanogo nor the experts of the Commission could find the presence of these L-shaped bars at the Belgrand site where all parts of the structure were stored. Nevertheless, Mr. Sanogo maintained before the Commission that the request was made to DIMS.[272] It is important to mention that Mr. Sanogo's field notes do not refer to any correction to the reinforcement in the cantilevers of the de la Concorde overpass.[273]

4.7.4.3.5 Cleaning of the surface and bonding agent

Repairs were also carried out under the overpass, in the areas where the concrete was delaminated.[274] After sectioning off the surface to be repaired with a saw cut, the delaminated concrete was removed with a light pneumatic hammer, the bars were sandblasted, mesh was attached to 10 M bars anchored in the sound concrete and the fresh concrete finally poured using shotcreting.

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[262] T. Sanogo, Transcript, May 2, 2007, p. 169 to 171.
[263] D. Simic, Transcript, May 1, 2007, p. 247 and 251 to 254.
[264] T. Sanogo, Transcript, May 2, 2007, p. 163 to 166 and 170; D. Simic, Transcript, May 1, 2007, p. 242.
[265] T. Sanogo, Transcript, May 3, 2007, p. 17 and 24 to 26.
[266] T. Sanogo, Transcript, May 3, 2007, p. 26.
[267] T. Sanogo, Transcript, May 3, 2007, p. 27.
[268] T. Sanogo, Transcript, May 3, 2007, p. 28 and 29.
[269] T. Sanogo, Transcript, May 3, 2007, p. 29 and 35 to 37.
[270] P. Scapin, Transcript, May 3, 2007, p. 123 to 126.
[271] R. Petruzzo did not testify before the Commission but issued an affidavit: Exhibit COM-55A.
[272] T. Sanogo, Transcript, May 3, 2007, p. 30 and 31.
[273] Exhibit COM-54.
[274] T. Sanogo, Transcript May 2, 2007, p. 207 and 208.

4.7.4.3.6 Lack of the membrane specified

According to the report submitted by the MTQ experts,[275] the premanufactured membrane[276] requested by the specifications, which was to be installed on the entire road surface, was not installed because the concrete surface was too severely damaged.

Mr. Sanogo's job site report includes several photographs that show a black liquid being spread before applying the asphalt.[277] It may be a binder or a membrane, which in this case would be of a lesser quality than the one stipulated in the specifications. In his notes, Mr. Sanogo refers to a product (RC-30) applied before the asphalt (MB-16).[278]

Findings of the Commission

Confronted with a series of unexpected defects during the repair work, Mr. Sanogo did not try to determine the cause of the problems or evaluate their possible harmful effects on the structure. This is true for the level and extent of concrete degradation as well as for the inadequate placement of reinforcing steel that he noticed without correcting the situation. The Commission notes Mr. Sanogo's claims that he asked the contractor to correct the problem by installing additional bars, but also notes that there was no mention of these bars in Mr. Sanogo's field notes nor were they found during the dissection of the structure.

The Commission also noticed that the degradation of the concrete became a reason for not applying the membrane stipulated in the specifications while to the contrary, this degradation precisely demonstrated its necessity.

While the Commission reproaches Mr. Sanogo for his management of the repair work on the de la Concorde overpass in 1992, it mostly blames the MTQ for tolerating ambiguity in the accountability of Messrs. Simic and Sanogo, lacking discipline in its file keeping and never being able to translate its knowledge into an inspection and maintenance programme adapted to this particular structure.

4.7.5 Inspections, maintenance and repairs between 1993 and 2004

Following the reorganisation in 1993, Mr. Gilbert Bossé, engineer, took over the responsibility of the de la Concorde overpass. Mr. Bossé and Mr. Paul Roussy, technician, performed all inspections on the de la Concorde overpass until September 2006 and are the only individuals to see to the annual inspections of all 262 structures under the jurisdiction of the *Direction territoriale de Laval–Mille-Îles*.[279] Mr. Bossé is also responsible for managing the scheduling of maintenance on these structures.[280]

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[275] Exhibit MTQ-1, p. 17.

[276] This type of membrane is now known as "type 3 membrane."

[277] Exhibit COM-1C, p. 57 and 58.

[278] Exhibit COM-54, p. 40.

[279] G. Bossé, Transcript, May 3, 2007, p. 169 and 183.

[280] G. Bossé, Transcript, May 3, 2007, p. 171.

Mr. Bossé does not have any specialised academic training in structures, but he took courses given by the *Direction des structures*, namely in inspection and materials.[281]

Mr. Bossé declared that before performing his inspections of the de la Concorde overpass, he consulted the file kept at the Inventory and Planning Service. This file included the drawings of the structures,[282] previous inspection reports, photographs (when available) and an inventory. There was also a sheet summarising previous operations performed on the structure (this sheet was introduced in 1993) and the relevant correspondence, if any.[283] Mr. Bossé was satisfied with the information available for all of the structures he had to inspect on his territory.[284] It should be kept in mind that the version of the drawings he had access to was not the "as-built" version.

Messrs. Bossé and Roussy performed routine inspections (in 1997, 1998, 2000, 2001, 2003 and 2004) and general inspections (in 1995, 1999 and 2002). These inspections essentially led to the following findings : [285]

- Since 1995, all reports mention the expansion joints continue to leak. In 1997, their replacement is considered.
- In 1995, the slab receives a rating of 4, which would have called for an assessment of the slab no later than 1999. This assessment was never performed. Actually, no condition evaluation or core sampling was ever requested.
- The repairs made in 1992 appear to be of dubious quality. In 1997, it is noted that some "shotcrete" obstructed the expansion joint. This concrete delaminated and threatened to fall. In 2002, all loose concrete pieces were removed.
- The first explicit mention of cracks was in 1997. However, even if the presence of cracks was noted, there were no detailed observations (number, width, length, exact location) that could have allowed the monitoring of their progression.
- In 2002, the general rating of the overpass was lowered from "good" to "acceptable." In the same year, the report indicates that the concrete of the beam seats was [TRANSLATION] "*greatly disintegrated*" and a material rating of 3 was attributed to the beam which east side end is deteriorated. However, after the walk-through inspections of 2003 and 2004, the general rating returned to "good" without explanation. When the Commission questioned Mr. Bossé about the inconsistent use of general descriptions of the structure's status, that throughout the years it went from "good" to "acceptable" and back to "good" again without any work being performed on the structure in his opinion, this was not a source of concern because he viewed these as interchangeable general terms.[286]
- In 2002, the report states the necessity to seek advice from the *Direction des structures* on how to repair the end of the box girders.

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[281] G. Bossé, Transcript, May 3, 2007, p. 164 and 165.

[282] These drawings were consulted during the first inspections: G. Bossé, Transcript, May 3, 2007, p. 177.

[283] G. Bossé, Transcript, May 3, 2007, p. 175 to 180.

[284] G. Bossé, Transcript, May 3, 2007, p. 182.

[285] More detail on the inspections performed during the useful life of the structure is in Appendix 19, Additional Note No. 6.

[286] G. Bossé, Transcript, May 14, 2007, p. 90 to 96.

None of these inspections can be considered as an in-depth inspection of the structure. With the arrival of Mr. Bossé in 1992, the manual in use at the time recommended in-depth inspections for such complex structures as the de la Concorde overpass. This notion was introduced in 1984 in the *Guide de l'entretien des structures,* with a 10-year timeframe, and maintained when the Guide was reviewed in 1987, this time without specifying a timeframe. In 1993, when the Guide was reviewed again, the reference to complex structures disappeared. The end result is that the de la Concorde overpass was never the subject of an in-depth inspection or any other type of investigation that involved core sampling or evaluating its load carrying capacity when it was under Mr. Bossé's responsibility (not to mention since its construction in 1971).

Except for the removal of delaminated concrete under the deck in 2002, the MTQ did not perform any repair work on the de la Concorde overpass between 1993 and 2004. Still, the structure was listed on the intervention programme and some of its elements had a rating of 3, which meant that interventions were required within one or two years, according to the manual in use.[287]

Mr. Bossé was aware that the de la Concorde overpass was a particular structure and was concerned by the state of the beam seats, which were impossible to inspect. Nevertheless, his worries did not call for urgent action, because he did not see any obvious signs of deterioration or structural distress of the overpass.[288] He shared his concerns with the *Direction des structures* in 2004, requesting technical assistance in order to determine whether he could change the priority order of his interventions. This was the only tangible action performed by Mr. Bossé that showed he was aware of and concerned about the particular character of the structure.

4.7.6 2004 special inspection

On June 17, 2004, Mr. Gilbert Bossé requested technical assistance from the *Direction des structures*, in a letter addressed to Mr. Claude Leclerc, Eng., then head of the *Service de l'entretien*. Mr. Bossé wrote:

[TRANSLATION] *"During the most recent general inspections, damage was observed and should be given special attention. The beam seat condition cannot be accurately assessed since the configuration of these elements prevents a reliable visual inspection. Based on the damages observed near side faces of the abutment, a major beam seat degradation problem is suspected. In addition, the presence of wide shear cracks on the cantilevers is worrisome."*[289]

Since 2002, Mr. Bossé was concerned more with the concrete delamination problem than with cracking.[290] He did not suspect the existence of a major cracking plane within the cantilever. He believed that water came from the interface between the sidewalk and the asphalt.[291] Obviously, nothing led him to foresee the collapse of the overpass, as he believed that such an outcome would be preceded by the occurrence of major deformations.[292]

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[287] Exhibit COM-30N, p. 57; G. Bossé, Transcript, May 3, 2007, p. 307 to 309.

[288] G. Bossé, Transcript, May 14, 2007, p. 15 to 18.

[289] Exhibit COM-31B, p. 140.

[290] G. Bossé, Transcript, May 3, 2007, p. 287 to 290.

[291] G. Bossé, Transcript, May 14, 2007, p. 28.

[292] G. Bossé, Transcript, May 14, 2007, p. 29.

In fact, it was the beam seat condition that worried him, more specifically the capacity of reinforcement steel bars and concrete to ensure satisfactory behaviour of the structure: [293] [TRANSLATION] *"the bearing pad was exposed on each side, there were cavities of approximately 100 mm where concrete was missing or eaten away by de-icing salts."* [294] He was also worried about the quality of the repair carried out in 1992 since if the shotcrete [TRANSLATION] *"was already falling apart, one could imagine what the condition was in the areas that had not been repaired in '92"*.

The only way to clear the matter was to inspect the beam seats. That required lifting the central part of the deck and this is precisely what Mr. Bossé had in mind.[295] He admitted to the Commission that he wanted to [TRANSLATION] "*suggest the answer*"[296] to his own request, going so far as to indicate that it would be necessary, once the deck was raised, to repair the beam seats, the slab ends and the bearing pads.

The *Direction des structures* assigned engineer Christian Mercier to address Mr. Bossé's request. An engineer since 1996, Mr. Mercier had been working for the *Direction des structures* since November 2000 and with the maintenance section of the *Service de l'entretien* since November 2002.[297]

4.7.6.1 Special inspection and preliminary work

The inspection carried out by Mr. Mercier was a special inspection.[298] This type of inspection is always carried out by an engineer of the *Direction des structures*, at the request of the engineer responsible of the DT; it does not necessarily include core sampling or performing calculations of the load carrying capacity. It relies upon the same tools as those used during the general inspections.[299] According to Mr. Mercier, the added value of the *Direction des structures* engineer is to [TRANSLATION] "*take a second look [...] more specifically on a special structural problem,*" with the additional overall knowledge of Québec's entire roadway structure inventory.[300]

Mr. Mercier first examined the drawings of the structure[301] and the file on the overpass kept at the *Direction des structures*. This file included the latest general inspection report available in the database, a few previous hard copy inspection reports – some dating back to the 1980's – and some photographs, in particular those sent by Mr. Bossé with his request for assistance. The file did not include any bar list nor did the drawings. Moreover, it contained no

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[293] G. Bossé, Transcript, May 14, 2007, p. 16 and 32.

[294] G. Bossé, Transcript, May 14, 2007, p. 30.

[295] G. Bossé, Transcript, May 14, 2007, p. 32 and 33.

[296] G. Bossé, Transcript, May 14, 2007, p. 52.

[297] Exhibit COM-58, p. 4 and 5.

[298] C. Mercier, Transcript, May 14, 2007, p. 230. The *Manuel d'inspection des structures – évaluation des dommages* defines this type of inspection as follows: [TRANSLATION] *"a meticulous examination of a structure's primary elements in order to detect faults and specify the effect of these faults on the capacity or stability of these elements and the structure. This inspection may be required due to the complexity of a structural system or the size of the faults observed on the primary elements of a structure, during the main inspection"*: Exhibit COM-30D, p. 25 and 26. On the other hand, the general inspection, carried out on average every three years by a team of two DT inspectors, [TRANSLATION] *"consists of systematically examining all elements of a structure in order to detect faults, determine their size and evaluate their effect on the capacity, stability and useful life of the structure as well as the comfort and safety of users."*: Exhibit COM-30D, p. 19 to 21.

[299] C. Mercier, Transcript, May 14, 2007, p. 232 and 233.

[300] C. Mercier, Transcript, May 14, 2007, p. 233 and 234.

[301] These were not in the latest version, as already discussed.

information relating to the repairs carried out in 1992. Mr. Mercier also filed a request to consult the semi-active file stored in a vault located in the City of Québec area (the so-called *Dalton* file), but no document relating to the de la Concorde overpass was found.[302]

Mr. Mercier then contacted Mr. Bossé and agreed to meet him on Thursday, July 15, 2004. On that day, he examined the de la Concorde overpass file kept at the *direction territoriale* and reviewed the inspection reports as well as the photographs that it contained.[303] He did not notice any specific reference to previous repair works. He did not take any further action to collect additional information in this respect (for example, to contact Mr. Simic, whose name appeared on the older inspection reports), nor did he ask Mr. Bossé to do it. The only notes he had of the repairs was collected on site during the visual inspection, as it was obvious that the joints had been replaced and that shotcrete was applied underneath the deck and the beam seats.[304]

Without the information provided to this Commission, Mr. Mercier could not really appreciate the extent of the repairs carried out in 1992. Nevertheless, he believed that the information he had was sufficient to answer the questions raised by the *direction territoriale* and by Mr. Bossé. He knew that the structural system of the overpass was unique and that such a design had been abandoned several years before because of the difficulties of inspection.[305] Yet, he had no reason to believe that the 1992 works on the bridge might have gone beyond routine and minor repairs.[306]

Retrospectively, he considers that Mr. Sanogo's photographs would not have enabled him to establish that the concrete had degraded abnormally (since he considered it to be sound when he probed it), although he is not denying that he could have raised questions concerning some reinforcement details.[307] Obviously, if the file had contained any mention indicating that reinforcement was misplaced, urgent action would have been taken.[308]

Findings of the Commission

The Commission took note of the deficiencies of the file available to Mr. Mercier. It lacked a note about the 1992 repair that would have allowed Mr. Mercier to understand the magnitude of the work that was then performed, the observations regarding the reinforcement and the possible consequences of the combination of concrete degradation, improper placement of reinforcement bars and the removal of the concrete around them. Also, there was insufficient quantitative information concerning the problems observed in previous inspections; as will be discussed in Chapter 5, this prevented the full appreciation of their progression with time.

The unavailability of such information is unexplainable, at least as regards the file kept at the direction territoriale, as is the fact that no action was taken to update the file. The repair in 1992 had revealed major flaws affecting the core of the structure and it was imperative to document this and add this information to the file.

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[302] C. Mercier, Transcript, May 14, 2007, p. 219 to 230.
[303] C, Mercier, Transcript, May 15, 2007, p. 150 to 152.
[304] C. Mercier, Transcript, May 14, 2007, p. 225 to 228.
[305] C. Mercier, Transcript, May 14, 2007, p. 255 and 256.
[306] C. Mercier, Transcript, May 14, 2007, p. 310.
[307] C. Mercier, Transcript, May 14, 2007, p. 300 to 310.
[308] C. Mercier, Transcript, May 15, 2007, p. 211 to 213.

The fact that some documents were lost during the administrative reorganisation of 1993 in no way diminishes the responsibility of the MTQ; it should have made sure that the *directions territoriales* were aware of the particularities of structures under their jurisdiction and of the major aspects of the repairs conducted.

Finally, the MTQ should have issued precise instructions so that the DS staff and the DT engineers responsible for the inspections would know that joint repairs on this type of structure could not be considered as simple routine repairs.

4.7.6.2 ***In situ*** observations

After having examined the *direction territoriale*'s file with Mr. Bossé, Mr. Mercier carried out a hands-on inspection of the north side of the east abutment, of the underside of the deck and of the south side of the east abutment using an inspection platform. The two engineers then moved on top of the deck to check for signs of subsidence and to assess the condition of the joints and pavement. Their examination of the east abutment, which, according to Mr. Mercier[309] was considered more problematic by Mr. Bossé, lasted between 60 and 90 minutes. They decided together not to move the inspection platform on the west side of the overpass. The inspection of the west abutment was performed visually from the ground only, as it was considered sufficient information had been collected.[310]

With regards to the beam seats, the observations of Mr. Mercier were similar to those reported by Mr. Bossé. There was deterioration of the concrete around the bearing pads – he noticed deterioration of approximately 120 mm around a bearing pad located next to a wall – but the concrete of the corbel appeared to be sound except for surface damage. They were able to inspect 20% of the bearing pads and seats (i.e. 4 devices out of 20). The conclusion was that the load-bearing capacity of the elements was not affected.[311]

As for the quality of the concrete, the underside of the deck of the cantilever was, according to Mr. Mercier, in [TRANSLATION] "excellent condition," which prompted him to state that the quality of the concrete was good, without [TRANSLATION] "actually going more in-depth into the analysis." The exterior of the concrete also appeared to be in good condition when it was sampled and the top of the pavement did not show signs that could lead one [TRANSLATION] "to suspect there was significant delamination of the concrete cover over the main reinforcing bars." These observations convinced him that he had all the information necessary and that there was no need for performing destructive tests such as core-sampling.[312] He also did not believe the poorly bonded shotcrete repairs underneath the deck, dating back to 1992, needed further investigation. Considering the fact that the technique was fairly recent at the time, the observed state of degradation did not appear abnormal to him.[313]

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[309] C. Mercier, Transcript, May 14, 2007, p. 273.

[310] C. Mercier, Transcript, May 14, 2007, p. 244 to 246.

[311] C. Mercier, Transcript, May 14, 2007, p. 263 to 271.

[312] C. Mercier, Transcript, May 14, 2007, p. 294 to 296.

[313] C. Mercier, Transcript, May 14, 2007, p. 262 and 310 to 312.

In the case of cracking, Mr. Mercier qualified as "insignificant" the cracks observed on the side faces of the abutments at the time of his inspection. The largest crack recorded by Mr. Mercier originated from the re-entrant corner of the southeast abutment seat, where its width reached approximately 0.5 to 0.6 mm, and it went with a 45° angle down in the cantilever, decreasing rapidly in width to a hairline crack. The only other crack recorded by Mr. Mercier in his field notes was also diagonal and originated in the re-entrant corner of the deck end, on the north side. It had a maximum width of about 0.1 mm. Once cleaned of the efflorescence that covered them, the other visible cracks on the side faces of the east abutment were all very fine or hairline-size according to Mr. Mercier. Their location and size were however not quantified.[314]

In his request for technical assistance, Mr. Bossé referred to the presence of [TRANSLATION] "wide shear cracks." To support his comments, he had attached a photograph of a relatively significant crack located on the north face of the west abutment.[315] However, that crack, for which no quantitative information was available, had not been observed closely or measured by Mr. Mercier since the west abutment was only inspected summarily from the side slope of the freeway.[316]

When testifying before the Commission, Mr. Bossé tried to tone down the terms used in his letter of June 2004. He indeed affirmed that the use of the term "wide" had nothing to do with the terminology of the MTQ damage rating system.[317] Nevertheless, the explicit reference to "shear" was reiterated in his testimony.[318] In contrast, Mr. Mercier claimed that it was not possible to establish clearly that the diagonal cracks observed on the side faces of the overhangs and deck were shear cracks.[319]

Mr. Mercier considered the observed cracks to be passive, although there was no prior mention of cracks. This conclusion was thus based primarily on the information obtained verbally from Mr. Bossé, whereby cracking had not changed since the inspection performed in 2002,[320] as well as on the presence of deposits in the crack.[321] Nevertheless, he mentioned later in his testimony that the cracks recorded in his notebook were those that appeared to be the most active.[322]

All things considered, Mr. Mercier judged that the cracks observed in July 2004 were not problematical, both from the point of view of safety and structural capacity.[323] He admitted in his testimony that the efflorescence originating from the cracks evolved over the years but, according to him, it does not mean that the cracks have progressed.[324]

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[314] C. Mercier, Transcript, May 15, 2007, p. 78 to 87.
[315] Exhibit COM-31B, p. 140.
[316] C. Mercier, Transcript, May 15, 2007, p. 90.
[317] G. Bossé, Transcript, May 14, 2007, p. 37 to 43.
[318] G. Bossé, Transcript, May 14, 2007, p. 37 and 110.
[319] C. Mercier, Transcript, May 15, 2007, p. 109 and 110.
[320] C. Mercier, Transcript, May 15, 2007, p. 97.
[321] C. Mercier, Transcript, May 15, 2007, p. 104 and 105.
[322] C. Mercier, Transcript, May 15, 2007, p. 184 and 185.
[323] C. Mercier, Transcript, May 15, 2007, p. 185 to 187.
[324] C. Mercier, Transcript, May 15, 2007, p. 96 to 105.

4.7.6.3 Preliminary answer and analyses

At the end of his visit, Mr. Mercier reassured Mr. Bossé, saying to him there was nothing urgent or critical to be repaired.[325] He told him on site that the visible cracks were not problematical in the short-term and that they did not represent a risk for public safety, but that they had to be monitored. With regards to the state of deterioration of the corbels, after having examined the reinforcement details, Mr. Mercier informed Mr. Bossé that the capacity of the corbels did not appear to be a cause for concern.[326] He told him that recommendations would be put forth, but that they would likely not call for short-term actions beyond follow up monitoring. Mr. Mercier stated that he had reconfirmed his conclusions to Mr. Bossé over the telephone in the following days,[327] which, however, Mr. Bossé does not remember.[328]

Upon returning to City of Québec, Mr. Mercier discussed the case with Mr. Jacques Prévost, his immediate superior.[329] They examined the photographic file and concluded that there was nothing urgent to repair. Moreover, in their mind, nothing justified a deeper investigation with tests, core sampling or instrumentation.[330] They considered, however, that the behaviour of the corbels and cracking had to be monitored.[331]

In his request, lifting of the bridge deck was suggested by Mr. Bossé as an alternative to be considered in order to establish a reliable diagnosis of the seat condition. Insofar as it did not appear necessary to repair the latter, Mr. Mercier and Mr. Prévost rejected this option.[332]

4.7.6.4 Written reply sent by the ***Direction des structures*** in March 2005

The official reply to Mr. Bossé's request for assistance was sent by letter on March 3, 2005.[333] Essentially, the *Direction des structures* recommended not to take short-term action, but to monitor closely through subsequent inspections the progress of the distresses noted during Mr. Mercier's visit in July 2004. An enclosed letter summarised the observations and recommendations of Mr. Mercier the engineer.[334] He recognised that the beam seats were

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[325] C. Mercier, Transcript, May 15, 2007, p. 117 and 118.

[326] G. Bossé, Transcript, May 14, 2007, p. 41 to 46.

[327] C. Mercier, Transcript, May 15, 2007, p. 164.

[328] G. Bossé, Transcript, May 14, 2007, p. 49.

[329] It is worthy of note that the head of the Service de l'Entretien at the time, Mr. Claude Leclerc, ing., who was also the immediate superior of Mr. Prévost, was not an expert in the area of structures nor in materials, nor did he have any experience in the area. However, he had taken courses given by the DS on structure maintenance: C. Leclerc, Transcript, May 14, 2007, p. 168 to 171.

[330] In January 2005, Mr. Mercier planned to remove the two joints, which he thought to be the origin of the problem. However, results show that the absence of an extension joint would result in too great of stress in the structure due to the tremendous rigidity of the abutment anchored in the rock. The alternative chosen for future work thus consisted of eliminating the fixed joint only: C. Mercier, Transcript, May 15, 2007, p. 121 and 122. See also Exhibit COM-56, p. 157 to 174 for calculations.

[331] C. Mercier, Transcript, May 15, 2007, p. 117 to 119. According to Mr. Mercier, if Mr. Bossé had any concern over the disintegration of the seats, it is because he had not consulted the details for the corbel reinforcement on the drawings. After studying the plans, Messrs. Mercier and Prévost were convinced that the state of the seats did not pose any problem: C. Mercier, Transcript, May 14, 2007, p. 270.

[332] Lifting the 700 tonne deck by a height of 1.0 m is no easy task. Such an operation had never been performed by the DS and it would have required an interruption in public utilities. There was no question that Messrs. Mercier and Prévost would lift the deck simply to inspect it, especially since, according to them, the state of the seats did not require immediate action. If follow up on these defects eventually revealed that they were becoming serious (as in an active crack or lowering of bearing pads), it would have been recommended to repair the seats completely, from the top of the structure by supporting the central span, rather than by lifting it: C. Mercier, Transcript, May 15, 2007, p. 126 to 133.

[333] Exhibit COM-56, p. 177 and 178.

[334] Exhibit COM-56, p. 175 and 176. Mr. Mercier's letter suggested corrective work on the seats. It was stated that these works should only be planned when more significant damage was notice, as in an active crack or lowering of bearing pads. Mr. Mercier mentioned in his testimony (following the example of Mr. Bossé) that the MTQ was ensuring risk

inaccessible and that they were showing significant signs of deterioration close to the side faces. He added, however, that it was not necessary at that stage to carry out a more detailed inspection. The cracking issue that concerned Mr. Bossé is not addressed explicitly in the letter. In his testimony, Mr. Mercier stated that he had reassured Mr. Bossé verbally on that matter and that it was implicitly dealt with in the letter through the recommendation for monitoring the distress.[335]

It should be noted that in his testimony, Mr. Guy Richard, director of the *Direction des structures*, insisted on the fact that the opinion issued in response to Mr. Bossé's request for assistance fully reflected the technical opinion of the *Direction des structures* and not only that of Mr. Mercier.[336] It is also necessary to recall that the DS was aware of the difficulties related to the inspection and maintenance of this type of structure, in particular because of the vulnerability of the expansion joints, which became evident over the years. The DS had placed the structures of this type in the level 1 category, which requires inspections by A1 inspectors. However, no specific guidance or measures had been developed before the collapse of the de la Concorde overpass to call the attention of DT personnel on the necessity of paying close attention to this type of structure.[337]

4.7.6.5 Delay for answering and producing a special inspection report

Mr. Leclerc concedes that in the case of the de la Concorde overpass, the written reply was sent to Mr. Bossé more than eight months after his request for assistance, although he tried, as a manager, to assure a follow-up within six months. He recalls, however, that Mr. Bossé's concerns were answered verbally very early and had agreed with him that the written report would be produced at a later date. Mr. Mercier had reassured him on the condition of the overpass at the end of his inspection and had informed him that there was no urgency.[338]

In his testimony before the Commission, Mr. Mercier admitted that, apart from the March 1, 2005, letter sent to Mr. Claude Leclerc, no special inspection report was produced.[339] While there is no typical form or sheet intended for this type of inspection, it should be noted that the *Manuel d'inspection des structures – évaluation des dommages* requires a report to be produced in the prescribed form.[340]

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management, due to the significant requirements for repairs and limited resources. Therefore, the de la Concorde overpass structure needed maintenance work, but in the medium term. According to him, interventions were not urgent, although follow-ups were still desirable. The recommendation to wait before intervening did not hinder the Direction Territoriale from making preparations to carry out the work: C. Mercier, Transcript, May 15, 2007, p. 199 and 200.

[335] C. Mercier, Transcript, May 15, 2007, p. 164 and 165.

[336] G. Richard, Transcript, May 16, 2007, p. 53.

[337] G. Richard, Transcript, April 12, 2007, p. 242 to 244; May 16, 2007, p. 241 to 246; Exhibit COM-6, p.5. The last construction date that appears on the list of these works is 1972. However, Mr. Richard was not employed by the DS at this time, he can only confirm that no construction of this type was authorised since he was hired in 1986. The design manual mentions this specifically.

[338] C. Leclerc, Transcript, May 14, 2007, p. 194 to 196.

[339] C. Mercier, Transcript, May 14, 2007, p. 259 and 260.

[340] Exhibit COM-30D, p. 25 and 26. Incidentally, Mr. Mercier's letter was not accompanied by photos or sketches, contrary to what the manual allows for illustrating the extent of faults observed. However, the notes and photos taken by Mr. Mercier during his inspection (Exhibits COM-56, p. 150 to 152 and COM-1E), as well as his subsequent calculations (Exhibit COM-56, p. 157 to 174), were added to the DS file.

4.7.6.6 Follow up of recommendations by the ***Direction des structures***

The *Direction des structures* is a state-of-the-art centre of expertise that the *directions territoriales* consult when needed. In the current system, although the DS wields a certain power, its authority is much more technical than administrative. The DS allows the *directions territoriales* to assume full responsibility for choosing the type of monitoring it deems appropriate.[341]

In this respect, in addition to the recommendation made in his letter of March 1, 2005, to monitor the damage, Mr. Mercier claimed to have verbally advised Mr. Bossé about the necessity to monitor the cracks and record quantitative information (width and length).[342] Mr. Bossé admitted in his testimony that quantitative follow-up (recording of the size and location of the cracks) was considered, but that he never followed up on the recommendation of the DS even though two inspections (summary inspection during the fall of 2004 and general inspection in 2005) were carried out thereafter. According to Mr. Bossé, the letter from the DS did not specify that it was necessary to undertake precise crack monitoring immediately.[343]

Mr. Mercier only learned after the collapse of the overpass that the DT had not undertaken any quantitative crack monitoring.[344] He himself did not follow up on the situation after sending his recommendations.[345] In fact, Mr. Leclerc did not introduce systematic measures for monitoring related to the recommendations issued to the DT following special inspections.[346]

Findings of the Commission

In the current organisation, the DS is defined as an internal consulting department of the DT, which is ultimately responsible for taking decisions regarding operations on structures. Although the DT generally follow the recommendations formulated by the DS, this situation is ambiguous and is characterised by the absence of clear accountability with regards to critical decision-making.

The Commission notes that in the system in force in 2004 – and which still is – the engineer who calls upon the Direction des structures to obtain an expert opinion remains responsible for following up on the advice obtained. This suggests a relationship between the DS and the DT similar to that of an external consulting firm with its client rather than that of a specialised service providing support to another part of the same organisation, both being accountable for final decisions.

This ambiguity of responsibilities has consequences. The Commission issues recommendations on this matter in Chapter 7.

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[341] G. Richard. Transcript, May 16, 2007, p. 13-15 and 36. Se also Exhibit COM-30D, p. 36. For more detail on the role of the *Direction des structures*, see Appendix 19, Additional Note No. 3. Keep in mind that the procedure currently in force at the DS does not plan for systematic verification to monitor the follow up performed by the *directions territoriales* upon receiving notices from the DS.

[342] C. Mercier, Transcript, May 15, 2007, p. 224.

[343] G. Bossé, Transcript, May 14, 2007, p. 65, 142 and 143.

[344] C. Mercier, Transcript, May 15, 2007, p. 228.

[345] C. Mercier, Transcript, May 15, 2007, p. 136 and 137.

[346] C. Leclerc, Transcript, May 14, 2007, p. 197.

The Commission is of the opinion that the 2004 inspection was insufficiently rigorous. Mr. Bossé had clearly voiced his concerns to the Direction des structures. Since Mr. Mercier represents the MTQ service providing state-of-the-art expertise, it would have been normalthat he performs a more in-depth inspection. On the contrary, the inspection performed by Mr. Mercier was similar to the ones Mr. Bossé had previously conducted.

Considering these facts, the Commission, although deploring the lack of a rigorous approach by Mr. Mercier in the conduct of his 2004 inspection, addresses its blame mainly to the MTQ for tolerating the ambiguity in accountability between the *Direction des structures* and the *direction territoriale*, for lacking discipline in its file keeping and for never being able to translate its know-how into an inspection and maintenance programme adapted to this particular structure.

4.8 Inspections between 2004 and 2006

Two inspections were performed after the special inspection of the *Direction des structures* in 2004.

A new summary inspection took place in October 2004. It essentially reported the same observations noted on previous inspections. Curiously, only a few months after a special inspection was performed due to concerns about the cantilevers, and without any intervention having been carried out, the general condition of the overpass was rated as "good."[347]

The last inspection performed on the de la Concorde overpass before its collapse was conducted by the DT in 2005. The CEC rating for the box girders was lowered to 3 (extremities). Consequently, the overpass was rated CECS-3, which corresponds to a "mediocre" general condition as per the MTQ's reference table. In this inspection report, the general condition of the overpass is described as "acceptable", with explicit reference to the March 3, 2005, letter from Mr. Leclerc. In March, the general inspection report was updated in the System 5016 to reflect the suggested repair work and the corresponding estimate prepared by Mr. Mercier. The cost for the same work was revised to $516,500, in all likelihood to take into account more realistic costs for replacing the joints. Despite the recommendations of the *Direction des structures*, no specific follow-up concerning the cracks was recorded in the report.[348]

The main intervention carried out on the de la Concorde overpass between 2004 and 2006 consisted in removing loose fragments of concrete (*safety improvement*) under the superstructure. Work was performed on September 15, 2005.[349]

Findings of the Commission

From all inspection reports submitted to and the testimonies heard by the Commission on this matter, it is clear that, for over 30 years, service personnel (either at the *direction territoriale*

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[347] Exhibit COM-31B, p. 153.

[348] Exhibit COM-31B, p. 179 to 196.

[349] Exhibit COM-31B, p. 254.

or *Direction des structures* level) was aware of the particular characteristics of the de la Concorde overpass, built according to an unusual design and posing major problems with regard to inspections.

However, at no time does the documentation or the testimonies heard reveal any intention of the *Ministère* to adopt any specific monitoring or maintenance measures that would take into account the distinctive features of the de la Concorde overpass and other similar structures.

The Commission notes that many opportunities were missed throughout the years to investigate in detail the condition of the structure and that provisions in the manuals were not all followed.

The Commission considers that the *Ministère* must ensure that its professionals and technicians strictly abide to and implement its regulations.

The Commission is of the opinion that the *Ministère* must better identify the structures that are at risk and award them special status in the management system for structures under its responsibility. The Commission, aware of the alleged shortages in human and budgetary resources for inspections, maintenance and repairs, is of the opinion that this does not alter the *Ministère*'s responsibility to efficiently prioritise interventions in a disciplined manner.

Finally, the Commission is of the opinion that the individual expertise of MTQ personnel is good and that the regular training programme is adequate. However, testimony has shown a lack of teamwork and a culture that promotes individual autonomy without any real quality control by the hierarchy. The resistance by professionals of a hierarchical mode of operations cannot favour a sustained development of high-end expertise throughout the organisation.

CHAPTER 5

5. EXPERT INVESTIGATIONS

5.1 Introduction

One of the three parts of the Commission's mandate is to determine the causes of the collapse of the de la Concorde overpass. For that purpose, the Commission concentrated its research on:

- design of the structure,
- construction,
- surveillance during its construction, and
- inspection and maintenance.

The Commission also wanted to determine both the rupture mechanism of the de la Concorde overpass and the condition of the structure on September 30, 2006.

The Commission retained the services of a group of experts under the direction of Professor Jacques Marchand, Eng., Ph. D., and Professor Denis Mitchell, Eng., Ph. D., respectively professors at Laval University and McGill University. Both with international reputations, Jacques Marchand has extensive knowledge in the area of materials while Denis Mitchell is a specialist in concrete structures. Under their supervision, the work of the Commission's experts was conducted by a multidisciplinary team, which included Mr. Alexander M. Vaysburd, P.E., Ph. D. and Professor Benoit Bissonnette, Eng., Ph. D., both experts in the field of inspection and repair of civil engineering structures.

The MTQ and DSA also appointed their own experts to conduct a certain number of investigations on subjects that were of interest to them. For the MTQ, Professor Bruno Massicotte, Eng., Ph. D., professor at the *École Polytechnique de Montréal*, acted as coordinator for a team of experts from the *Ministère* and university circles. DSA, for its part, engaged Professor Frédéric Légeron, Eng., Ph. D., professor at Sherbrooke University, and Mr. Mohan Malhotra, a specialist in concrete materials, formerly with CANMET.

The complete list of experts involved in the Commission's work, as well as their qualifications and titles, is presented in Appendix 12, while the expert reports are presented in Appendix 14.

The Commissioners requested that the participants' and the Commission's experts hold a preliminary conference in order to try to reach a consensus regarding certain technical aspects, before the Commission heard their testimonies.

This preliminary conference took place on June 26, 2007, under the supervision of the Commission's technical director, with the contribution of experts from the Commission, the MTQ and DSA. Numerous topics were discussed at that meeting and a substantial consensus emerged on many subjects, which was important for the continuation of the Commission's work.[1]

The consensus reached during this preliminary conference represents the common denominator accepted by all participants. However, each participant reserved the right to let their own experts express opinions on controversial issues or opinions beyond the consensus.

Chapter 5 presents a summary of the various expert reports.[2] In each section, a box will describe *in extenso* the partial or total consensus on a particular issue. Furthermore, opposing arguments will be pointed out and briefly described. The Commission will also highlight some fundamental aspects of the experts' opinions, or will give its point of view when presented with conflicting opinions, where appropriate.

5.2 Nature and scope of expert work

The investigations began the day following the collapse. On October 1st, 2006, experts from the Commission and the MTQ were already examining what remained of the de la Concorde overpass. Coring operations, non destructive tests and other observations, performed at the site of the collapse, went on until October 21, 2006, at which time the overpass was demolished.

The Commission's experts reviewed all the available evidence and carried out tests on the de la Concorde and de Blois sites, on the Belgrand storage site, in the eastern part of Laval, as well as in the laboratory. They performed various calculations and took measurements as required to fulfill their mandate defined by the Commission. In addition, they assisted the experts of the MTQ with their tests, by coordinating work on sites that fell under the Commission's jurisdiction.

Work on the Belgrand site took place between November 2006 and February 2007. During that period, experts from the Commission took various readings, extracted additional cores and dissected certain pieces. On February 12, 2007, the site was handed over to the MTQ which performed its own observations on the concrete blocks which were left in place (Figure 5.1). In August 2007, further dissection and coring activities were carried out following a protocol which was agreed upon by the experts prior to the operations (see section 5.10 in this chapter).

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[1] Exhibit COM-72.

[2] The full reports are provided in Appendix 14 “Rapports d'expertise et répliques”.

Figure 5.1 Operations carried out on the site of the collapse and on the Belgrand Street storage site

Investigations by the various participants required many laboratory tests, some of which were performed on concrete and reinforcing steel samples taken from the overpass itself, before its dismantling, or on pieces that were stored on Belgrand Street. Other tests required the construction of prototypes representing the overpass's cantilevers. Finally, analyses of the thermal and structural behaviour by finite elements were also carried out.

In general, laboratory tests took place between the end of October 2006 and mid-April 2007, while structural analysis continued until the end of April 2007.

Finally, the experts proceeded to write their reports and prepare their testimonies before the Commission.

Some thermal analysis results were communicated by MTQ experts in September 2007 as described in section 5.9.4.2.

5.3 Design

5.3.1 Particular nature of the structure

The de la Concorde overpass owes its particular nature to the fact that the beams of its central span rest on chair-shaped bearing supports (or corbels) located at the ends of the cantilevers extending from the abutments. In most other structures, the spans rest on the abutments, directly above the foundations.

Most of the cantilever consists of a thick slab and is referred to as the "regular zone" of the cantilever. The end of the cantilever contains a "disturbed zone", in the vicinity of the seat, where stress distribution is much more complex.

Furthermore, the structure is skewed, which influences stress distribution and concentrates more force towards the southeast and northwest corners of the abutments.

The cantilevered abutment ends with a continuous bearing support which runs the whole width of the bridge. This type of support, practically inaccessible for inspection and maintenance, except at the outer faces, promotes the accumulation of water, de-icing salts and debris. The current bridge Code CSA-S6-2006 does not allow such a design, because of the obvious maintenance difficulties. However, there was no mention of such type of design in the CSA-S6-1966 Code.

Examination of the structure after the collapse shows that the bearing seat on the south part of the east abutment, which supports the prestressed girders, did not fracture and remained intact. This is also true of the bearing seat on the west abutment.

Consensus of the experts, dated June 26, 2007, regarding the particular nature of the structure

[TRANSLATION]

"The bearing seat was not involved in the collapse."

"The bearing seat along the span is a structural element difficult to access. The configuration of the bearing seat promotes the accumulation of water, de-icing salts and debris in a critical zone of the structure. It is a critical structural element located in a zone of potential damage."

"The MTQ stopped building this type of structure over 20 years ago."

5.3.2 Verification of load carrying capacity under CSA-S6-1966 Code

Calculations by the finite element method (FEM) using powerful computers were uncommon at the end of the 1960s and microcomputers did not even exist. Engineers therefore had to rely on hand calculations to obtain approximate stresses in a structure, using simplifying assumptions in order to analyse complex situations.

In the case of the cantilevers of the de la Concorde overpass, the designer testified that he assumed a uniform load distribution across the entire width of the overpass. The analysis was done considering a unit slice of the thick slab as representative[3] of the structure. At the time, the Code gave no instruction regarding the effects of the skew, which creates stress concentrations at the sharp corners of the cantilevers, i.e. the *north* corner of the *west* abutment, and the *south* corner of the *east* abutment (the importance of the stress concentrations due to the skew will be discussed in the next section). Mr. Dupaul accounted for the skew by considering the length of

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[3] G. Dupaul, Transcript, 19 April 2007, p. 29.

the cantilever as being measured along the axis of the overpass and not perpendicularly to the axis of the supports. Experts testified that Mr. Dupaul's calculations were in compliance with standard practices, given the means available at the time.[4]

5.3.2.1 Shear resistance

According to the experts, the shear stress as calculated by the designer of the de la Concorde overpass was below the allowable stress permitted at the time,[5] and the Code had no provision for minimal shear reinforcement in slabs.

5.3.2.2 Calculations of disturbed zones

The codes in force in 1969-70 did not contain any provisions specific to disturbed zones, where the transmission of internal stresses is complex, as is the case at the ends of the cantilevers. In addition, reports and expert testimonies have established that the literature available at the time contained incomplete and sometimes incorrect information regarding the arrangement of the rebars in a corbel-type support at the end of a beam or a slab.

As indicated in the June 26, 2007 consensus, there is general agreement that the design did comply with the requirements of the CSA-S6-1966 Code.

June 26, 2007 consensus regarding the compliance of the design to CSA-S6-1966 Code

[TRANSLATION]

"The design does not contravene any of the critical provisions of the S6-1966 Code."

"The Code did not require that the thick slab of the cantilever be reinforced with stirrups."

"The Code did not contain any provision concerning the design of disturbed zones."

5.3.2.3 Evolution of the codes between 1966 and 2006

Major technical advances have taken place in the field of reinforced concrete since the 1980s, leading to considerable evolution of the codes. Two major aspects of this evolution deserve particular attention: unit resistance of concrete to shear in regular zones, and design of disturbed zones.

a) Unit resistance to shear in regular zones

In the calculation of reinforced concrete elements in regular zones, calculations of shear resistance have become more complex and precise. In particular, current calculation methods account for a scale effect, whereby the shear unit resistance of non-reinforced concrete diminishes as the thickness of the element increases. In other words, the shear resistance that is allowed for un-reinforced concrete in a thick slab today, is less than that allowed in 1966.

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[4] Exhibits COM-62, p. 102 DS-1, p. 6 and MTQ-1(amendments included), p. 34.

[5] Exhibits COM-62, p. 102 DS-1, p. 6 and MTQ-1(amendments included), p. 34.

The scale effect on shear resistance is a phenomenon that has been studied in Japan by Shioya in 1989 (Figure 5.2), amongst others. The theory was developped by Collins and Mitchell[6] and the scale effect was incorporated in the Canadian Standard for the Design of Concrete Structures for Buildings in 1994 (CSA-A23.3-1994) and in the Canadian Highway Bridge Design Code in 2000 (CSA-S6-2000).

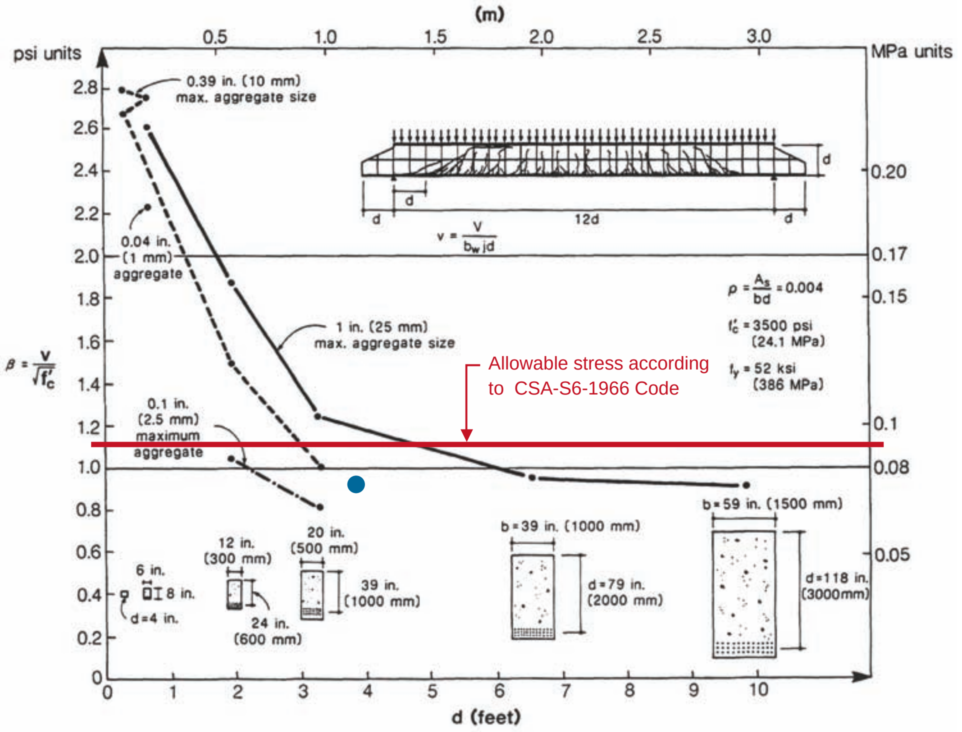

Figure 5.2 Scale effect affecting shear resistance in un-reinforced concrete[7]

b) Design of disturbed zones

Modern design codes for reinforced concrete structures rely on the "Strut and Tie" model for the calculation of disturbed zones. This model was developed by Collins and Mitchell. It was incorporated in the Canadian Standard for the Design of Concrete Structures for Buildings in 1994 (CSA-A23.3-1994) and in the Canadian Highway Bridge Design Code in 2000 (CSA-S6-2000). Figure 5.3 illustrates the "Strut and Tie" model which should be used for the analysis of the disturbed zone of the cantilevers of the de la Concorde overpass.

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[6] Collins and Mitchell (1990). Prestressed Concrete Structures, Englewood Cliffs, N.J., Prentice Hall.

[7] Exhibit COM-69, p. 84.

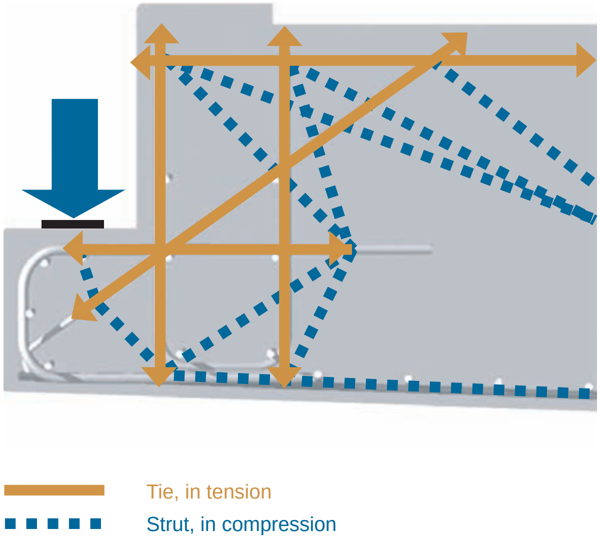

Figure 5.3 Analysis of the disturbed zone of the cantilevers of the de la Concorde overpass, using the “Strut and Tie” model[8]

5.3.3 Verification according to the CSA-S6-2006 Code

The question of conformity to the requirements of the current CSA-S6-2006 Code is addressed following the three themes developed in the last section, namely stress analysis, shear design of the regular zone and design of the disturbed zone in the bearing support area.

5.3.3.1 Stress analysis

The CSA-S6-2006 Code allows the use of a simplified calculation method to account for the effect of the skew. When applying this simplified analysis method to the de la Concorde overpass and comparing the results with those of three-dimensional finite element analysis, it has been established that the simplified analysis underestimates the real effect of the skew and that the significant weight of the sidewalk on the cantilevers further increases the concentration of stresses in the sharp angle[9] (figure 5.4). The Commission and MTQ experts presented comparable results regarding the distribution of bearing pad reactions on the bearing supports, which can increase by a factor of about two towards the external supports on the sharp side.[10, 11]

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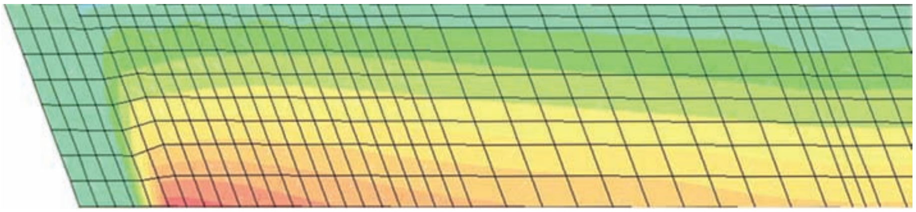
[8] Exhibit COM-69, p. 89.

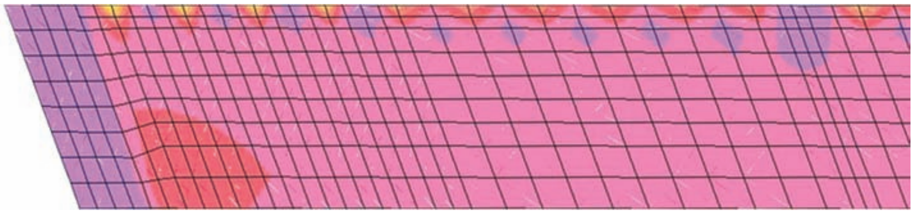
[9] Exhibit COM-62, p. 106.

[10] Exhibit COM-62, p. 107.

[11] Exhibit MTQ-1 (amendments included), p. 30.



Bending moment



Shear force

Figure 5.4 Distribution of the bending moment and the shear force in the cantilever of the de la Concorde overpass under dead load, showing the concentration of stresses due to the skew[12]

5.3.3.2 Shear resistance of the thick slab

Using results from the refined stress analyses, the Commission's experts conclude that the capacity of the cantilever slab, without shear reinforcement, is insufficient to resist the dead and live loads in the external zone of the cantilever, according to the requirements of the CSA-S6-2006 Code.[13] Consequently, shear reinforcement should have been placed, at least in some parts of the thick slab. This shear reinforcement could have been provided by a series of vertical bars, placed at regular intervals in each direction, and correctly anchored to the main steel at the top and bottom of the slab.

The CSA-S6-2006 Code does not require minimal shear reinforcement, unless required to satisfy strength requirements.

Considering the load concentrations calculated in the structure and the requirements of the current code, the experts believe that such shear reinforcements along the length of cantilevers would have been required if the current reference vehicle CL-625 (625 kN or 62.5 tonnes) indicated in the Code is used for live load.[14,15,16] With the exception of DSA's expert, the experts agree that shear reinforcement is also required using the much lighter H20-S16 (32 tonnes) truck, which was the reference vehicule in the CSA-S6-1966 Code. However, DSA's expert used the simplified method of analysis.[17]

With respect to the fact that the shortcomings in shear strength was localised to a portion only of the slab, the MTQ's expert expressed the opinion that this would not justify a reduction in the rating of the bridge and that the question had to be addressed with due consideration of

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[12] Exhibit COM-69, p. 79.

[13] Exhibit COM-62, p. 112.

[14] Exhibit COM-62, p. 112 and 113.

[15] Exhibit MTQ-1 (amendments included), p. 34.

[16] Exhibit DS-1, p. 8.

[17] Exhibit DS-1, p. 8.

the condition of the overpass, of the transverse distribution of the loads, and of specific factors which could reduce the actual load.

Findings of the Commission

The Commission considers inappropriate to rely on any presumed load redistribution effects when analysing a brittle rupture mechanism, such as one associated with a shear failure in concrete without shear reinforcement. The Commission does not accept the interpretation of the MTQ's experts.

Because of the brittle behaviour of concrete without shear reinforcement, the Commission believes that insufficient shear strength, even localised, can lead to catastrophic consequences.

5.3.3.3 Design of the disturbed zone of the bearing seat

Considering the philosophy of the current codes which is based on limit states design,[18] current practice would require that hanger bars be capable of developing their full capacity in tension at the strength limit state. This is only possible if the upper hooks of the hangers and of the inclined bars are attached to the No. 14 bars. In Mr. Dupaul's design, the link to the No. 14 bars was achieved by putting the upper hooks of these bars parallel to the upper steel, an incorrect approach according to present-day practices.

Experts agree that the bearing support details "as designed" provides for a theoretical strength of the order of 850 kN, supposing that the forces from the horizontal hooks of the U-shaped hanger bars are fully transmitted to the No. 14 bars as it should be. However, deterioration of the concrete in the area of the expansion joint can considerably decrease this theoretical resistance.

The weak point of the rebar detail which must accomplish this load transfer is the bond around the No. 14 bars at the end of the cantilever. The bond strength is not sufficient because a considerable load has to be transferred over a short distance. If this load transfer fails, then the greater part of the load transfer must be carried by the No. 6 inclined bars, which can only resist a limited load.

Finding of the Commission

The design of the disturbed zone of the chair-shaped bearing support does not meet the requirements of the current standards and does not comply with today's best practice.

5.3.3.4 MTQ Manual for load-bearing capacity evaluation

It has been demonstrated during expert testimony[19] that the current 2004 edition of MTQ's *Manuel d'évaluation de la capacité portante des structures*,[20] prescribes certain criteria for

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[18] F. Légeron, Transcript, 12 July 2007, p. 188.

[19] D. Mitchell, Transcript, 10 July 2007, p. 68.

[20] Exhibit COM-30G.

evaluating the load-bearing capacity of its structures which are less stringent than those found in Chapter 14 of the CSA-S6-2000 or CSA-S6-2006 codes. In particular, the load-bearing capacity of thick slabs, calculated using the manual, is overestimated.[21] This situation constitutes a serious shortcoming, and the Commission has already suggested that the MTQ require calculations be carried out according to the CSA-S6-2006 Code rather than its own Manual, when evaluating the condition of structures.

The Commission considers that the key points with respect to the compliance with current code requirements, are included in the wording of the consensus.

June 26, 2007 consensus regarding compliance of the design with the CSA-S6-2006 Code and load-bearing capacity of the structure

[TRANSLATION]

"The design does not meet the requirements of the current S6-2006 Code with respect to shear resistance."

"The cantilever did not possess the required structural strength for shear according to the provisions of Chapter 14 of the S6-2000 and S6-2006 codes"

"The MTQ's *Manuel d'évaluation de la capacité portante des structures* must be updated to be made consistent with the requirements of Chapter 14 of the S6-2006 Code."

5.3.4 Detailing of the rebars

One of the major weaknesses of the de la Concorde overpass pertains to the faulty anchoring of both the No. 8 U-shaped hangers and the No. 6 diagonal bars to the No. 14 longitudinal bars. Notwithstanding the way in which the bars were actually placed during construction, the drawings did not provide for mechanical contact of rebars to transmit the load from the bearing supports towards the top bars. The anchoring method retained by the designers consisted of a hook at the upper end of the U-shaped hanger placed parallel to the No. 14 bars, in the same horizontal plane. Because of this arrangement, many rebars were located on the same plane, which formed a zone of weakness in that area. In fact, at the time of the collapse and during laboratory tests, it was found that the corbel remained in a monolithic state after failure, and the overpass' weak point was precisely the connection between the rebars of the disturbed zone and those of the rest of the cantilever.

According to the MTQ experts, the ends of the No. 14 bars were incorrectly anchored to the top of the bearing support. Instead of being straight, they should have ended in a 90° or 180° hook.[22] According to them, [TRANSLATION] "*these requirements were mentioned in the CSA-S6-1966 Code and still remain valid today*". Regardless, the MTQ experts agree with the consensus to the effect that the design contravenes none of the critical provisions of the CSA-S6-1966 Code.

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[21] Exhibit MTQ-1 (amendments included), p. 43.

[22] Exhibit MTQ-1 (amendments included), p. 79 and 80.

The arrangement of the rebars in the disturbed zone was designed according to the knowledge and methods available at the time. Today, such an arrangement would be unacceptable and non-compliant.

June 26, 2007 consensus regarding reinforcing steel details

[TRANSLATION]

"The approach chosen by the designer to anchor the No. 8 U-shaped hangers in the upper part of the cantilever does not meet the requirements of the current Code S6-2006."

"The anchoring of the No. 14 upper bars does not comply with current practice."

5.3.5 Specification for the concrete

The requirements concerning concrete mixes were defined by the engineers at DSA. They are described in Section 203 of the Special Specification (the "*Devis Spécial*") for Contractors which was issued to the bidders.[23]

The note appearing under Table E-4.1 mentions that "*in this project, only type A exposure applies to all structures*". This category is suitable for concrete exposed to the atmosphere. However, in the case of the de la Concorde overpass, condition " C " should have applied. This condition takes into account exposure to freeze-thaw cycles in the presence of de-icing salts and is more stringent than condition " A ". Specifically, this means that the specified maximum water-cement ratio was 0.56, whereas, according to the CSA-A23.1 Standard – 1967, it should have been 0.49 or 0.54 (for horizontal or vertical surfaces respectively). The same Table mentions an air content of 6% ± 1% for Type " A " exposure concrete.

The same section, in sub-article 3 found below Table E-4.1, contains a list of the various structural components and the corresponding requirements. The section relating to abutments points out that the concrete had to be manufactured using a 20 mm (¾'') aggregate and entrained air content of 4% to 6%. This concrete also had to have a 100 mm slump and be able to develop a compressive strength of 4,000 psi (or 27.6 MPa).

The requirement concerning the water-cement ratio described in condition " A " did not meet the requirements of Canadian Standard CSA-A23.1–1967, in force at the time, for concrete exposed to freeze-thaw cycles in the presence of de-icing salts.

The recommended air content value for Type " A " exposure in Table E-4.1 (6% ± 1%) is within the range prescribed in the CSA-A23.1–1967 Standard (from 4.5% to 7.5%). However, the range indicated in the section relating to abutments is slightly lower (4% to 6%), which can lead to confusion and contradicts the requirements of the Standard.

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[23] Exhibit COM-20A, p. 105.

Recognising the confusion of the requirements of the Special Specifications document, the DSA expert,[24] for his part, believes that the contractor or the concrete supplier should have asked for explanations and clarifications from the engineer.[25]

June 26, 2007 consensus regarding the Special Specification

[TRANSLATION]

"The requirements of the Special Specification for air content in the concrete mixes were somewhat confusing."

"The requirements of the Special Specification for water-cement ratio and air content in the concrete specified for this project, namely those contained in condition A, did not comply with the specifications of the CSA-A23.1-1967 Standard. Those for condition " C " would have met the requirements of the CSA-A23.1-1967 Standard."

Consequently, the Commission agrees with the consensus of the experts and believes that this confusion created by the Special Specification resulted in the use of low quality concrete, which progressively deteriorated under the influence of freeze-thaw cycles in the presence of de-icing salts.

Findings of the Commission

The Special Specification is difficult to understand: on the one hand, it prescribes Type " A " exposure for all structures, and on the other hand, it calls for different properties for the various components of each structure.

The Special Specification does not comply with the CSA-A23.1-1967 Standard for the concrete in the slab of the abutment.

The combination of these shortcomings led to the progressive deterioration of the concrete during the lifespan of the structure.

In reality, the quality of concrete in the thick slab of the abutment was inadequate with regard to its porosity and its capability to withstand freeze-thaw cycles in the presence of de-icing salts.

5.3.6 Drainage

The drainage of the deck of the de la Concorde overpass does not comply with today's good practice. The overpass is too flat and is not equipped with any drains to channel and evacuate runoff water.

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[24] Exhibit DS-3, p. 1.

[25] Exhibit DS-3, p. 3.

The crosswise slopes prescribed for the deck vary from 0.8% to 1.2%. According to the current CSA-S6-2006 Code, the minimum slope should be at least 2%. The longitudinal slope is 0.4%; in today's current practice, this slope would be considered insufficient. For example, the MTQ's *Manuel de conception des structures*, volume 1, 2004 edition,[26] requires a longitudinal slope of 0.5%. According to current MTQ requirements, the slopes of the deck were too mild to ensure good drainage of the roadway. The CSA-S6-1966 Code did not contain any requirement for drainage.

This fact may have resulted in the accumulation and infiltration of water behind the shoulder of the expansion joint, in particular through a visible pothole in the corner of the southeast abutment, above the collapsed zone. The presence of this pothole is itself the result of the concrete crumbling under the asphalt. This deterioration probably comes from water infiltration between the pavement and the shoulder. Faulty drainage also promoted water seepage through the leaking joint, creating conditions for the deterioration of concrete in a critical part of the structure.

5.4 Construction

5.4.1 Geometry

A review of the documents revealed that there were two sets of drawings for the overpass: one was in the MTQ's possession and was stamped "as built"; the other was held in the personal files of the designer, Mr. Dupaul. After verification, it appeared that Mr. Dupaul's drawings reflected the actual structure more accurately than the MTQ drawings. Mr. Dupaul's drawings were also more recent than the MTQ drawings. Actually, the MTQ had affixed an "as-built" stamp on the latest version of the drawings it had in hand.[27]

The main differences between both sets of drawings were, among others:

- The bearing pad details at the ends of the box-girders,
- The 2½" thick shoulder on each side of the expansion joint,
- The 2" by 3/8" bent steel plates welded to the steel angles on both sides of the expansion joint,
- The U-shaped hanger details,
- The bar marks identifying the bending types,
- The service ducts in the sidewalks, and
- The details of the upper and lower reinforcement layers in the deck slab.

A closer look at the drawings has shown that some minor dimension incompatibilities existed, particularly on the MTQ drawings.

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[26] Exhibit COM-30J, p. 50.

[27] G. Richard, Transcript, 12 April, 2007, p. 229.

Systematic surveying and laser scanning of the structure were performed after the collapse. These operations have shown actual dimensions of the structure were quite consistent with the drawings.

Finding of the Commission
Minor differences between planned and measured dimensions had no effect on the collapse.

5.4.2 Placement of rebars

Observations through openings made in the concrete surfaces of the abutments and during the dissection of pieces stored at the Belgrand site showed that the reinforcing bars were improperly placed. Major rebar placement deficiencies were observed in the bearing support area.

The U-shaped hanger bars were not installed as shown on the drawings (Figure 5.5). The upright parts of the hangers were not installed vertically. Furthermore, at the top of these bars, the hooks designed to transfer the load to the No. 14 bars were inclined, instead of being on the same plane and parallel to these bars, as intended by the designer. On the east side, the hooks are under the No. 14 bars, contributing to the creation of a zone of weakness.

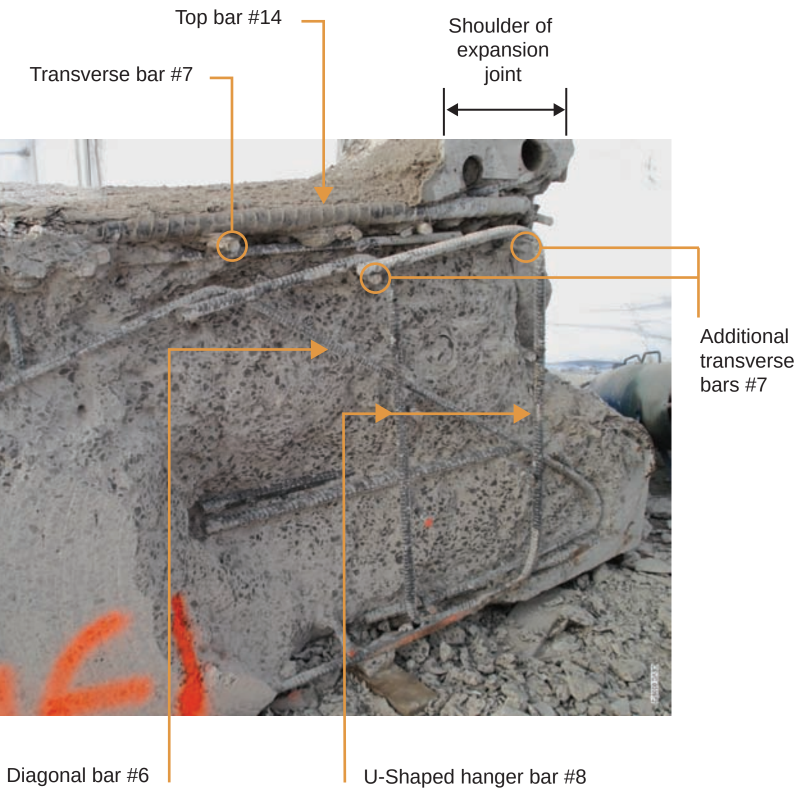

Figure 5.5 Faulty placement of reinforcing bars in the bearing support area[28]

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[28] Exhibit COM-62, p. 51.

The No. 6 diagonal bars were also misplaced. The bend in the corbel area does not go around any transverse bar, as it should according to the drawings. Furthermore, the hook at the top end is lower than that of the U-shaped hangers and well below the No. 14 bars.

The hairpin bars of the corbel are also installed at an angle and they are unevenly spaced, as are the No. 14 bars. The concrete cover over the No. 14 bars is variable because there is considerable sagging along these bars.

June 26, 2007 consensus on construction

[TRANSLATION]

"Steel reinforcement bars in the top part near the end of the cantilever were placed wrong, particularly the No. 8 U-shaped hanger bars and the No. 6 diagonal bars."

5.4.3 Concrete Strength and Air Content

Concrete testing has shown that the compressive strength and the air content were not uniform across the structure. Results indicate that, in some areas, these properties did not meet the values specified at the time of construction.

Compressive strength results, obtained on cores sampled at four out of eleven locations on the abutments, barely reach the minimum strength of 4 000 psi (27.6 MPa) specified at 28 days, and this, after 36 years. The average compressive strength measured across all samples exceeds the specified 28 days compressive strength (31.1 vs. 27.6 MPa). However, taking into account that concrete keeps on gaining strength over the years, the results suggest that the strength at 28 days, back in 1970, was most probably lower than specified.

The air content measured at different sampling locations on the abutments of the de la Concorde overpass is often below the 5% minimum and in one location, higher than the 7% maximum, which were the specified limits for Type " A " exposure. In addition to the variability of the air content measurements, results have clearly shown that the concrete did not have the required characteristics to withstand freeze-thaw cycles in the presence of de-icing salts. All measured air-void spacing factors were above the maximum limit allowed by the current version of Canadian Standard CSA-A23.1.[29]

De-icing salt scaling tests were carried out on concrete samples from the northeast abutment. These tests have confirmed without a doubt that the concrete of the abutments had a very low resistance to de-icing salt scaling and that it disintegrated rapidly when subjected to freeze-thaw cycles in the presence of de-icing salts.

DSA experts attribute the poor quality of in-place concrete to many factors: poor quality control by the supplier at the construction site, poor practice during placement and poor curing. They claim that the specification documents are not the cause.

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[29] It should be pointed out that the control methods on the site did not offer the possibility of measuring the air bubble spacing, a parameter that is even more significant than the total air content when it comes to guaranteeing adequate resistance to freeze-thaw cycles, whether or not de-icing salts are present.

June 26, 2007 consensus on concrete properties

[TRANSLATION]

"Most of the compressive strength values measured on cores now exceed the 28-day specified value; however, some results are low for a healthy 36 year-old concrete."

"The measured air contents are variable. Some values are below 5% and one value is above 7%. Air content measured on hardened concrete may be higher or lower than that measured on fresh concrete."

"The in-place concrete did not have the required properties to avoid deterioration caused by freeze-thaw cycles in the presence of de-icing salts."

The Commission agrees with the consensus reached by the experts. However, the evidence gathered does not allow the Commission to clearly attribute reasons for the low quality concrete to any single action or participant.

Findings of the Commission

The de la Concorde overpass was built using low quality concrete.

For lack of documentation, it is not possible to attribute this to either the supplier of the concrete, or the contractor, or the materials control laboratory.

5.4.4 Waterproofing of the Deck

Observations made on the abutments and during the dissection have clearly shown some serious concrete degradation under the asphalt pavement. The extent of this degradation was such that water could penetrate deep inside the thick slab, down to the failure plane. Adequate waterproofing of the deck surface in the joint area was of prime importance, especially during the 1992 repair work, when large quantities of degraded concrete had to be removed. This finding could not go unnoticed. Even in 1970, the importance of providing some degree of waterproofing of the deck was known and was indeed specified.

At the time the overpass was built, it was unusual to install a high quality membrane and the specifications were in accordance with the practice of the time. The specified waterproofing consisted in the application of a tar-based compound or mastic.[30]

When the asphalt pavement was replaced in 1992, MTQ engineers did not find any trace of this coating.[31] Payment requests and ministry approvals in 1970 indicate that the specified tar compound for waterproofing of the deck was billed to the *Ministère* and paid.[32] If the tar

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[30] Exhibits COM-20A, p. 109 and COM-20C, p. 82.

[31] Exhibit MTQ-1A (amendments included), SR07-01, p. 29.

[32] Exhibit COM-23 p. 318.

compound was indeed applied, it is possible that it was bound to the original asphalt and was removed along with it.

The specifications for the 1992 repairs required the installation of a prefabricated adhesive membrane (today known as a Type 3 membrane), which corresponded to the best practice then in use. This membrane was not found during the investigations, except for a 600 mm wide strip along the expansion joint on the west abutment.[33] In its written brief, dated July 27, 2007, the MTQ mentions the following:

"The state of the concrete after the repair made it very difficult to install a (prefabricated) glued membrane (type 3). The alternative was to apply a liquid membrane. Some pictures show that this was in fact done […]" [34]

Findings of the Commission

The Commission notes that in 1992, the contract required—and rightly so—the application of a prefabricated glued membrane according to the best practices in use at this time for this kind of repair work.

The state of concrete degradation, observed when the asphalt was removed, should have made it very clear that the deck surface needed to be protected by a membrane in order to avoid further degradation of the deck after the repairs.

Realising the state of the slab, the engineer responsible for the project should have asked himself questions about the cause of the damage.

5.5 1992 Repair

The 1992 repair work was described in detail in Chapter 4. In this chapter, the Commission analyses various factors that make this repair a major event in the service life of the overpass.

5.5.1 Scope of Work

The scope of the 1992 repair work clearly exceeded that of work usually required to replace an expansion joint. The notes and photographs submitted as evidence are from the MTQ archives. Normally, these documents should have been destroyed in 2005, according to the file-keeping procedures in use, but, inadvertently, this was not done.[35] Retrieved documents indicate that the de la Concorde overpass was seriously damaged.[36] Actually, the extent of the work on large sections of the abutments was more substantial than anticipated in terms of the amount of damaged concrete which had to be removed and in terms of the lengths of reinforcing bars which were exposed in the process. It is mentioned in the report submitted by the expert group

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[33] Exhibit COM-62-C p. 6.

[34] Appendix 15, Written brief by the Minister of Transportation of Québec, p. 8, translated by the Commission.

[35] Exhibit COM-54B, p. 1.

[36] Exhibits COM-1C, p. 45 and 46 and COM-1C in general.

led by Professor Massicotte that "the Type 3 membrane […] was not installed, given the poor quality of the concrete surface." [37]

According to the Commission's experts, in such conditions, the 1992 repair should have been preceded by an evaluation of the condition of the structure.[38] This operation should have included material sampling, an assessment of the condition of the concrete and, eventually, an evaluation of the load-bearing capacity of the structure.

5.5.2 Joint repair procedures at MTQ

As mentioned in the preceding chapter, the 1992 joint repair should have been done in accordance with the MTQ's internal procedures. These procedures had been in use since 1978.

5.5.3 Evaluation of the 1992 repair and its impact on the service life of the structure

From the review of MTQ's manuals, of Mr. Tiona Sanogo's files (photographs and notes[39]), from the testimonies of Mr. Sanogo and Mr. Simic and from the analysis of the concrete in the area of the joint repair,[40] the following highlights are noted:

- There was no real evaluation of the structure's condition before the repair work was done,
- No structural evaluation was carried out to evaluate the risks of such a repair on the structure,
- The cantilevers were not supported prior to the repair work,
- Heavy equipment and traffic circulated on the overpass during the repairs,
- Reinforcing bars near the expansion joint were found to be damaged, probably during the repairs,[41] and
- Bonding between the old concrete and the repair concrete was weak, probably because there was dirt and excessive water on the repair surface when the new concrete was cast.

The Commission experts have noted that the 1992 repair did not comply with some requirements of the MTQ Standard pertaining to joint replacement (N-2141):

- Exposed reinforcing bars were damaged during the demolition of old concrete,
- The depth of the marks suggests that they were caused by a hydraulic jackhammer rather than a manual pneumatic hammer, which would have developed less energy and therefore, induced less damage to the bars. Moreover, some pictures found in Mr. Sanogo's survey show that the concrete was demolished with a hydraulic jackhammer mounted on a backhoe,

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[37] Exhibit MTQ-1 (amendments included), p. 17.
[38] Exhibit COM-64, p. 54.
[39] Exhibits COM-1C, COM-1C amended and COM-54.
[40] Exhibit COM-62, p. 122 to 124.
[41] Exhibit COM-1D, p. 5 and 6.

- The weak bond observed between original concrete and repair concrete indicates inadequate surface preparation, and

- The waterproofing membrane specified by the standard was not installed on the entire deck surface.

Information obtained during Mr. Sanogo's testimony or found in the 1992 repair file indicates that the overpass deck had to sustain major loads during the joint replacement. According to Mr. Sanogo, two lanes out of three were closed on each side of the overpass.[42] Traffic was thus maintained on one lane in each direction for the full duration of the repair work.

Furthermore, according to Mr. Sanogo's notes, a Caterpillar 235C hydraulic excavator,[43] weighing at least 85,000 pounds, was present on the centre span removing asphalt together with two smaller excavators, one of which was equipped with a hydraulic jackhammer.[44] According to Mr. Sanogo, the hydraulic jackhammer was not used to remove the old expansion joint.[45] However, the marks observed on the bars suggest that the impact energy that created them was greater than that produced by pneumatic manual hammers.

The issue of allowable loads on a structure during repair is not explicitly discussed in the "*Guide d'entretien des structures*" of the MTQ, but the 2110 Special Specification mentions the following:

> *"The contractor must take all necessary measures to make sure that the parts of the bridge that are to remain are not damaged by the demolition and, therefore, the type and weight of the pneumatic hammers that the contractor intends to use must be adapted to the kind of demolition to be performed and must be approved by the site supervisor."*[46]

Contrary to the opinion expressed by the MTQ experts, that the repairs were done "by the book", the experts of the Commission are of the opinion that the 1992 repairs were not done according to the best practice for this kind of work.

Two factors at the time of repair will combine with the design details of the bearing support area, to further weaken the end of the cantilever: first, the removal of considerable amounts of concrete in some places, way beyond the immediate area of the shoulder, and second, the significant exposure of some reinforcing steel bars. The experts do not agree on the effect this could have had on the creation of permanent damage: according to the MTQ experts, there was only a slight reduction in the load-bearing capacity of the cantilevers.[47]

Some of the photographs taken from Mr. Sanogo's files show the misplacement of U-shaped hanger bars. Mr. Sanogo claims he noticed the anomaly when the joints were removed and asked the contractor to add some bars to correct the situation. None of these additional bars were found by the experts of the Commission during the dissection.

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[42] T. Sanogo, Transcript, 2 May 2007, p. 157.
[43] Exhibit COM-54, p. 31.
[44] Exhibit COM-1C, p. 102.
[45] T. Sanogo, Transcript, 2 May 2007, p. 151.
[46] Exhibit COM-30C, supplement 1, p. 4.
[47] Exhibit MTQ-1 (amendments included), p. 17.

With regards to the 1992 repair work, the experts of the Commission testified that more draconian measures should have been taken. Indeed, based on the observations made during the construction, notably the misplacement of reinforcing bars and the advanced degradation of the concrete, the traffic should have been stopped, shoring should have been installed under the cantilevers and the condition of the structure should have been assessed, before authorising the resumption of repairs.

In general, the expert hired by DSA agrees with the findings and the conclusions drawn by the experts of the Commission. He goes further by stating that the 1992 repair work, considering the loads actually applied and without any shoring, induced stresses in the No. 6 diagonal bars that were slightly higher than their calculated load capacity, which may have created permanent damage.[48]

Because the repairs were carried out without shoring to relieve the load applied on the bearing seat, he also points out that the new repair concrete could not play any role in sustaining the dead loads after the repairs were completed. He is of the opinion that shoring should have been provided during the repair work. According to him, the structure has deteriorated faster in the years following the 1992-1993 repair work.

The report submitted by the MTQ experts states that the 1992 repairs were executed according to standard practice.[49] The part of this report about the 1992 repair provides a factual summary of the work that was done, without demonstrating that the work was compliant with the N-2141 standard.

The conclusion of the expertise report submitted by the MTQ includes the following statement:

> [TRANSLATION] *"The method employed for replacing the joint in 1992 was in accordance with standard practice at that time. The extent of the areas where concrete was removed shows the high level of degradation of the concrete near the end of the cantilever. The effectiveness of the No. 14 bars could have been affected by this degradation, which probably already reduced the bonding effectiveness of the* No. *14 bars. The removal of the joint has not contributed much to the progression of the failure plane, which was probably already present inside the slab without being visible from the outside. During localised demolition work, such as performed in 1992, it was practically impossible to detect the presence of failure planes."*[50]

For their part, the experts of the Commission conclude:

> [TRANSLATION] "*Although it may have aggravated the situation, the joint repair is not one of the principal causes of the collapse of the de la Concorde overpass. Despite the lack of rigour with which it was carried out, the joint replacement did not create the failure plane or the concrete degradation around it. Indeed, a study of photographs taken in 1992 by MTQ personnel before the expansion joint was repaired clearly shows the presence of shear cracks on the lateral surface of the structure.*

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[48] Exhibit DS-1, p. 28.

[49] Exhibit MTQ-1 (amendments included), p. 103.

[50] Exhibit MTQ-1 (amendments included), p. 103, translated by the Commission.

> *It must however be mentioned that the 1992 repair should have been an opportunity to assess the extent of degradation of the concrete and correct the faulty placement of reinforcing bars near the joint and the absence of adequate anchorage of the U-shaped hangers.*[51]

Findings of the Commission

In the opinion of the Commission, the original scope of work which included limited replacement of concrete around the expansion joints did not require any shoring of the abutments.

However, in fact, the extent of the repair work done in 1992 greatly exceeded that of a simple expansion joint replacement.

The extent of the work and the degree of concrete degradation should have led to an in-depth investigation of the structure and characterisation of the concrete to determine the cause of this deterioration.

Given the actual extent of the work and the particular character of the overpass, the MTQ should have provided shoring of the structure during the repairs, especially when it had realised the state of deterioration of the concrete, the large quantities of concrete having to be removed, therefore exposing several reinforcing bars near the seat of the cantilever, sometimes over considerable distances from the joint.

Moreover, these repairs should have enabled the MTQ engineers to notice that some reinforcing bars were not placed in accordance with the drawings and that the U-shaped hangers were not connected to the No. 14 bars.

The MTQ should have carried out a proper evaluation of the condition of the structure at the time the repairs.

In all probability, the procedure used in 1992 has contributed in accelerating the propagation of the crack under the No. 14 bars into the mass of the cantilever.

5.6 Inspections performed by the MTQ

MTQ witnesses and experts from the Commission and other parties testified at length about the MTQ's manuals and the inspections performed during the service life of the structure.

During a preliminary conference held on June 26, 2007, the experts reached a fairly broad consensus on this point. The content of this consensus is given below:

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[51] Exhibit COM-62, p. 196, translated by the Commission.

June 26, 2007 Consensus Regarding the Inspection and Maintenance of the de la Concorde Overpass

[TRANSLATION]

"MTQ inspection manuals are of comparable quality to similar documents used in North America."

"The records on this structure were missing the real "as-built" drawings, the maintenance file and the specified and in-place material properties."

"Some requirements of the MTQ inspection manuals were not entirely met regarding:

i) The values assigned to some of the ratings

ii) The detailed content of inspection reports

iii) The frequency intervals prescribed by the manual for maintenance activities."

"Efflorescence stains are a sign that water is flowing through the cracks."

However, it must be mentioned that the experts of the Commission went beyond this consensus with respect to (1) MTQ manuals, (2) file keeping and (3) inspections performed by MTQ representatives during the service life of the structure.

5.6.1 Inspection Manuals

The experts of the Commission have emphasised that a certain number of fundamental objectives relative to inspections are not defined in the MTQ's *Manuel d'inspection des structures*, while they are in manuals published by other jurisdictions. The main elements highlighted are listed below.[52]

- The importance of diagnosing the cause of a reported damage. The cause of problems and not only their symptoms must be addressed. The *AASHTO Manual for Condition Evaluation of Bridges* is explicit on this aspect:

  > *"Inspections should not be confined to searching for defects which may exist, but should include anticipating incipient problems. Thus, inspections are performed in order to develop both preventive as well as corrective maintenance programs."* [53]

- The importance of diagnosing not only the structural problems, but also those affecting the materials, especially the concrete, and the importance of evaluating the impact of these problems on the current and future performance of a structure.

- The importance for an inspection system to be adaptable to different types of structures under various conditions. For example, in the case of the de la Concorde overpass, the

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[52] A. Vaysburd, Transcript, 11 July 2007.

[53] A. Vaysburd, Transcript, 11 July 2007, p. 203.

particular character of the structure should have been taken into account. Regarding this, the AASHTO mentions:

> "The inspection plan and technique should consider unique structural characteristics and special problems [...]"[54]

- The need to better define the scope of a special inspection and that of a condition evaluation of a bridge. The actions of the inspectors must be clearly specified in the manuals for these two types of evaluation.

It has been established that for MTQ, the activities closest to the condition evaluation of a structure are the damage report and the condition evaluation of a slab.[55] In the bridge management system currently in use at MTQ, these latter surveys are only undertaken when it has already been decided to repair a structure, to precisely establish what has to be repaired.[56, 57, 58]

Moreover, the experts of the Commission have brought to light some concerns regarding the evolution of the manuals:

- Over the years, the crack evaluation criteria have become more permissive.[59] For example, the maximum width of a "medium-sized" crack went from 0.35 mm in 1996 to 0.80 mm in 2005.

- As for the Material Evaluation Indices (CEM) and the Behaviour Evaluation Indices (CEC), the MTQ's *Manuel d'inspection des structures* recognises the difference in severity between a shear crack, associated with a brittle failure mode, and a flexure crack, associated with a ductile failure mode.[60] On the other hand, the most recent criteria published by the MTQ in its internal Info-structure bulletin no. 2007-06 dated April 13, 2007[61] practically eliminate this difference. Shear and flexure cracks are evaluated the same way when they are narrower than 0.8 mm.[62] This procedure was questioned by Professor Mitchell in the case of thick slabs without shear reinforcement.[63] Moreover, since April 2007, a shear crack wider than 0.75 mm, that would have been given a rating of "2" (deficient) before, now corresponds to a rating of "5" (good).[64]

- In the most recent versions of the *Manuel d'inspection des structures*, the suggested maximum time intervals before taking corrective actions, which vary according to the CEC or CEM indices, have doubled.[65] These changes appear difficult to justify, considering that the degree of obsolescence of the structures is constantly increasing.

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[54] A. Vaysburd, Transcript, 11 July 2007, p. 206.
[55] Exhibit COM-70, p. 85 to 88.
[56] G. Bossé, Transcript, 14 May 2007, p. 51.
[57] C. Mercier, Transcript, 15 May 2007, p. 47 and 48.
[58] G. Richard, Transcript, 16 May 2007, p. 123 and124.
[59] Exhibit COM-70, p. 65 and 66.
[60] Exhibit COM-30D, p. 256 to 274.
[61] Exhibit COM-52C.
[62] Exhibit COM-52C, p. 3.
[63] D. Mitchell, Transcript, 10 July 2007, p. 41 and 42: "*[…] clearly, the 0.8 mm crack width limit for thick slabs without shear reinforcement is way too high and should be immediately reduced.*"
[64] Exhibit COM-52C, p. 4 and 5.
[65] Exhibit COM-64, p. 51.

Findings of the Commission

The Commission notes, in agreement with the MTQ's experts and its own experts, that the manuals in use at the MTQ are generally of good quality and can be compared to those published by other North American jurisdictions.

However, the Commission is of the opinion that MTQ manuals should be improved regarding certain specific aspects. They should mention fundamental objectives that are found in the manuals of other North American jurisdictions, such as the importance of adapting the inspection system to different types of structures, the need to clearly define the scope of a special inspection and the importance of seeking the causes of reported damages.

The Commission is also of the opinion that MTQ manuals should be revised to re-establish the stricter criteria where these have become less stringent in recent years. This is the case, for example, of crack width assessment, particularly for shear cracks in unreinforced concrete, of the rating of cracks (CEM and CEC indices) according to crack widths and of the time intervals allowed for undertaking corrective measures.

The Commission also notes that MTQ manuals are not strictly followed by its personnel.

5.6.2 File Keeping

The file kept at the *Direction territoriale de Laval-Mille-Îles* was incomplete. The following important pieces of information were missing:

- The original "as-built" drawings and the results of quality control tests done during the construction of the overpass;
- The documents related to the maintenance of the structure, particularly those pertaining to the 1992 repairs;
- A formal report on the special inspection performed in 2004 by the *Direction des structures*.

Also, the file does not mention the special character of the overpass. According to Mr. Richard's testimony, this type of structure was no longer built after 1972.[66]

According to the "*Rapport sur les causes techniques de l'effondrement du pont d'étagement de la Concorde*" submitted June 1st 2007 by the *Direction des structures* of the MTQ,[67] this type of structure had serious deficiencies:[68]

[TRANSLATION]

1. *"The presence of two bearing seats above the central span*
2. *The presence of deck joints on the same axis as the bearing supports*

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[66] G. Richard, Transcript, 13 July 2007, p. 169.

[67] Exhibit MTQ-2.

[68] Exhibit MTQ-2, p. 5.

3. *The difficulty of inspecting the details of the bearing supports and their maintenance*
4. *The difficulty of accessing the bearing supports during repairs*
4. *The absence of structural redundancy in the event of a failure (isostatic structure*)
6. *The presence of narrow box-girders that cannot be inspected from the inside."*

After mentioning that he would have written a report about his observations if he had been in charge of the 1992 repairs, Mr. Ellis, expert for the MTQ, emphasised the importance of proper file keeping:

"And I think one of the key findings here is that all of the observations from that nineteen ninety-two (1992) repair work were lost or they were not put on a file or something and, as I mentioned, file keeping, record keeping is (a) critical recommendation."[69]

The experts of the Commission agree.

Findings of the Commission

The absence of a complete file accessible to the MTQ inspectors (those from the *direction territoriale* and those from the *Direction des structures*) was a key factor that contributed to the lack of follow-up on the progressive deterioration of the overpass.

The files kept at the *direction territoriale* and at the *Direction des structures* should have included a "red-flag" warning about the particular character of the structure and the need for in-depth inspections.

5.6.3 Inspections Performed During the Service Life of the Overpass

The experts of the Commission have meticulously analysed the inspection reports kept in the de la Concorde overpass files. Overall, 23 routine, general and special inspection reports were produced between 1977 and 2005. Generally, over this time span, the frequency intervals specified in the manuals for the various inspection types were adhered to.

However, the experts noted some non-compliant elements in the reports as well as a lack of care in the way the information was gathered. The following issues were identified:

- The location and the extent of observed damages were not documented according to the requirements of the *Manuel d'inspection des structures* in use (almost no quantitative information):
    - Absence of sketches;
    - Few or no comments;
    - Photographs sometimes included.

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[69] R. Ellis, Transcript, 16 July 2007, p. 138.

- The description of the structure in the reports has changed repeatedly over the years:
    - Description and classification of the cantilever portion of the abutments (variously termed a single- or a triple-span bridge);
    - Description of the abutments (normal abutment, or combination abutment-inclined pier);
    - Description of the diaphragms (position, number).
- The bearing seats were always regarded as secondary elements which is true when a span rests on typical massive abutments. However, in the present case of in-span supports, they should have been considered as principal elements.
- The frequent use of inaccurate or inappropriate terms has negatively affected the quality and accuracy of the reports. For example:
    - In 1999, despite a "4" CECS rating, which corresponds to an "acceptable" rating according to the Manual, the general condition of the structure was qualified as "good".
    - After the routine inspection of June 10, 2004 where the general condition of the structure was rated as "good", a request for assistance was sent to the *Direction des structures* on June 17 2004, in which the engineer reported "worrying" signs of deterioration.
- The damage reported during the 1995 inspection should have led to corrective measures within the next four years, according to the intervals suggested at the time by the *Manuel d'inspection des structures*. Subsequent general inspection reports (1999, 2002, 2005) also called for such measures, but within shorter delays. After the 1992 repair work, no corrective maintenance was done on the de la Concorde overpass, except for the removal of loose pieces of concrete on the underside of the deck.
- The damage reported during the 1999 general inspection should have led to the condition evaluation of the slab within the next four years, according to the intervals suggested then by the *Manuel d'entretien des structures*. No condition evaluation of the slab was ever performed on the de la Concorde overpass.
- No preventive maintenance intervention was ever planned in the inspection reports.

Findings of the Commission

The inspection reports filed by the MTQ personnel show significant deficiencies and are not compliant with the manuals.

The inspection reports exhibit lack of care and lack of precision.

These deficiencies, along with inadequate record-keeping, made it difficult to accurately monitor the evolution of the structure's condition.

5.7 Special inspection of 2004

The Special inspection carried out on July 15, 2004 by Christian Mercier, an engineer from the *Direction des structures*, is described in detail in Chapter 4. It was analysed and commented on by the experts during the Commission hearings. Different opinions were expressed with regards to the significance of this inspection and the role it should or might have played in the diagnosis of the overpass's deficiencies in 2004.

It should be recalled that the entire inspection was carried out in two or two and a half hours,[70] and that a "hands-on" inspection was performed with a cherry-picker on the north and south faces of the east abutment only.[71]

In his testimony about the peculiar character of the structure, Mr. Mercier said:

> [TRANSLATION] *"Well, I knew (...) that we were not building this type of structure anymore because it was very difficult to inspect and maintain; it was causing problems."*[72]

In his letter, Mr. Bossé referred to two major problems: 1) a major deterioration of the bearing seats and 2) the presence of wide shear cracks on the cantilevers of the abutments. The experts of the Commission noted that, in his letter of March 1, 2005 addressed to Mr. Claude Leclerc and transmitted to the *direction territoriale* on March 3,[73] Mr. Mercier completely eluded the crack issue which worried Mr. Bossé.[74]

Indeed, Mr. Mercier mentioned in his letter that it was not necessary to carry out a more detailed analysis and that the deficiencies were a consequence of the leaking expansion joints.[75] He then recommended:

> [TRANSLATION] *"[...] to await the manifestation of more significant deterioration in the seat areas (active cracking or beam subsidence at the support) or underneath the deck before carrying out the repair work described hereafter."*[76]

According to the experts of the Commission, the request for assistance sent by the *direction territoriale* and the on-site observations should have triggered a condition evaluation of the structure, instead of the recommendation from the *Direction des structures* to the *direction territoriale* quoted above.

To engineer Mercier's credit, the experts of the Commission consider that he was not provided with a complete file on the overpass at the time of the special inspection in 2004. In his testimony, Professor Jacques Marchand was very clear on this point.[77] In particular, there were neither data nor observations relating to the 1992 repairs, nor any quantitative information on the progression of observed disorders (location and size of the cracks over the years). Without the possibility of comparing the deficiencies at the time of his inspection to those observed in

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[70] C. Mercier, Transcript, 15 May 2007, p. 92.
[71] C. Mercier, Transcript, 14 May 2007, p. 244 to 246.
[72] C. Mercier, Transcript, 14 May 2007, p. 255 and 256, translated by the Commission.
[73] Exhibit COM-31B, p. 178.
[74] Exhibit COM-64, p. 48.
[75] Exhibit COM-31B, p. 177.
[76] Exhibit COM-31B, p. 177, translated by the Commission.
[77] J. Marchand, Transcript, 5 July 2007, p. 87 and 88.

1992, it was impossible for him to appreciate the evolution of the problems, such as depicted in the photographical montage of Exhibit COM-68D (Figure 5.6).

Figure 5.6 Views of the east cantilever, from the south side of the de la Concorde overpass, showing the evolution of cracks in the bearing support area[78]

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[78] Exhibits COM-69, p. 180 and COM-68D.

According to the experts of the Commission, a condition evaluation of the structure should have been conducted on several occasions:[79]

- in 1992, prior to the repairs associated with the replacement of the expansion joint;
- after the 1999, 2002 and 2005 general inspections, based on the results thereof;
- after the 2004 Special inspection, based on the observations.

The DSA expert made the following remarks:[80]

- The presence of a great quantity of efflorescence on the side faces was an obvious sign of degradation;
- Although Mr. Mercier indicated in his testimony that the maximum opening of the cracks was 0.5 mm, the crack photographed on the northern face of the western abutment seemed wider; yet, no quantitative information on this crack was available, thus leaving some doubt;
- The signs of deterioration were obvious;
- The external crack was a forewarning of the collapse.

He concluded that the *Direction des structures* should have been more precise in its exchanges with the *direction territoriale* and that the latter was lax in the subsequent monitoring of the cracks.

All these indices pointed towards the need for carrying out an evaluation of the load-carrying capacity of the structure in 2004. The results of such an analysis would have led more rapidly to remedial actions on the overpass.

The position of the MTQ and its experts is diametrically opposed to that of the Commission's and DSA's.

With respect to the condition of the overpass in 2004, the experts for the MTQ state in their report that:

> [TRANSLATION] *"The bridge was inspected regularly since 1977 and the latest general inspection took place in 2005. A special inspection was also carried out in 2004. According to the inspection reports, the bridge was in an acceptable condition. It was however recognised that repair works needed to be planned to fix the beam seats and deteriorated concrete in the areas adjacent to the deck joints."*[81]

To support their statement, the authors refer to a series of photographs taken in 2004. These photographs show some diagonal cracks from which large quantities of efflorescence are

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[79] Exhibit COM-64, p. 54 to 56.

[80] Exhibit DS-1, p. 31 to 34.

[81] Exhibit MTQ-1 (amendments included), p. 20.

emanating on the north face of the east abutment. They do not acknowledge that these were shear cracks.

Moreover, and this is a fundamental aspect of the MTQ's position, they assert in their report that there was no connection between the external cracks observed in 2004 and the internal cracks at the origin of the collapse:

> [TRANSLATION] *"The presence of cracks on the side faces of the de la Concorde bridge slabs […] was due to an independent phenomenon, and was not a manifestation of the internal cracking plane having caused the collapse […]. The first signs of structural disorder appeared in the very last moments before the collapse with the emergence of a long crack in the lower portion of the slab […]."*[82]

In his testimony, the principal expert for MTQ added:

> [TRANSLATION] *"the evidence tends to show in a […] possible but probable way, with a lot of certainty in fact, that there is no connection between the surface cracks which were identified as shear cracks and the fracture plane which was happening inside."*[83]

Conversely, the experts for the Commission and for DSA are categorical: the cracks observed on the side walls of the two abutments were shear cracks. The 2004 inspection should have led to a condition evaluation of the structure, including an analysis of the condition of the materials and an evaluation of the load-carrying capacity. These analyses could have led to a diagnosis of the condition of the bridge and its components, and induced the MTQ to take appropriate actions, which perhaps might have prevented the collapse in 2006.

Finally, it is important to stress that one of the MTQ's experts, Dr. Ellis, admitted that it would have been more prudent to carry out a "hands-on" inspection on the four side faces of both abutments if access was possible.[84]

Findings of the Commission

The special inspection of 2004 does not fulfill the requirements set out in the MTQ manuals and the report, which actually took the form of a letter, was produced only eight months later.

This inspection was intended to reassure the engineer at the *direction territoriale* who had expressed concerns; it should have led to a condition evaluation of the structure including an evaluation of the load-carrying capacity and an evaluation of the condition of the materials.

During the life of the de la Concorde overpass, the MTQ neither required, nor carried out any such condition evaluation. Had a condition evaluation been conducted when any of the opportunities arose, it is likely that the nature of the problems of the de la Concorde overpass would have been detected and therefore, appropriate remedial actions would certainly have been taken.

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[82] Exhibit MTQ-1 (amendments included), p. 100.

[83] B. Massicotte, Transcript, 17 July 2007, p. 96.

[84] R. Ellis, Transcript, 16 July 2007, p. 105 and 106.

5.8 Laboratory load tests

The Commission mandated its experts to carry out load test on prototypes of the cantilevers, in order to study their structural behaviour in detail. These tests were carried out in a laboratory at McGill University. The MTQ's experts carried out similar laboratory experiments at École Polytechnique de Montréal. The detailed results of these experimental studies are reported in the exhibits filed during the hearings.[85]

Together with the load-carrying capacity calculations described in section 5.3.3 and the FEM (finite-element method) numerical simulations addressed in section 5.9, these experiments provide a sound basis for identifying the causes of the de la Concorde overpass collapse.

5.8.1 Similarities and differences between the two series of tests

Both investigations were carried out on 4-ft (1.2 m) wide cantilever strips and sought to evaluate the influence of the misplacement of the reinforcing steel in the beam seat area on the load-carrying capacity of the structure. In each case, two prototype cantilevers were tested: on the one hand, the "as-designed" version, based on the drawings of the overpass[86] and, on the other hand, the "as-built" version, based on surveys of the reinforcing bars carried out on-site after the collapse, or at the Belgrand Street site in Laval, where the parts were kept after dismantling of the bridge.

Prior to the experiments, the experts agreed on the testing loads, which were selected to be representative of the loading conditions on the second bearing pad starting from the abutment side face. The dead and live loads on the support were established to be 350 kN and 90-100 kN respectively, the latter corresponding approximately to the H20-S16 vehicle design load, whose weight amounts to 32 tons.

The investigations carried out on parts of the overpass revealed that the structure had suffered serious concrete degradation in certain areas. The experiments were carried out on pristine concrete prototypes having suffered no deterioration.

In the tests ordered by the Commission, the load corresponding to the dead weight of the deck was maintained throughout the experiment and the live load was superimposed as a cyclic load. The "as-built" prototype replicated the existence of some additional bars, not shown in the drawings, which were added by the contractor to support the upper rebar prior to concreting.

Furthermore, the influence of repair works associated with the 1992 expansion joint replacement was evaluated after having subjected the prototype to a number of loading cycles representative of what the bridge had carried prior to 1992.[87] At that point, the cyclic tests were interrupted and, while maintaining the dead load corresponding to the weight of the central span, the concrete in the area adjacent to the joint was demolished, the new expansion joint was installed and new concrete was placed in the joint area. The joint replacement was simulated in the laboratory according to the information the experts had at the time of the tests.

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[85] Exhibits COM-62, COM-62H, MTQ-1 and MTQ-1A.

[86] Exhibit COM-19, p. 15.

[87] Exhibit COM-62, p. 139.

In the tests ordered by MTQ, an "as-designed" prototype (identified as (1) in Table 5.1) and an "as-built" prototype (identified as (2) in Table 5.1) were first loaded in steps up to failure. A third prototype (identified as (3) in Table 5.1), prepared with the "as-built" reinforcement details of the overpass, was then subjected to a thermal conditioning intended to simulate the heating of the thick slab surface under the effect of solar radiation or the installation of the asphalt pavement. Subsequently, this third prototype was subjected to cyclic loadings and then loaded up to failure.

5.8.2 Test results

Table 5.1 summarises the main results obtained during the loading experiments.

Table 5.1 Summary of principal laboratory loading test results

	Commission Experiments **McGill University**[88]	**MTQ Experiments** **École Polytechnique**[89]
"As-designed" prototype	Cyclic test	Loading to failure
Number of cycles at failure	58 700 cycles	Static test to failure
Recorded load at failure	810 kN	900 kN (1)
Theoretical load at failure - (CSA-S6-2006 Code calculation method)	839 kN	850 kN
Theoretical load at failure – FEM (FEM calculations - see 5.10)	900 kN	-
"As-built" prototype		Static test to failure
Recorded load at failure	No static test	1 050 kN (2)
	Cyclic test	Cyclic test
Number of cycles at failure	18 700 cycles up to joint replacement 65 200 cycles total	30 000 cycles then load increased up to failure
Recorded load at failure	**1 075** kN	**1 070** kN (3)
Theoretical load at failure - (CSA-S6-2006 Code calculation method)	964 kN	-
Theoretical load at failure – FEM (FEM calculations - see 5.10)	950 kN	925 kN

It can be observed that the results obtained in both investigations are quite similar, taking into account the minor differences between the test protocols, the steel reinforcing bar sizes and strengths, and the concrete strength.

In all cases, failure occurred in an explosive and sudden way, without any warning. The failure plane was found to be similar to the one observed on site after the collapse of the de la Concorde

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[88] Exhibits COM-62 and COM-62H.

[89] Exhibits MTQ-1A (amendments included).

overpass (see Figure 5.7). In the upper part of the slab, a horizontal crack extends up to the end of the hooks of the hangers and diagonal bars. The crack then suddenly becomes inclined as a shear crack, traveling downwards through the slab, then finally turns horizontal along the lower rebars, splitting the cantilever up to the junction with the inclined wall.

Figure 5.7 Failure of the "as-built" cantilever during the laboratory loading tests at McGill University[90]

5.8.3 Comments on the results

Overall, it is observed that the ultimate loads and the cracking modes of the various tested specimens were similar. As compared to the quasi-static loading to failure, the cyclic loading does not influence the ultimate load to a significant degree. It appears clearly that the damage related to the cyclic character of the live load (and thus any consideration of fatigue of materials[91]) is of secondary importance, even negligible.

The fact that the failure loads recorded for the "as-built" test specimens — with the bearing support reinforcement misplaced — were higher than those of the "as-designed" specimens is obviously intriguing. According to the Commission's experts, this apparent incongruity is explained partly by the presence of additional vertical bars that were not shown on the construction drawings. These bars increase the shear strength of the cantilever by intercepting some of the diagonal cracks.[92] Moreover, in the "as-designed" prototype, the congestion of rebars located in the plane of the No. 14 bars reduces the bond between the reinforcement and the concrete in the upper portion of the beam seat, and therefore weakens this zone prematurely.[93] In the "as-built" prototype, there is more concrete in that area and the concrete embedment is better, resulting in more effective rebar bonding, in the case of sound concrete.

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[90] Exhibit COM-69, p. 152.
[91] Exhibit DS-1, p. 16. According to Professor Légeron, "fatigue is not a dominant factor in the way the structure failed."
[92] Exhibit COM-62, p. 167.
[93] D. Mitchell, Transcript, 9 July 2007, p. 38, 59 and 72.

Replacement of the expansion joint without relieving the cantilever from the dead load of the central span, has had no apparent effect, under laboratory test conditions. However, during his testimony, Professor Mitchell stressed that the repair simulated in the laboratory had been performed with great care, using light handheld hammers and without any live load being applied. Actual conditions during the 1992 repairs, which he learned of after the laboratory experiments were completed, would have been rather "brutal".[94] Moreover, in 1992, the length over which the upper rebars were actually exposed largely exceeded those simulated in the laboratory.

Findings of the Commission

The laboratory specimens failed under high loads, exhibiting a safety factor sufficient to resist the loads that were acting on the bridge when it collapsed. However, the specimens were new and made with sound concrete.

Therefore, the concrete deterioration, which was clearly evidenced by the work of the experts, had a considerable and decisive effect on the load-carrying capacity of the bridge and on its level of safety.

The reinforcement details of the abutment created a plane of weakness under the No. 14 bars, which promoted the development of the cracks involved in the collapse. This observation is supported experimentally by the results obtained with both the "as-designed" and "as-built" prototypes.

The shear failure is explosive and sudden and is not preceded by any notable deformation. The only noticeable signs before failure are fine inclined cracks.[95] It is thus necessary to be extremely careful and to pay special attention when evaluating this type of cracking in a structure without shear reinforcement.

The design codes must include provisions to make sure that such brittle failure modes are avoided.

5.9 Structural Analysis

Several theoretical analyses of the behaviour of the cantilever portion of the abutment have been presented to the Commission.

5.9.1 Analysis of the structure's behaviour under dead and live loads

In some cases,[96,97] the experts used non-linear analyses, which allow numerical modeling of the load distribution inside the structure by taking into account the non-linear stress-strain relationships of the different materials and the properties of the materials as influenced by

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[94] D. Mitchell, Transcript, 9 July 2007, p. 77; 10 July 2007, p. 89 and 90.

[95] During the laboratory loading tests, tilted cracks with a width of 0.5 to 0.8 mm were noted just prior to the failure condition.

[96] Exhibit COM-62I

[97] Exhibits MTQ-1 (amendments included) and MTQ-1A (amendments included).

the cracking and the degradation of the concrete. One expert[98] presented a more theoretical analysis of a slice of the cantilever assuming the materials were homogeneous and elastic.

In each of these cases, regardless of the respective merit of each approach, these analyses aimed at corroborating manual calculations evaluating the failure loads (for example by the “strut and tie” method). They were also performed so as to reproduce experimental results obtained in the laboratory and simulate other effects that can be reproduced faster and more economically than in a laboratory, such as the effects of shrinkage and degradation of the concrete.

Non-linear analyses have accurately reproduced the laboratory test results for both series of tests and for “as-designed” as well as the “as-built” specimens, as shown by the values of Table 5.1. It should also be noted that the theoretical models provide good predictions of the observed crack patterns and position of the failure plane.

5.9.2 Analysis involving degradation

Non-linear analysis goes further than laboratory tests by allowing the modeling of the presence of degradation in the upper portion of the cantilever, observed through openings made on the surface of the abutments and during the dissection operations.

Professor Mitchell has modeled a progressive degradation in the zone of weakness located under the No. 14 bars by introducing elements along the path of the failure plane. These elements are at their full width when the concrete is sound and are reduced to zero when degradation is at 100%. These results have shown that following progressive deterioration of the concrete, the overpass could collapse under very low live loads, even under its own weight. For example, failure is obtained with a load on the bearing support corresponding to the dead load plus nominal live load (a total load of 450 kN) when the degradation level reaches 80%.

The results obtained numerically by the MTQ’s experts also show a marked reduction in the load-carrying capacity when concrete degradation under the No. 14 bars is introduced in the analysis. According to Professor Massicotte:

> [Translation] *“The analyses presented and the laboratory tests done in parallel demonstrate that the design details allowed the development of the required strength. However, concrete deterioration around the end of the No. 14 bars, as observed on the cantilever slabs, negatively affects the anchoring of the No. 14 bars leading to a strength loss in the cantilever slab.”*[99]

5.9.3 Analysis involving replacement of the joint

The replacement of the expansion joint in 1992 was also modeled by removing the concrete around the No. 14 bars across the width of the shoulder. As was observed in the laboratory results, the numerical modeling of the joint replacement did not affect the strength of the

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[98] Exhibit DS-1, p. 60 to 66.

[99] Exhibit MTQ-1 (amendments included), p. 91.

cantilever. It should however be emphasised that during the 1992 repair work, the exposed length of the No. 14 bars was greater than that assumed for modeling purposes.

5.9.4 Thermal analyses

5.9.4.1 Main Report by the MTQ Experts

In his report, Professor Massicotte also presented preliminary analyses aimed at modeling the thermal behaviour of the structure when subjected to solar radiation and hot asphalt application.[100]

This study is based on the assumption that, under certain conditions, the presence of stresses induced by a temperature gradient in the concrete could create a shear plane parallel to the surface of the thick slab. When the concrete surface is heated, it expands relative to the core of the slab, which remains cooler. This surface expansion can be caused by solar radiation or by the application of an asphalt layer.

Preliminary thermal analyses were carried out using the finite elements method. For laboratory testing, solar radiation was simulated on the third prototype by means of infra-red lamps.

According to Professor Massicotte, thermal analyses, laboratory tests and field observations, especially on the de Blois overpass, suggest that cracking was of thermal origin.[101]

The experts of the Commission are of the opinion that it is difficult to pinpoint a particular mechanism for the origin of cracking. They list the following possible causes:[102]

- Presence of a weak zone above the No. 8 U-shaped hangers and the No. 6 diagonal bars;
- High bond stresses of the No. 14 bars in the beam seat area;
- Concrete degradation caused by freeze-thaw cycles in the presence of de-icing salts;
- Concrete shrinkage at the level of the No. 14 bars;
- Thermal effects induced by the heat of hydration of concrete, solar radiation and/or application of hot asphalt;
- Repeated impact on the expansion joint caused by vehicles and snow removal equipment.

5.9.4.2 Additional Thermal Analyses

In his expert report on the additional dissection of blocks CNE1 and CSE4,[103] Professor Massicotte referred to recent thermal analyses to support his opinion that the cracking apparent on the lateral faces of the cantilevers was not linked to the internal failure plane that led to the

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[100] Exhibits MTQ-1 (amendments included), p. 44 to 60 and MTQ-1A (amendments included) SR07-05.

[101] Exhibit MTQ-1 (amendments included), p. 95.

[102] D. Mitchell, Transcript, 10 July 2007, p. 84 and following; Exhibit COM-62, p. 192.

[103] Exhibit MTQ-9, p. 44.

collapse of the structure. On September 4, 2007, after a Commission meeting at the Belgrand site, the commissioners requested a report from Professor Massicotte on these recent thermal analyses. On September 10, 2007, Professor Massicotte submitted his report on Additional Thermal Analyses of the de la Concorde Overpass. The document is identified by its authors as an "interim" report and conclusions are presented as being "preliminary".

Professor Frédéric Légeron, expert for DSA, submitted his comments on the additional thermal analyses performed by Professor Massicotte on September 12, 2007. The following is an excerpt from Professor Légeron's comments:

> *[TRANSLATION]"The crack patterns predicted by the MTQ analyses are based on a very unfavourable modeling of the structure and very severe, even unrealistic, thermal loadings.*
>
> *Despite these very severe assumptions, the predicted cracking represents only a small part of the cracks observed on the lateral faces of the structure and predicts numerous other cracks where none were observed, on the southeast abutment. At best, these same calculations could only explain radial cracking around a duct on the northeast sidewalk and even then, only partially. This radial crack has not been observed on the southeast abutment, and it is therefore unrelated to the failure.*
>
> *It is my opinion that a more representative modeling of the structure, with more realistic thermal gradients, would lead to much lower stresses that would not explain in any way the presence of cracking on the lateral faces."*[104]

Findings of the Commission

The report on thermal analyses submitted by Professor Massicotte is a preliminary document in which missing information does not allow for a more in-depth analysis that could better do justice to the work. Missing amongst other data, are the dimensions and shape of the sidewalk in the model which do not match the actual geometry.

Given the preliminary nature of the conclusions, they cannot be retained for analysis by the Commission.

The Commission notes however that thermal effects may be one of numerous possible causes at the origin of the internal cracking, but that thermal effects probably do not stand out among other possible causes.

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[104] Exhibit DS-6, p. 9.

5.10 Additional dissection and coring

5.10.1 Additional Dissection Operations

Two questions pertaining to the dissection operations were raised during the hearings of the Commission:

- Is there continuity between the inclined cracks visible on the four lateral surfaces of the cantilevers and the internal plane of weakness that led to the collapse?
- Were the cracks present before the collapse or were there certain cracks caused during demolition and transportation of the pieces to the Belgrand storage site?

In order for the experts of the Commission and of the participants to perform the observations that would allow them to reach a consensus about these questions, the Commission decided to carry out additional dissection and coring operations.

The Commission asked all experts to agree on an experimental protocol for the execution of these additional investigations. After this was done, blocks CNE1 and CSE4 were sliced in August 2007, in the presence of the experts from the Commission, the MTQ and DSA, who had expressed an interest in attending. The expert reports about these additional dissection and coring operations are provided in Appendix 14 of this report.

The Commissioners then visited the storage site in Laval, together with all the experts and representatives of the participants, in order to listen to their comments and examine the dissected pieces themselves.

5.10.2 Continuity of cracks

Observations made on the slices taken from block CSE4 showed the presence of, not only one, but of a series of internal planes of cracking, one above the other, near the lateral surface.

Observations made on the slices taken from block CNE1 from the northeast abutment, showed cracks of the same nature as those seen on the southeast side (Figure 5.8) and that this portion, although less loaded because of the skew in the structure, was liable to collapse at some point in time.

Figure 5.8 Transverse partial cuts of the east abutment performed during the additional dissection operations of August 2007 showing the northeast corner (top) and southeast corner (bottom)[105]

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[105] The photo is rotated to show the piece in the orientation it was in during the life of the structure; note the row of No. 14 bars underneath the sidewalk, and the three service ducts in the sidewalk.

Observations made on the surfaces of the slices and chloride ion content measurements confirm the opinion of the experts of the Commission about the following aspects:

- The continuity of the internal cracking to the outside face
- The path and location of the main failure plane (between the No. 14 bars and the hooks of the No. 8 and No. 6 hangers)
- The chloride distribution inside the abutment.

The Commissioners have read the various reports submitted after these additional dissection and coring operations. They also made their own observations on the site.

Findings of the Commission

In general, the link between the surface cracks and the internal failure plane is confirmed.

An examination of slices made of block CSE4 from the southeast abutment showed, in all cases, the continuity of the horizontal cracks, which extended across the entire width of the pieces.

An examination of slices of block CNE1 of the northeast abutment shows that five out of the six surfaces exposed during the dissection, and probably the sixth as well, contained an internal failure plane related to the cracks visible on the surface.

5.10.3 Pre-existence of the cracks

Since the de la Concorde overpass was dismantled a short time after the collapse, and given the storage conditions of the pieces brought to the Belgrand site, in Laval, it can be safely concluded that these components were not exposed to sources of chloride ions or any other contamination after the collapse. The concrete degradation in the vicinity of the cracks, the presence of efflorescence and the presence of chloride ions are all signs that the cracks were already formed when the structure collapsed. The Commission noted that a consensus was reached on this point during the September 4 visit to the storage site.

However, it is difficult to evaluate the age of the cracks or their order of appearance. Indeed, the extent of concrete degradation and the measured chloride ion contents in cores sampled in the structure are influenced by a host of local conditions such as temperature cycles, wetting and drying cycles and the presence of reinforcing steel. For example, the fact that concrete is less deteriorated along the cracks near the lateral surface can probably be explained by drier conditions in that area and, more importantly, by the presence of surface reinforcement near the outside faces.

Findings of the Commission

The results of additional dissection and coring operations clearly demonstrate that:

- There is continuity between the internal weakness planes and the inclined cracks visible on the lateral surfaces of the abutments.
- The cracks observed during the dissection survey existed prior to the collapse.

5.11 MTQ Plan of Action and its Evolution Through the Course of the Inquiry

5.11.1 Issues relating to the identification of potentially dangerous structures

Within hours following the collapse, the MTQ prepared a list of 18 structures that were potentially at risk, given the failure mode of the de la Concorde overpass. Initially, the structures were identified as those with a continuous bearing support within a span, and later, those with bearing supports at the end of cantilevers.

From the testimonies heard and the investigations carried out by its experts, the Commission noted the brutal and unpredictable nature of the collapse and the existence of several key factors, including the following:

- The development of significant concrete degradation over time and the propagation of cracks inside the thick slab of the cantilever;
- The anchorage details of the reinforcement in the area of the bearing supports, and the completely faulty placement of steel reinforcing bars resulting from construction and surveillance deficiencies;
- The absence of shear reinforcement in the thick slab.

Thick slabs designed around 1968-1969 could be designed with shear reinforcement or without. The codes in use at that time did not require that kind of reinforcement in the case of the de la Concorde overpass.

Shear stress calculation methods have evolved since then and, according to the CSA-S6-2006 Code, shear reinforcement would have been specified for the de la Concorde overpass, in the zones of higher load concentration of the thick slab.

5.11.2 Communications between the Commission and the MTQ

Faced with the important issue of identifying potentially dangerous structures, and in the interest of the safety of the public, the Commissioners had communications with government authorities and MTQ representatives. These communications took place before and during the public hearings. The Commissioners organised meetings at various levels between the

MTQ's specialists and the Commission's technical experts on the identification of vulnerable or potentially dangerous structures.

Of the 18 structures originally identified by the MTQ, special measures were implemented on three: the de Blois overpass was demolished, a structure on Highway 31 in Joliette was strengthened and another overpass on Autoroute 10 in Saint-Alphonse-de-Granby was demolished on May 22 and 23, 2007.

In May 2007, the Commission's experts presented their analysis and laboratory modelling results to the Commissioners. After analysing and discussing these results, the Commission came to the conclusion that *solid, thick slabs without shear reinforcement could be vulnerable to brittle failures*, without notable prior deformations, especially if concrete degradation was present. On May 16, 2007, the Commission decided to inform the Government of its concerns. More specifically, it recommended reviewing the plan of action worked out by the MTQ in October 2006, in the days following the collapse. The Commission suggested including all structures with a thick slab and without shear reinforcement in the MTQ plan, paying special attention to structures showing evidence of concrete degradation. Also, the Commission recommended that the shear resistance of these structures be checked according to the recommendations of the most recent version of the CSA-S6-2006 Bridge Code.

Additional discussions took place between the Commission's experts and the MTQ regarding this recommendation. These communications resulted in a revised version of the Plan of Action dated June 1, 2007.[106]

On June 18, 2007, the Commission submitted some comments to the Government regarding the content of some sections of the revised version of the MTQ Plan of Action, notably insisting on the importance of concrete degradation and the application of revised sections of the CSA-S6-2006 Code. The MTQ then issued a detailed specifications document intended for engineering firms to be hired for the evaluation of potentially dangerous structures for the *directions territoriales* and for the municipalities. This document was reviewed by the Commission, which presented additional comments to the MTQ.

Later, the MTQ informed the Commission of the measures taken to integrate its latest comments to the instructions given to the firms carrying out the evaluations.

On July 12, 2007, the MTQ informed the public about in-depth inspections of 135 structures under its jurisdiction and asked the nine large municipalities to inspect and evaluate the structures under their respective jurisdictions. The MTQ also offered technical assistance to the municipalities. To that end, it provided the municipalities with a typical specifications document for assessing the load-bearing capacity of this type of structure. This typical specifications document was presented as evidence during the public hearings of the Commission.[107]

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[106] Exhibit MTQ-2, p. 21 to 23.

[107] Exhibit COM-52D.

5.11.3 Communications between the Commission and regulatory authorities

The CSA-S6 Code is used throughout Canada for the design of highway bridges. Since the code did not necessarily require shear reinforcement in thick slabs in the 1960s, the Commission's concerns about these slabs were not limited to structures located in Québec. Indeed, these structures are present in all of Canada.

The Commission informed the Canadian Standards Association, which is responsible for upkeeping of the CSA-S6 Code. The Code Committee, in which representatives of the provincial governments participate, may therefore convey the concerns of the Commission to the relevant authorities throughout Canada.

Moreover, the American bridge code has some similarities with the CSA-S6 Code and the Commission deemed it appropriate to share its concerns with the American federal authorities, with which it had established contacts in the course of its activities.

5.12 Conclusions about the expert investigations

The investigations performed by the experts of the Commission, the MTQ and DSA have enabled the Commission to get to the heart of the matter, to understand the collapse mechanism and to establish the causes of the tragedy that occurred on September 30, 2006.

These causes are the subject of Chapter 6, which follows.

CHAPTER 6

6. CAUSES OF THE COLLAPSE

6.1 Introduction

The collapse of the de la Concorde overpass is the result of a series of physical causes that the various observations, calculations and tests conducted during the enquiry have established with a high level of certainty. There is a consensus among the experts of all parties as to the primary physical causes of the collapse. These experts, however, issued diverging opinions regarding secondary contributing causes. Nevertheless, the Commission considers secondary causes as significant and discusses them in this chapter, along with the human interventions associated with the physical circumstances of the collapse.

The fact that the physical causes were not detected and corrected before September 30, 2006 generated a two-part question: was it possible to anticipate the collapse, or at least the existence of a major structural deficiency? And could it have been prevented? The Commission, for its part, tried to understand what could have led to the event of September 30, 2006.

The Commission is of the opinion that the real condition of the structure was masked by shortcomings in the inspection and maintenance systems. These shortcomings, combined with unclear accountability, involve the carrying out of inspections, follow-up to certain interventions prescribed by the inspection programme, and MTQ record-keeping and internal communications. Responsibility for this situation lies with the MTQ management process and limited technical supervision of personnel, rather than with individual actions or omissions by participants. Indeed, participants were unable, over the years, to identify the signs of the structure's deterioration in a way that would have brought about effective action.

6.2 Consensus of the experts

The purely physical or mechanical causes of the collapse were the focus of in-depth studies by several groups of experts, whose work and conclusions were reported in the previous chapter. These experts also rendered opinions on many points related to the design, the technical specifications, the actual construction of the structure, as well as inspection and maintenance practices.

Experts from the Commission, the MTQ and the consulting design engineers held a preparatory conference to establish a consensus, the content of which is recorded in the minutes of the June 26, 2007 conference.[1] The Commission generally concurs with the unanimous agreement that emerged around the following elements :

- The particular nature of the de la Concorde overpass
- Compliance with the design standards applicable at the time of the construction, including Code CSA-S6-1966

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[1] Exhibit COM-72.

- Non-compliance with current design standards, prescribed by Code CSA-S6-2006
- Confusion in the specifications prepared by the designers with regard to the characteristics of the concrete
- The low quality of the concrete used, in particular its inability to resist deterioration caused by freeze-thaw cycles in the presence of de-icing salts
- The shortcomings of the MTQ's *Manuel d'évaluation de la capacité portante des structures*, which does not comply with the requirements of Code CSA-S6-2006, despite the generally good quality of MTQ manuals
- The MTQ deficiencies regarding the inspection and maintenance file, as well as regarding compliance with certain requirements in the manuals
- The primary physical causes of the collapse, set out in the box below

June 26, 2007 consensus as to the failure mode and its primary causes

[TRANSLATION]

Failure mode

"The overpass collapsed due to a shear failure in the southeast cantilever."

Primary causes of the collapse

1) "Regarding design, the detail of the steel rebar on the upper part near the end of the cantilever could not prevent the propagation of the cracking plane."

2) "Regarding construction, the misplacement of the steel rebar in the upper part of the cantilever end created a weak area which helped speed up the propagation of cracking plane."

3) "Regarding materials, the concrete used did not have the properties to withstand freeze-thaw cycles in the presence of de-icing salts, which also contributed to the propagation of cracking plane."

Factors regarding the onset of the cracking plane

"At this time, there is no certainty as to what initiated the cracking plane."

6.3 Collapse mechanism

The testimony and expert consensus have given rise to a commonly shared understanding of the collapse mechanism.

6.3.1 Sequence of the collapse

First, a piece of concrete approximately 700 mm long detached from an area just behind the corbel on the south lateral face of the east abutment (Figure 6.1 a).

Figure 6.1 Vertical face of the south side of the east abutment, near the corbel:
a) Top: picture taken by Jules Bonin on September 30, 2006, less than 60 minutes before the collapse
b) Bottom: after the collapse

The unreinforced part of the internal concrete mass then abruptly split along an inclined surface down to the reinforcing steel at the bottom of the slab.

The overpass collapsed due to a shear failure in the south part of the east abutment's cantilever. The beam seat, or corbel, was not involved; this section remained attached to the lower portion of the thick slab following the collapse. The failure occurred in the core of the thick slab.

Figure 6.2 Front view of the east abutment shortly after the collapse, on September 30, 2006[2]

The upper part of the cantilever remained intact, hanging over Autoroute 19, whereas the lower part pivoted towards the ground, breaking into three large blocks and a number of smaller pieces (Figure 6.2). The three main pieces that separated from the bottom of the cantilever remained attached to the top of the abutment, held by the longitudinal rebars in the bottom of the slab and also partially by the transverse bars in the beam seat near the center of the abutment.

As explained in Chapter 3, the south half of the superstructure fell as soon as it lost its support on the east abutment. The superstructure collapsed in a single block, almost instantly, hitting the ground on the east side first. The box girders broke upon hitting the concrete divider in the middle of the freeway (Figure 6.3). Upon impact, they also partially broke apart from each other, while the external box girder pivoted on its side, under the weight of the overhanging sidewalk.

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[2] Exhibit COM-1-A, p. 31.

Figure 6.3 View looking to the west of the collapsed overpass, from the east abutment, on September 30, 2006[3]

The sequence of the collapse was reproduced using a virtual model and a film of the reconstructed collapse was presented during the hearings.[4]

6.3.2 Observations relating to the failure surfaces

Figure 6.4 represents the east abutment, seen from the front, generated by the three-dimensional reconstruction of a survey done with laser scanning by the Commission's experts. The viewpoint is similar to the viewpoint in Figure 6.2, except that the suspended lower blocks and the north superstructure have been removed. The gray sections were surveyed at the collapse site following removal of block CSE-4 (taken to the Belgrand Street site for measurement and analysis) and the partial dismantling necessary to its removal (a dismantled section, to the left of block CSE-4, is visible on Figure 6.5). The results of a similar survey were presented during the testimony of one of the experts, Professor Bruno Massicotte.[5]

The failure of the cantilever took place along a three-dimensional surface, which can be broken down into three separate longitudinal profiles (i.e. along the axis of the structure) according to their respective positions inside the abutment.

Interior profile A is visible in the central part of the failure surface. This zone, identified as inner zone A, is defined by the red vertical lines drawn in Figure 6.4. In this section, the failure surface is deep and regular.

On each side of the inner zone A, the failure surface curves more rapidly and sharply downwards. This profile (profile B) is visible in the outer zones in Figure 6.4.

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[3] Exhibit COM-1A, p. 28.

[4] Appendix 18, collapse scenario.

[5] Exhibit MTQ-6, p. 87.

Finally, on the exterior south face of the abutment, the profile of the failure surface is even more abrupt, and a small vertical slice of concrete remained attached to the abutment (as can also be seen on Figure 6.1 b). The failure surface, in this case, follows profile C.

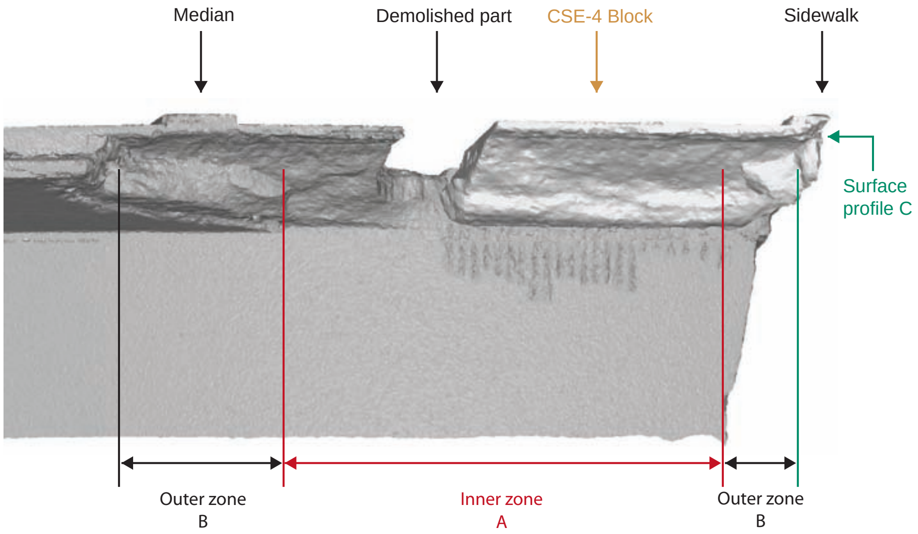
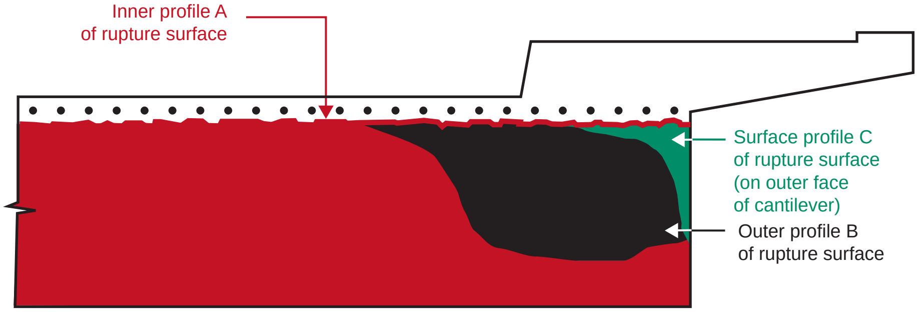
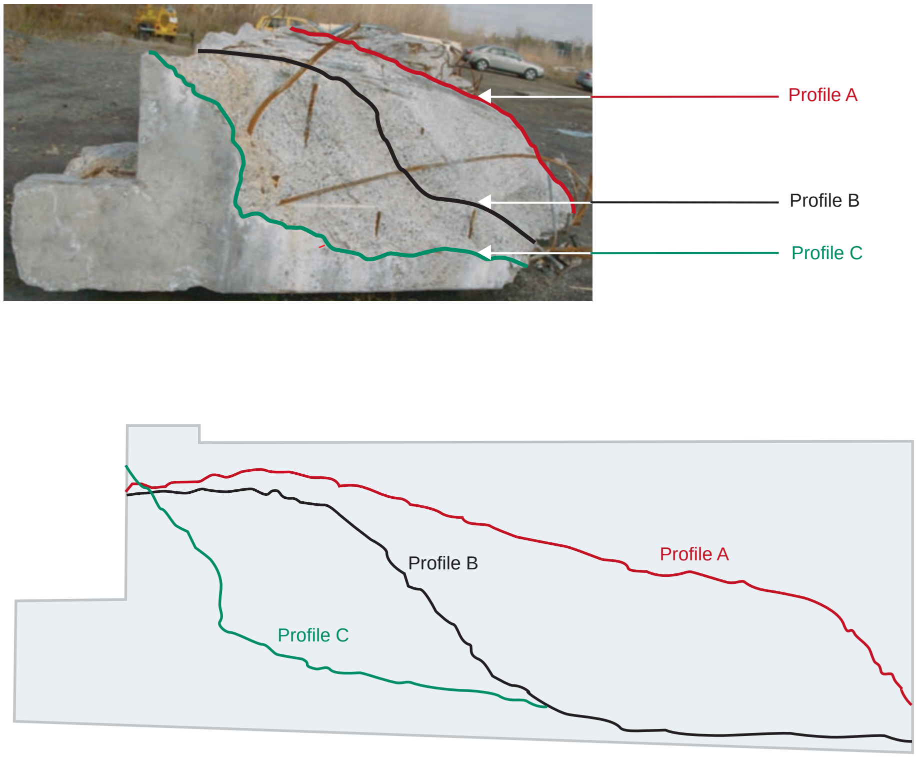


Figure 6.4 Three-dimensional reconstruction of the failure surface from survey report

The three profiles of the three-dimensional failure surface are also schematically shown on the views in Figure 6.5. The picture of exhibit CSE3, detached from the overpass, included in Figure 6.5, clearly shows the contours of these three profiles.



Transverse section



Longitudinal section

Figure 6.5 Schematic elevation of the cantilever of the east abutment, showing profiles of the failure surfaces.[6]

According to the Commission's experts, the failure profiles A and B are quite similar to those obtained through theoretical and experimental studies.[7] Theoretical resistances calculated for both profiles are almost identical. The presence of surface reinforcement on the exterior south face adds to the shear strength, which explains why the path of the surface failure plane is even more abrupt (profile C). The vertical surface reinforcement bars are also visible, protruding under the concrete, in the picture in Figure 6.1 b)

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[6] Exhibit MTQ-6, p. 94 and 95 and Exhibit COM-69, p. 186.

[7] Exhibit COM-69, p. 158.

Towards the center of the cantilever slab, shear stresses gradually decrease as one moves away from the southeast corner, where the loads on the supports are more concentrated. The failure of the thick slab stops at the center of the abutment, at a point where the available resistance is sufficient to halt the splitting. The photograph in Figure 6.6 shows many U-shaped hangers severed at the root of the hooks, which indicates that these hangers did possess some anchoring capacity.

Figure 6.6 Photograph of the area of the corbel, towards the center of the abutment, where the slab stopped splitting.[8]

6.3.3 Sudden collapse

The collapse was not the result of particularly heavy or unusual dynamic loads on the structure. The evidence also indicates that the collapse was not due to an external accidental cause, nor to a rare phenomenon, such as a violent explosion at the nearby quarry,[9] or an earthquake.[10]

The technical literature underscores the suddenness and lack of warning for a shear failure in a beam or a slab without shear reinforcement. The shear failure's explosiveness was also emphasised by the expert testimony and demonstrated by films of the laboratory tests on prototypes of the cantilever.[11]

The laboratory tests were conducted on specimens that featured new, high-quality concrete, without any deterioration. These tests reproduced a typical section of the abutment, along the longitudinal axis of the overpass, and did not take into account the stress concentrations caused by the skew and the sidewalk. Resistance values measured during the laboratory loading

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[8] Exhibit COM-1-B, p. 8.

[9] Exhibit COM-13, J.-M. Forget, Affidavit.

[10] Exhibit COM-11, p. 6 and 7; Exhibit COM-62, p. 94.

[11] Exhibit COM-69, p. 134 and 150 ; D. Mitchell, Transcription, 9 July 2007, p. 69 and see the video Appendix 18; B. Massicotte, 18 July 2007, p. 69 and see the video Appendix 18.

experiments were similar to those derived from theoretical calculations carried out according to the method prescribed by Code CSA-S6-2006. Strength results both from the tests and from theory, were much greater than the loads applied to the structure at the time of the collapse.

Therefore, on September 30, 2006, the condition of the de la Concorde overpass had to have reached an advanced state of deterioration for the overpass to collapse almost under its own weight, without any significant overload.

The shear failure was probably already initiated when the concrete piece picked up by the road supervisor detached from the structure, about one hour before the collapse. The condition of the southeast abutment, as observed by Jules Bonin and illustrated in Figure 6.1 a), shows a diagonal crack whose horizontal extension, near the bottom of the face, is long and very wide. The failure had then started inside the thick slab along the failure surface described previously. The remaining strength was then provided by some reinforcing bars and concrete around the deteriorated zone. The experts all testified that they would have closed the overpass if they had themselves seen the structure in this condition.

Thus, just before the collapse, the structure had some remaining strength, though not very much. This was a transitory state, and the rate at which cracking progressed until the collapse depended only on the load conditions created by the combined weight of the structure itself and of the traffic on the de la Concorde overpass. Moreover, the slab's primary reinforcement did not provide sufficient ductility, i.e. the capacity to continue standing up to loads, after having undergone substantial deformation.

6.3.4 Progressive damage

While the collapse of the de la Concorde overpass on September 30, 2006 must be considered as instantaneous in terms of the structure's behaviour, this tragedy was the outcome of a mechanism of progressive deterioration which took place over many years.

The most commonly reported deterioration mechanism in reinforced concrete structures, namely corrosion of the reinforcing steel, is not a causal factor in the collapse, even though it may have contributed to localised cracking. There was little corrosion on the rebar in the internal parts of the abutment. The deterioration of the rebar was, however, more advanced in the area of the beam seat of the abutment and at the ends of the box girders, but this phenomenon proved inconsequential because the failure occurred somewhere else. The structure's bearing seats could not be inspected without undertaking the major operation of raising the bridge deck.

In the case of the de la Concorde overpass, the experts unanimously recognise that the deterioration of the concrete, and not the rebar, is at fault. The collapse results from the development and the spread of a cracking plane inside the thick slab, which was facilitated by the deterioration of the concrete caused by the action of successive freeze-thaw cycles in the presence of de-icing salts.

The presence of a cracking surface inside the thick slab was noted in the very first visits to the collapse site. The characteristics of this surface were thoroughly documented after observation windows were opened in the abutments of the de la Concorde and de Blois overpasses, and after careful examination of the pieces of the de la Concorde overpass transported for analysis to the Belgrand Street site. Similar cracking planes were observed in the abutments that did not collapse. These observations indicate that the factors having brought about the collapse were present elsewhere, but to a lesser extent than on the south side of the east abutment. There was therefore a risk of collapse in an indefinite future.

The photographs in Figure 6.7 taken during the dissection of the pieces stored on the Belgrand Street site clearly show :

- The presence of highly deteriorated concrete on the surface of the thick slab, behind the shoulder of the joint, and the profile of the zone of weakness associated with the internal cracking
- The substantial depth of deteriorated concrete, reduced to flaking, in the internal cracking zone
- The continuity of the internal cracking plane to the outside lateral face of the slab

Expert testimony has illustrated the cracking plane's progressive penetration into the abutment[12] and, using numerical simulations, demonstrated the cantilever's gradual loss of strength as the internal damage progressed.

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[12] Exhibit COM-69 p. 208 to 220.

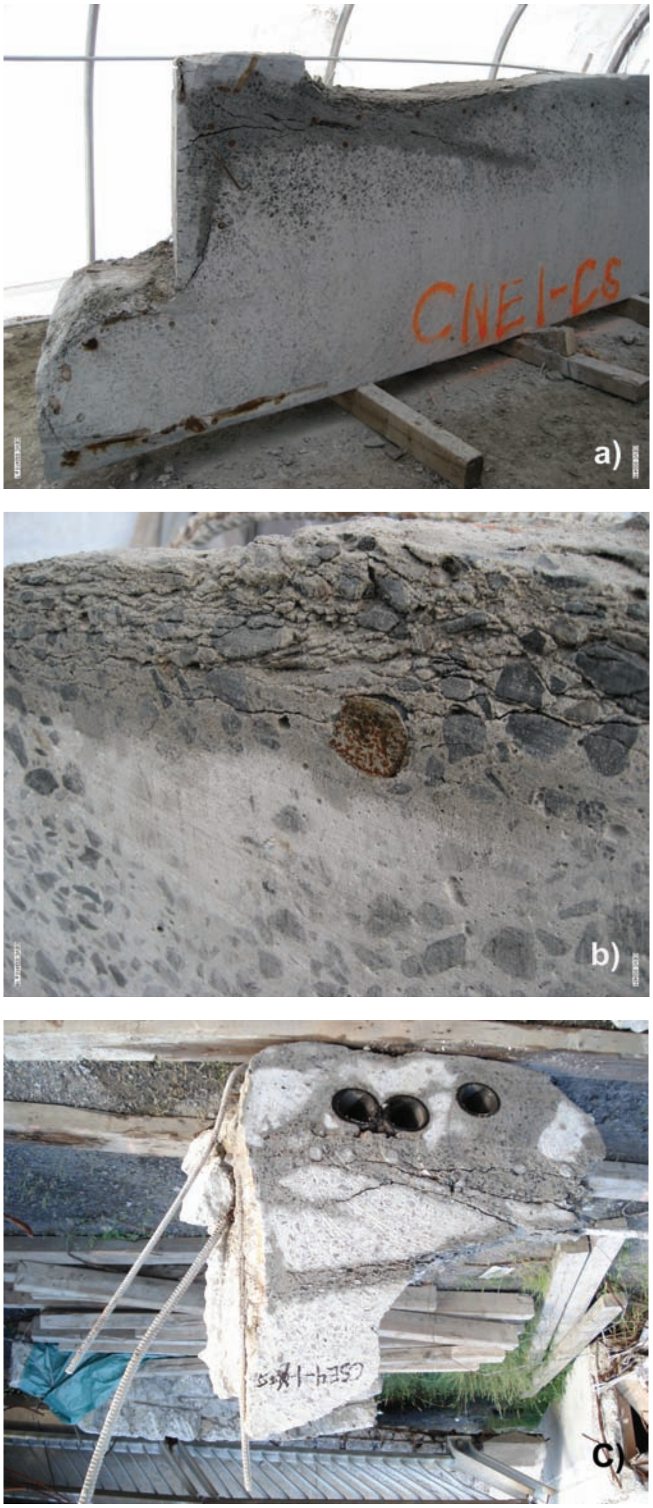

Figure 6.7 Picture of pieces of the east abutment :
a) Longitudinal section of the non-collapsed part of the slab
b) Flaking concrete in the upper part of a collapsed piece
c) Transversal section of the upper corner of the east abutment, on the collapsed side[13]

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[13] The photo in Figure 6.7 c) has been turned around to show the piece in its orientation during the structure's life: the row of No. 14 bars under the sidewalk, and the three ducts in the sidewalk are shown.

6.4 Principal physical causes

All the experts agree that the collapse of the de la Concorde overpass is related to a combination of factors, not a single cause. The consensus opinion reports three primary causes which are respectively associated with the design, construction and concrete quality.

These primary causes are related to the presence of a weak zone under the No. 14 bars in the top of the abutment, near its end, to the appearance of a crack in this weak area and to its propagation inside the thick slab until failure occurred.

6.4.1 Poor anchoring detail for the reinforcement in the top of the seat

The intent of the designer, as reflected in the drawings and confirmed during his testimony, was to transfer the tensile loads developed in the U-shaped hangers and the diagonal bars upward, so as to engage the entire cantilever. According to the layout shown on the drawings, the loads were supposed to be transferred through the concrete; the drawings show that the hooks of the No. 8 hangers were to be placed parallel to the No. 14 bars along the same horizontal plane.

In fact, regardless of problems associated with the actual placement of the steel bars during construction, the presence of a large amount of reinforcement on the same plane, in the upper part of the abutment, creates a weakness plane where horizontal cracking was prone to develop because of the high stresses transferred to the concrete in this area. This horizontal plane included the No. 14 bars and the hooks on the No. 8 bars and No. 6 bars.

Furthermore, experts’ studies have shown that the anchoring of the No. 14 bars was inadequate. Indeed, the limited anchoring capacity of the No. 14 bars reduces the limit state strength of the structure. The loads that have to be transferred through No. 14 bond strength are considerable, given their large diameter. The stresses at the steel-concrete interface are critical and cannot be exceeded without breaking the bond. To avoid this, the anchoring should have been longer to call upon the full capacity of the No. 14 bars. The stresses that develop in the cantilever at the back of the seat are very high. In this area, insufficient bond between the No. 14 bars and the concrete appears to have resulted in horizontal crack formation in the area of weakness mentioned earlier. To prevent this from occurring, the bars should have either been bent downwards or the reinforcement details should have been modified.

According to current practice, the reinforcement details must be designed in order to fully develop the capacity of each rebar along the full length over which it must participate to the strength of the structure. It is thus critical that the No. 14 bars be bent downward and the hooks of the No. 8 and No. 6 bars be bent around the bars on which they are to rest, and not run alongside them.

Furthermore, in a proper layout, any plane of weakness must be crossed by rebar in order to impede the initiation of cracks and control their opening. This results in a ductile mode of failure controlled by the progressive stretching of the bars.

6.4.2 Misplacement of reinforcing bars

Misplacement of the No. 8 U-shaped hanger bars and of the diagonal bars in the bearing support area transformed the horizontal weakness plane created by the high concentration of reinforcement into a curved zone of weakness that extended further inside the thick slab.

It was observed during the dissection of abutment pieces that cracking in the weak area developed toward the bottom end of the hooks, forming a path that allowed water and de-icing salts to penetrate the concrete.

6.4.3 Concrete unable to resist freeze-thaw cycles

Investigations have shown that the concrete used for the abutments of the overpass did not have the properties to withstand freeze-thaw cycles in the presence of de-icing salts: the concrete was too porous and its network of air bubbles was deficient.

The concrete's vulnerability to freeze-thaw cycles does not, on its own, explain the origin of the crack that led to the failure of the cantilever. However, the gradual deterioration of the material contributed directly to the slow propagation of the internal crack that led to the collapse.

6.5 Origin of the cracking plane

The experts, notably the MTQ experts, spent significant efforts to determine what initiated the internal cracking, as discussed in Chapter 5.

According to the experts,[14,15,16] the initiation of the cracking along the failure surface is most probably attributable to a combination of factors. The Commission lists the following :

- High bond stresses for the No. 14 bars in the seat area
- Presence of a weak zone at the top of the No. 8 U-shaped hangers
- Concrete degradation caused by freeze–thaw cycles in the presence of de-icing salts
- Shrinkage of the concrete at the level of the longitudinal bars
- Thermal effects created by the hydration of the concrete, by solar radiation or by the application of asphalt
- Repeated impact from vehicles passing on the expansion joint
- Corrosion of No. 8 and No. 14 bars.

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[14] Exhibit COM-69B, p. 8.
[15] Exhibit MTQ-1 (amendments included), p. 95.
[16] Exhibit DS-1, p. 18.

The crack then propagated into a critical area of weakness in the cantilever which was not crossed by any steel reinforcement. The progressive and cumulative nature of the phenomenon explains why the collapse occurred 36 years after its construction.

Findings of the Commission

The Commission agrees with the analysis of the primary causes that led to the collapse of the de la Concorde overpass: poor anchoring detail for the reinforcement in the top of the bearing support, misplacement of the reinforcement, and the inability of the concrete to resist freeze-thaw cycles. The Commission concurs with the opinion that the collapse is related to the presence of a weak zone under the main No. 14 bars in the upper part of the abutment, near the end of the cantilever, to the initiation of a crack in this weak zone, and to the slow propagation of this crack inside the thick slab of the abutment. The Commission acknowledges the progressive nature of the internal cracking and the cumulative effect of the different primary causes.

6.6 Contributory Physical Causes

6.6.1 Absence of Shear Reinforcement in the Thick Slab

The evidence showed that the code design requirements for shear reinforcement of concrete structures have evolved considerably since the de la Concorde overpass was built. The codes applicable in 1970 were less conservative and less safe than the current ones.

According to the experts, the design of the thick slab on the de la Concorde overpass would have required some shear reinforcement if its calculations had conformed to current codes.

The shear reinforcement would have crossed the plane of weakness and controlled the internal cracking. Such a design would have prevented the collapse or, at worst, resulted in a gradual mode of failure accompanied by noticeable prior deformations.

6.6.2 Absence of proper waterproofing on the surface of the Thick Slab

The information obtained during the investigation and presented in Chapters 4 and 5 as to the waterproofing membrane on the thick slab of the de la Concorde overpass comes from a variety of sources: specifications, photographs, testimonies and MTQ reports. This information is not precise. It is impossible to determine with certainty the type, quality or even the presence or absence of a membrane. The 1992 repair work erased any trace of the original waterproofing membrane, if any. Regarding the membrane that was to be installed in 1992, it was only found on a small portion of the west abutment, and the date of its installation could not be determined.

In any event, it seems clear that the membrane specified for the 1992 work, currently referred to as Type 3 membrane, was not installed. It is also clear that the thick slab on the cantilever was heavily degraded in 2006.

Freeze-thaw cycles do not cause concrete to deteriorate if it is not saturated with water. The need to protect concrete surfaces under traffic lanes has long been recognised. Since 1978, the general specifications in use at the MTQ include high-performance membranes.

The absence of adequate protection on the thick slab allowed the concrete to deteriorate, which is one of the main causes of the collapse.

6.6.3 Damages Induced by 1992 Repair Work

Experts are not unanimous as to the effect of the 1992 repair work on the collapse of the de la Concorde overpass. The MTQ experts expressed the opinion that this repair was done according to standard. This opinion is not shared by the other experts who studied the question and was not retained by the Commission.

Evidence was submitted that MTQ specifications were not met, particularly with respect to the demolition equipment used, the signs of permanent damage noted on the structure that can be attributed to the work, the inadequate cleaning and preparation of surfaces prior to concreting and the absence of an effective waterproofing membrane.

During the repair work, severe concrete deterioration was observed and substantial lengths of several No. 14 bars were exposed. Despite these signs, the personnel in charge of the repair work did not consider the possibility of a potential weakening of this highly stressed area of the cantilever. Furthermore, the structure had to keep supporting its dead load, part of the traffic load and heavy equipment, without shoring to relieve the loads in the critical area of the bearing support.

All experts, except those of the MTQ, are of the opinion that the 1992 repair work at the very least helped accelerate propagation of the critical crack that was already present further into the cantilever, and even created permanent damage.

In addition, theoretical analysis using numerical modeling confirms that the load-bearing capacity loss evaluated based on concrete deterioration is comparable to that caused by the removal of surface concrete in 1992 and has essentially the same effects.

Findings of the Commission

The Commission is of the opinion that the absence of shear reinforcement in the thick slab, the absence of waterproofing on the surface of the thick slab, and the damage caused by the 1992 repair work are contributory causes of the collapse.

6.7 Conclusions on the causes of the collapse

After having heard all testimonies and weighed all of the evidence submitted to it, after having analysed the facts, the documentation tabled and the expert testimony and after having debated and deliberated, the Commission arrived at the following conclusions as to the causes of the collapse of a portion of the de la Concorde overpass.

6.7.1 Conclusions as to the design of the de la Concorde overpass

Conclusions as to the design

The Commission concurs with the experts' consensus according to which the design generally complies with the requirements of the CSA-S6-1966 Code. Nevertheless, the Commission emphasises that such conformity does not guarantee that the structure is adequate.

In general, the design provides for a structure capable of supporting the loads to which it has to resist when the concrete is in good condition, as shown by the laboratory load tests.

The de la Concorde overpass was a particular structure, due mostly to the fact that the box-girders were supported by beam seats located along a span, which created inspection and maintenance problems.

The drawings and specifications prepared by DSA did not comply with best practice, among other things because the No. 14 bars were not properly anchored in the top portion of the seat area, and the hangers were not hooked to the No. 14 bars. These anchoring details, while not in contravention with the 1966 code requirements, would now be considered inadequate and faulty.

Concerning the properties of the concrete supplied at the job site, the specifications of the material were confusing and also, non conforming to the requirements of the 1967 CSA-A23.1 Standard. Consequently the structural concrete did not have sufficient resistance to freeze-thaw cycles in the presence of de-icing salts.

6.7.2 Conclusions as to the construction of the de la Concorde overpass

Conclusions as to the construction

The Commission concurs with the expert consensus according to which reinforcement near the ends of the abutments was misplaced, and not in compliance with the drawings, in that the No. 8 U-hangers were placed under the main No. 14 bars, as were the No. 6 diagonal bars, which created a weak zone without any reinforcement under the No. 14 bars.

This zone of weakness was conducive to the propagation of concrete deterioration on either side of cracks in a critical area of the cantilever.

The deterioration was caused by the penetration of water into the structure and by freeze-thaw cycles in the presence of de-icing salts, in a low quality concrete unable to resist its effects.

6.7.3 Conclusions as to the repairs on the de la Concorde overpass

Conclusions as to the repair work

During the execution of the 1992 repair work, MTQ engineers should have addressed the anchorage problem with the hanger bars in the demolition zone.

When looking at the drawings and comparing them with the reality observed on-site, the weakening was clear. Hooks at the top of the hangers and hooks of the diagonal bars were to be placed parallel and in the same horizontal plane as the No. 14 bars. According to the design, the linkage with the top bars would be achieved by bonding of these parallel bars through the concrete. Yet, it is precisely this concrete which was removed in-depth after its poor condition was discovered.

It would therefore have been necessary to perform a structural analysis in order to establish whether the abutment cantilevers needed to be supported.

In addition to preventing damage during the repair work, shoring up the cantilevers would have made the new concrete carry its share of the dead load in the cantilever.

The vulnerability of the structure to the penetration of water and de-icing salts – because no membrane was installed at the time of repair – contributed to the continuing deterioration of the concrete that was already substantially degraded.

Because of the circumstances under which it was done, the 1992 repair also contributed to further the cracking in the deteriorating concrete, in addition to being a missed opportunity to conduct a condition evaluation of the structure.

6.7.4 Conclusions as to the conduct of individuals and the activities of companies and organisations

The Commission concludes that no single entity or individual can be assigned the responsibility for the collapse. The reproaches made in chapters 4 and 5 are expressed in a context whereby it is a combination of actions and omissions by many persons and a sequence of many circumstances over the life of the structure which created the conditions that led to the collapse.

Conclusions as to the behaviour of individuals and the activities of companies and organisations

The Commission is of the opinion that DSA failed to fulfill its duty of ensuring complete construction supervision of the work, neglecting the systematic disciplined verification required to ensure that the work complied with the drawings and specifications.

The Commission is of the opinion that ISP and its sub-contractor AAM did not adequately control the quality of the work carried out by their sub-contractors, relying either on the workers themselves or on the consulting engineer who was in charge of surveillance, however absent or non-existent he may have been. The lack of quality control was such that it resulted in the obvious faulty placement of the steel reinforcement, one of the main physical causes of the collapse.

The Commission is of the opinion that the weaknesses of the overpass which was of a particular nature and difficult to inspect, were not taken into account adequately in MTQ's maintenance operations. MTQ did not rigorously and effectively use all the means available for thoroughly evaluating the condition of the structure, in spite of the numerous signs of degradation it exhibited. Furthermore, MTQ failed to keep a complete file that could have better guided its personnel in the inspection and maintenance of the structure.

The Commission is of the opinion that the inspections performed on the overpass were sometimes inadequate for the lack of reporting sufficient quantification of the damages, sometimes incomplete due to the short amount of time spent to perform the inspection work, or characterised by a lack of rigorousness, as expressed by the absence of any attempts to identify the causes of the deterioration observed.

CHAPTER 7

7. RECOMMENDATIONS OF THE COMMISSION

7.1 The third part of the Commission's mandate

The third part of the mandate entrusted to the Commission is to *make recommendations to the government to ensure such events never recur.*

The Commission's recommendations are based on a variety of sources, including the evidence presented during the hearing and the work of experts, as well as on documents or opinions not submitted as evidence. The Commission also consulted infrastructure organisations and individuals knowledgeable in infrastructures.

The Commission investigated the causes of the collapse of a structure designed and built nearly 40 years ago and that until the tragedy on September 30, 2006, had been managed by the *ministère des Transports du Québec*. The Commission's recommendations reflect both the lessons learned from a period dating back close to two generations and its concerns for the future.

It bears mentioning that although it ordered expert reports on the operating and inspection manuals used by the MTQ, the Commission did not delve into the *Ministère*'s organisational culture and structure. Such an investigation could only have been formally undertaken after the testimonies heard in July, requiring the Commission's mandate to be extended and thereby significantly delaying the submission of its report.

That said, the Commission must point out the divergence between the image the *Ministère* wishes to convey of itself in the documents submitted to the Commission[1] and the actual facts revealed by the evidence. According to the documents presented, the *Ministère* has extensive expertise and pays close attention to audits and team competency and training. While the Commission in no way means to undermine the value of the *Ministère*'s staff nor their good faith, the fact remains that the *Ministère*'s management system is not applied with sufficient rigour.

The Commission is of the opinion that its recommendations are valid and relevant to the present situation where the MTQ must imperatively adapt its management systems, as well as to the situation that will arise from the adoption by government of a major infrastructure rehabilitation programme. Whatever the scenario, the Commission is of the opinion that the MTQ must revise its management systems so that they factor in the generalised ageing of infrastructures, and better coordinate the activities of the *Direction des structures*, where high level expertise is concentrated, with the needs of its *directions territoriales*. The MTQ must adopt clearer accountability rules between these two units when it comes to any joint strategic decision making between them relating to work to be performed.

The Commission's recommendations encompass all the parties involved in design of structures, their construction and its supervision, and their management. They also take into account the

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[1] Exhibits COM-52, COM-52A and COM-52B; Exhibits COM-60 and COM-60A.

daunting task of rehabilitating these structures. The Commission was guided by four major principles: the effective use of public funds, the use of the best expertise available, the accountability of the designers and contractors for the quality of their work, because they all have a role to play in public safety, and lastly, the importance of being rigourous in implementing infrastructure management systems.

Moreover, the Commission clearly sees that bridges will require major rehabilitation work given their growing state of disrepair. To ensure the safety of the population and to avoid a negative impact on Québec's economic development, the trend of increased deterioration of infrastructures must not only be stopped but reversed.

The entire continent is awakening to the realisation that a massive investment will have to be made over the next 20 years to upgrade road infrastructures and especially bridges. While a daunting challenge, this essential rehabilitation can be transformed into a project that will enhance individual knowledge and skills as well as business expertise, and ultimately, contribute to Québec's development.

7.2 Management System of Infrastructures

7.2.1 Codes, standards, manuals

CSA Code S6-1966, which applied to the design of the de la Concorde overpass, did not require the addition of stirrups in full thick slabs as long as shear stresses remained below the allowable concrete shear resistance threshold, under all load conditions.

In the early '80s, the scientific community established a direct relationship between the thickness of a concrete element and the loss of unit shear resistance, resulting in the loss of load carrying capacity. Widely disseminated in scientific literature, these findings were only reflected in building codes 10 years later and not before the beginning of the 21st century in the case of the CSA-S6 Code, which deals with highway bridge design.

The work of the Commission's experts in the past year leads to the conclusion that where thick slabs are concerned, the requirements with regards to shear reinforcement are still insufficient, even in the CSA-S6-2006 version of the Code. Their work indicated clearly also that full thick slabs without shear reinforcement are even more vulnerable if there is deterioration of the concrete.

The Commission was so concerned by these findings that it apprised the Government of Québec of the situation on May 16, 2007 and made this information available to the Canadian and American authorities responsible for updating codes.

Recommendations of the Commission

1. **Revise CSA S6-2006 Code**
   The Commission recommends a revision of CSA-S6-2006 in order to require at least minimum shear reinforcement in thick slabs.

2. **Define concrete quality requirements**
   The Commission recommends that as regards bridges, Government require the use of high-quality concrete that meets the updated requirements set out in the CSA-S6-2006 and in CSA-A23.1-2004 and that all related MTQ manuals be modified accordingly.

3. **Improve the knowledge acquisition process**
   The Commission recommends that the MTQ take all useful measures to insure that its personnel in charge of designing bridges and updating codes and manuals have accelerated, timely access to new developments in the field.

   To this end, the Commission recommends that the Government ensure that there be an effective surveillance of scientific intelligence processes and knowledge involving academics and top-level practitioners; this will ensure that persons responsible for designing and maintaining structures, both in private practice and in Government services, be kept constantly informed of new developments and changes in standards and practices.

4. **Update of MTQ manuals**
   The Commission recommends that the inspection and evaluation manuals dealing with the critical load carrying capacity of structures be updated, paying special attention to the recommended timing of interventions, to inspection surveys of cracking and their interpretation, to structural condition assessment, and to the requirements of Chapter 14 of the CSA-S6-2006 Code.

7.2.2 Structure design, construction and supervision

Bridges are far more complex than a highway and most other types of civil engineering structures. Their design requires a high level of specialised engineering knowledge and expertise. Their construction demands rigour and proficiency in structural engineering and in the science of materials, as well as impeccable control and supervision. All these factors must therefore be taken into account when selecting firms for a project.

While the professional obligations of consulting engineers are relatively well defined, they are far less clear for contractors who build bridges, overpasses and other heavy civil engineering structures. The *Building Act* and its regulations, which define the conditions to be met by construction firms, are deficient for not requiring an adequate assessment of the professional qualifications and expertise of these companies. The *Régie du bâtiment du Québec* has informed the Commission of its efforts to modernise the provisions of the Act and its regulations in this regard.

This weakness is compounded by ignorance of the rules with respect to the division of work in the subcontractor chain and associated responsibilities, as well as their somewhat loose application. Consequently, when a problem arises, the responsability can be passed on so that no one takes effective responsibility. This situation is incompatible with the discipline required for the construction of structures, for their maintenance in good state of repair and to ensure public safety.

The Commission has noted that some jurisdictions have procedures to prequalify designers and contractors based on the complexity of the work. These procedures apply independently of the project's funding mode, i.e. public, private, public-private partnership or other.

Recommendations of the Commission

The Commission recommends that the Government review the legal framework for the design, construction and construction supervision for new structures and for major rehabilitation work, more specifically:

5. **Develop a competency-based policy for granting consulting engineering mandates**
   The Commission recommends that the Government use a transparent process to develop a policy for granting consulting engineering mandates for the design of structures and for the supervision of the construction work. Besides taking into account the competence of firms and of the individuals assigned to projects, this policy should provide for an evaluation of the candidate's past performance on similar contracts. Cost should then come into play only for the selection of a firm among those meeting the competence criteria.

6. **Develop a concept validation policy**
   The Commission recommends that any mandate for structure design should specifically be validated (verification of designer's concept, drawings and calculations). In the case of a consulting engineering firm, the contract should stipulate that the validation be subject to a certificate signed by an engineer, officer of the company. For projects to be executed by MTQ engineers, the departmental procedure should require the signature of a hierarchical superior to whom the design engineer reports and who is himself an engineer. In both cases, the engineer signing the validation certificate should have supervised the work. An alternate option is to have an independent firm perform and certify the validation.

7. **Implement a prequalification system for contractor selection**
   The Commission recommends that contractors be subject to selection criteria that take into account their qualifications for the type of structure to be built. Cost would then come into play among those contractors that fulfilled the competence criteria.

   To this end, the Commission recommends that the Government implement, at least for structures, a transparent prequalification system that takes into account the experience, qualifications, prior performance and quality control systems of the contemplated firm as well as the skills of the individuals proposed for the contract.

8. Obtain information regarding turnover of key personnel

The Commission recommends that the person in charge of prequalifying engineering consulting firms and contractors ensure, when awarding the contract, that the selected firm still has in its employ key personnel on which its qualification is based and that such personnel will be available for the duration of the work.

9. Control of sub-contracting

The Commission recommends that sub-contracting requirements be rigorously implemented to all structure projects. In their bids, general contractors must always be required to identify the work performed by their own teams. They must also identify their sub-contractors and the work entrusted to them, as well as produce a work quality-control plan for their own employees and those of their sub-contractors.

10. Implement an inspection process when structures are delivered

The Commission recommends that for all structures built in Québec, the supervisor of the work be required, upon delivery of the completed structure, to assemble all the documents associated with the work and the structure, including, without limitation to the foregoing, the "as-built" drawings, specifications, steel reinforcing bar and other lists, jobsite logs, material control reports and any details that might require an adjustment to be made to the inspection and maintenance programmes.

The Commission recommends moreover that the owner of the structure be given the responsibility of keeping these documents during the entire life of the structure.

The Commission also recommends that an engineer certify that the structure was built in accordance with drawings and specifications.

11. Conduct performance evaluations

The Commission recommends that all owners of structures evaluate, at the end of the work, the performance of the consulting engineering firms responsible for the design and supervision and also evaluate the performance of the contractors, and that these evaluations be kept on record.

7.2.3 MTQ management

The MTQ prepared a comprehensive report for the Commission describing its organisation, work methods and management. After reading the report, hearing testimonies and analyzing the evidence, the Commission finds that the stated ideal of excellence and efficiency is not, in fact, being fully achieved.

During its inquiry into the de la Concorde overpass, the Commission noted reluctance on the part of the *Ministère's* professionals to work in a hierarchical structure, with each one more or less left to his own devices in terms of decision-making and in the exercise of his responsibilities.

This reluctance appears in two types of situations. First, there are engineers who appear to hesitate to comment on the work of their colleagues despite their responsibility in this regard. The other situation is one in which an engineer of a *direction territoriale* asks for the support of an engineer in the *Direction des structures;* the latter perceives himself as providing a consulting service whereas the former views him as providing the ultimate professional opinion leading to a decision. This diverging perception of roles and ambiguity in the exercise of duties result in confusion in accountability and adversely affect the *Ministère*'s overall effectiveness and efficiency.

With respect to the *Ministère*'s manuals, although the Commission found them to be adequate, the procedures they set out were not always respected, particularly those pertaining to the writing and recording of inspection notes and diagnoses stemming from inspections. The lack of precision in the noted details makes it impossible to follow their evolution and to track special aspects or problems of structures over time. In 2004, the Québec Auditor General noted the same shortcomings, stating, for example, that [Translation] "*in over 60% of cases where a rating of 1, 2 or 3 was assigned to a component during a general inspection, no details are provided in the box reserved to this effect to provide more information on the observed deterioration.*"[2] There is nothing to indicate that this situation has since been corrected.

The MTQ has mentioned that a new electronic file management system is being developed. However, this system was not available during the Commission's work, and hence, the Commission could not evaluate its effectiveness.

In the specific case of the de la Concorde overpass, the Commission noted that over the years, despite the many interventions and engineering work performed by the professionals of the *Direction territoriale de Laval-Mille-Îles* and the *Direction des structures*, it seems that no one ever fundamentally questioned the deterioration of the overpass, a structure with a special and particular design. The lack of complete documentation apparently did not prompt anyone to conduct a search for the missing information or to assess the condition of the structure through such methods as load carrying capacity calculations and concrete core sampling, which might have answered questions that unfortunately were never asked.

Recommendations of the Commission

12. **Improve the MTQ's culture and work methods**
    The Commission is of the opinion that the *Ministère* must take action to address shortcomings in respect of its work, notably, as regards to poor record keeping, unclear accountability and the apparent difficulty of engineers to impose their professional judgment. The *Ministère* should implement an action plan to rectify this situation.

13. **Prepare and maintain complete records**
    The Commission recommends that the *Ministère* implement an accelerated, comprehensive and easily accessible on-line system containing all records and data relevant to the structure, including reports on inspections and repair activities. The Commission also addresses this recommendation to municipalities with populations of over 100,000.

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[2] Québec Auditor General, *Report to the National Assembly for 2002-2003*, Volume II, Chapter 4, p. 86.

14. Clarify the relationship between the *directions territoriales* and the *Direction des structures*

The Commission recommends that the *Ministère* clarify the responsibilities, functions and roles of the *directions territoriales* and the *Direction des structures* and ensure that these clarifications be communicated to the professionals and personnel concerned. Without recommending that structure inspection and maintenance be centralised at the *Direction des structures*, the Commission recommends that even if the *Direction des structures* does not assume responsibility for administrative management or the direct management of the work, it should be held jointly accountable with the *directions territoriales* for solutions to problems for which its expertise was solicited.

15. Add specific objectives to the structure inspection manuals

The Commission recommends that the MTQ include certain requirements currently missing from its structure inspection manuals but that appear in guides used by other North-American jurisdictions:

- formulate a diagnosis when damage is observed
- diagnose not only structural but also material-related problems
- adapt the inspection system to different types of structures under various conditions.

7.3 A deteriorating network

7.3.1 Bridges under MTQ responsibility

Québec has approximately 12,000 bridges, regrouped into four major categories:

- The *primary road network* (PRN) comprised 4,924 bridges in 2005. The *Ministère* is responsible for this network, which includes the major national highways.

- The *municipal road network* (MUNRN) of municipalities with populations under 100,000 comprised 4,397 bridges in 2005. These municipalities typically do not have the resources to inspect and maintain their bridges. The *Ministère* inspects these structures, provides technical and financial support and assumes the entire cost of structural repairs.

- The structures of municipalities with populations of over 100,000. These large municipalities are fully responsible for inspecting, repairing, and if necessary, replacing their structures. The MTQ's sole contribution is to provide them with its training manuals and practices.

- Bridges located on public lands under the responsibility of the *Ministère des Ressources naturelles et de la Faune*, the bridges belonging to the federal government and those privately owned.

The Commission focused primarily on the PRN and MUNRN bridges for which the MTQ assumes full responsibility and which in 2005 represented 9,321 structures.

7.3.2 The two major bridge classification indicators

In Québec, as in all of the other Canadian provinces and U.S. states, two major indicators are used to classify bridges. One assesses the condition of the structure and determines the extent and urgency of the work required to maintain it in good repair while the other assesses its degree of functionality, i.e. its ability to meet the demand to which it is subjected.

The ***condition indicator*** refers to the condition of the structure. [Translation] *"Any defect affecting the structure's elements – concrete delamination, steel corrosion, wood rotting, etc. – are covered by this parameter."*[3] In other words, the condition indicator measures the degree of the structure's soundness, or, conversely, its deterioration.

A low rating of the condition indicator does not mean there is an immediate danger of collapse; it means that the structure must be repaired within the next five years or less.

The ***functionality indicator*** [Translation] *"includes everything that makes a structure capable of providing users with the service they expect. Load carrying capacity, traffic volume, road width, and upper and lower vertical clearance are some of the main elements considered when evaluating structure functionality."*[4] In other words, functionality is the structure's ability to meet demand. For illustration purposes, a bridge can be in perfect physical condition; however, if it no longer meets demand due to increased traffic, it will be designated as functionally obsolete.

A structure can be deficient in both aspects. In such a case, it will only be recorded once, under the condition indicator.

7.3.3 Evaluation of structures under MTQ responsibility

An evaluation of Québec's structures was submitted by the MTQ's *Direction des structures* in a report titled *État des ouvrages d'art du réseau routier québécois – Bilan pour l'année 2005*:[5]

[Translation] "*A structure is deemed in good condition if no major maintenance is required over a five-year period.*"[6]

Based on this criterion, at the end of 2005, 53.3% of the PRN structures[7] and 46.1% of MUNRN structures[8] were in good condition.

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[3] Exhibit COM-52B État *des ouvrages d'art du réseau routier québécois – Bilan pour l'année 2005.* Direction des structures, *Ministère* des Transports du Québec, p. 2

[4] Exhibit COM-52B, p.2.

[5] Exhibit COM-52B.

[6] Exhibit COM-52B, p.2.

[7] Exhibit COM-52B, p. 13.

[8] Exhibit COM-52B, p. B-3

Table 7.1 Deficient Structures, Québec, 2005

	Condition Deficiencies	Functionality Deficiencies	Total Deficient Structures *
Primary Road Network (PRN)	46.4% (2,285 structures)	2.3% (111 structures)	46.7% (2,301 structures)
Municipal Road Network (MUNRN)	49.0% (2,156 structures)	12.6% (553 structures)	53.9% (2,369 structures)

* Some structures are deficient in both aspects but are recorded only once in the total.

7.3.3.1 Primary Road Network (PRN)

- The average bridge age in the PRN was 35.7 years in 2005. Calculated in terms of total value of construction, 73% of these bridge assets were added between 1960 and 1980.

- For several years now, the number of deficient structures in the PRN has been steadily increasing, from 1,752 in 1998 to 2,301 in 2005, despite the fact that certain inspection criteria were relaxed and despite the audit process implemented to evaluate inspection accuracy. As such, in 2005, the *Ministère*'s report stated that 20% of the repaired structures [Translation] "*are no longer deficient following changes made to some inspection criteria to make them less demanding. These changes seek to better reflect the extent of the defects found and are the result of inspector comments made during audits conducted in the last few years.*" Another 18% of the structures repaired in 2005 [Translation] "*are no longer deficient due to "spontaneous improvement,"*[9] *i.e. structures whose inspection ratings were revised upward although no action was taken.*"[10]

- Although the number of structures repaired in 2005 was the highest in the last three years, the proportion of deficient structures still rose 1.5% (64 structures) despite spontaneous improvements.[11] In 2004, two bridges were closed, overweight loads were banned from 116 others, and 44 had posted reduced load signs, for a total of 162 bridges (3%).[12]

7.3.3.2 The Municipal Road Network (MUNRN)

- The municipal road network (MUNRN) has more deficient structures than structures in good condition.

- The number of deficient structures has steadily increased, from 1,883 in 1998 to 2,369 in 2005.

- Approximately 20% of municipal bridges have posted reduced load signs. Including the bridges on which overweight loads are prohibited and the 14 closed bridges, 37% of the bridges in the MUNRN had signs posted in 2005.[13]

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[9] The quotation marks appeared in the *Ministère*'s document.

[10] Exhibit COM-52B, p. 11.

[11] Exhibit COM-52B, p. 13.

[12] Exhibit COM-52B, p. 17.

[13] Exhibit COM-52B, p. B-7.

This data shows that the deterioration in the MUNRN is even more pronounced than in the PRN. Given that the Commission formulates recommendations as regards bridge management in the future, the municipal road network is of particular concern.

In 1993, the Government of Québec transferred the municipal road network to the municipalities. Since then, in principle and generally speaking, the Québec road network has belonged to the local municipalities, except for freeways, which remain government property. The *Highway Act* also allows the government to decree that a road, whether national, regional, collector or access is an *autoroute* (freeway).

The fact that the government or a municipality owns a road does not necessarily mean that it is responsible for its maintenance. As such the *ministère des Transports* assumes responsibility for the maintenance of certain roads without necessarily owning them. The government decrees which roads fall under MTQ management, and this decree is regularly amended based on criteria that the Commission does not understand. This situation results in uncertainty, an inability to plan, and tremendous ambiguity between the *Ministère* and municipalities as regards maintenance, repair and even bridge replacement work.

Given the technical complexity and budget impact associated with managing bridges and structures, the MTQ set up, in 1993, a temporary assistance programme for the rehabilitation of bridges and other structures for municipalities with a population of less than 100,000. In the absence of an agreement with the municipalities, the MTQ has extended this programme each year. The question of funding is a major stumbling block to an agreement between the *Ministère* and the municipalities, the latter finding that the formula proposed by the *Ministère* respects neither their ability to pay nor equity between municipalities.

The terms and conditions of the current programme are as follows:

- The MTQ ensures inspections;
- Inspection results are transmitted to the municipality;
- The MTQ sets repair priorities, within the available budget;
- The MTQ prepares and hands over the drawings and specifications to the municipality;
- The municipalities issue the call for tenders;
- The MTQ funds the work.

In other words, notwithstanding the fact that it does not own the bridges, the MTQ inspects them, sets repair priorities, subsidises the work, develops drawings and specifications, and sometimes even issues a call for tenders on behalf of the municipality.

The Commission consulted various municipal representatives and learned that they were not comfortable with this situation:

- Municipalities with populations of less than 15,000 account for nearly 90% of the 4,397 structures surveyed in 2005 in the MUNRN. They do not have the financial resources to adequately assume responsibility for inspection, maintenance and repair. For a long time, the MTQ invested very little in these structures, i.e. $2.5 million in bridge repairs in 2005-2006. Although this figure climbed to $30 million in 2007, it is still far below what is needed given that inspections conducted by the MTQ itself reveal that 54% of municipal bridges require major work within the next five years.

- The identification of public roads under local municipal jurisdiction is a major legal issue. Municipalities with populations of less than 100,000 are very uncomfortable with the fact that they might be held accountable for the safety of structures on their territory.

Indeed, this municipal malaise was echoed in the Québec Auditor General's Report, which stated, in 2004, that communication between representatives of the MTQ and of municipalities with populations of less than 100,000 was lacking, [Translation] *"thus, among other things, preventing the Ministère from assessing the effect of its assistance programme on the rehabilitation of bridges and other structures."*[14]

7.3.3.3 Structures in municipalities with populations of over 100,000

The nine municipalities with a population of over 100,000 manage several hundred structures located on their territory. These municipalities are assumed to have the resources to adequately assume their responsibilities. The MTQ provides them with its inspection manuals and offers technical assistance with regards to inspector training and the preparation of work specifications. The Commission did not examine the situation of these municipalities and is not formulating any recommendations in their regard save the need for them to create and maintain complete records of the structures under their responsibility.

7.3.3.4 Budgetary considerations

In 1996, the Government of Québec created the *Fonds de conservation et d'amélioration du réseau routier (FCARR)* to fund investments in the PRN. The MTQ funds the FCARR, which in turn provides financing for the province's work on roads and structures.

Up until this year, the MTQ's investments in municipal bridges were made in cash for the MUNRN. However, as of this fiscal year (2007-2008), most of the investments will be financed by debt service over a period of 10 years. This is why the value of work supported by the MTQ can be substantially increased ($30 million), while the amount in the budget is $8 million.

The following table shows the investments made on Québec's bridges in the last decade.

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[14] Op. cit., note 2, p. 84.

Table 7.2 Investments in PRN and MUNRN Structures and Change in the Number of Deficient Structures

Fiscal Year	PRN		MUNRN	
	FCARR Investments* **($M)**	**Number of Deficient Structures**	**MTQ Investments** **($M)**	**Number of Deficient Structures**
1996-1997	79.9	n.a.	9	n.a.
1997-1998	94.2	n.a.	13.25	n.a.
1998-1999	111.2	1,752	14	1,883
1999-2000	137.8	1,821	14	1,911
2000-2001	152.2	1,924	8	1,961
2001-2002	173	1,994	8	2,022
2002-2003	194.2	2,032	8	2,056
2003-2004	165.9	2,127	1.6	2,128
2004-2005	175.8	2,237	8	2,229
2005-2006	247	2,301	2.5	2,369
2006-2007	251.5	n.d.	8.5	n.d.
2007-2008	539.9	n.d.	30**	n.d.

* These amounts include, in addition to the cost of work, administrative expenses and fees.

** For the first time in 2007-2008, a large part of the work ($23 million out of $30 million) is financed over 10 years by debt service rather than paid in cash.

The steady deterioration of the indicators and significant increase in the number of deficient bridges in the last decade clearly shows that the investments have been insufficient, at least until this year, to stabilise the condition of the network (this point will be covered again in section 7.4.2.).

Recommendations of the Commission

16. Clarify accountability with respect to the MUNRN

The Commission is of the opinion that the management framework of MUNRN bridges should be reviewed to better reflect reality. On the one hand, the MTQ evaluates the bridges, determines the priority of rehabilitation work and subsidises the work, while on the other, small municipalities do not and will never have the necessary resources to manage structures of this magnitude.

The MTQ should regain ownership of all the MUNRN bridges or, at the very least, fully assume responsibility for their inspection, maintenance and ultimately, replacement. The Commission is of the opinion that municipalities should remain responsible for street lighting, road signs, sidewalk maintenance and snow removal on structures on their territory.

7.3.4 Comparison with neighbouring networks

The evaluation of the condition of Québec's bridges has revealed many similarities with the ways of doing things in the other Canadian provinces and in the U.S. For example, they all use an indicator to measure structural deficiency (referred to as the "condition indicator" in Québec) and another to measure functional deficiency (referred to as the "functionality indicator" in Québec). These indicators all serve the same purpose: to assess the general condition of bridges and put a dollar figure on the work required to keep them in good repair. Moreover, all the structures were built using essentially the same materials and technologies, indicating consistency in standards and methodologies.

Consequently, although it should be done carefully, a comparison can be drawn using these two common indicators.

The following table compares the indicators used in the U.S. to those in Québec.

Table 7.3 Definition of Québec and U.S. Indicators

Road Administration	Deficiency	Obsolescence
États-Unis[15]	Structurally deficient (SD): "1) Significant load carrying elements are found to be in poor or worse condition due to deterioration and/or damage or, 2) the adequacy of the waterway opening provided by the bridge is determined to be extremely insufficient to the point of causing intolerable traffic interruptions". All bridges classified as "structurally deficient" are excluded from the category of "functionally obsolete." Number of SD bridges in the U.S.: 73,764 (12%) • Pennsylvania: 5,582 (25%) • New York: 2,110 (12%) • New Jersey: 760 (12%)	Functionally obsolete (FO): " If it has a deck geometry, load carrying capacity, clearance or approach roadway alignment that no longer meets the criteria for the system of which the bridge is a part". " Functionally obsolete bridges are those that do not have adequate lane widths, shoulder widths, or vertical clearances to serve the traffic demand or those that may be occasionally flooded". Number of FO bridges in the U.S.: 80,226 (13%) • Pennsylvania: 3,989 (18%) • New York: 4,501 (16%) • New Jersey: 1,532 (24%)
Québec[16]	Condition indicator: "Refers to the condition of its components. Any defect affecting the structure's elements – concrete delamination, steel corrosion, wood rotting, etc. – is covered by this parameter."	Functional indicator: "Includes everything that makes a structure capable of providing users with the service they expect (e.g.: load carrying capacity, road width, upper and lower vertical clearances, traffic volume, etc.)"
	In Québec, a structure is classified as deficient if it requires major maintenance within five years.	

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[15] For definitions of American management indicators: U.S. Department of Transportation, Federal Highway Administration, 2006, Bridge Inspector's Reference Manual, Volume 1. Publication No. FHWA NHI 02-001, Section 4: Bridge Inspection Reporting System. Topic 4.2: Condition and Appraisal. Page 4.2.12. Figures taken from the National Bridge Inventory, available on www.fhwa.gov.dot/bridge/.

[16] Exhibit COM-52B, p. 2: Québec management indicators and figures.

It is generally acknowledged that the structural deficiency indicator (condition indicator in Québec) points to a more serious problem in that it means the structure has deteriorated to a point where work is required within no more than five years.

When in the mid ’90s, the U.S. authorities sought to reduce the number of deficient bridges in the country, they allocated a hefty budget to the rehabilitation of structures referred to as “structurally deficient”. As a result, this indicator fell from 18.7% in 1994 to 12.4% in 2006. During the same period, the proportion of bridges classified as “functionally obsolete” remained stable, changing from 13.8% in 1994 to 13.4% in 2006.[17]

During this same period of time in Québec, almost one out of every two structures was considered structurally deficient (condition indicator), as table 7.4 shows.

Table 7.4 Percentage of Deficient Bridges in Québec and the U.S.[18]

Territory	Structurally Deficient (US) and Deficient Condition (QC)	Functionally Obsolete (US) and Functionally Deficient (QC)
New Jersey	11%	24%
New York	12%	25%
Pennsylvania	25%	18%
U.S.	12%	13%
QUÉBEC - PRN	46%	2%
QUÉBEC – MUNRN	49%	13%

NOTES : Data is for 2005 in Québec and for 2006 in the U.S.

It bears mentioning that the average age of the bridges in the three U.S. states mentioned above was approximately 50 years[19] whereas it was 35.7 years for those in Québec’s PRN. A detailed analysis of the data pertaining to the three U.S. states showed that a level of deficiency equivalent to Québec’s could only be found among bridges built more than 60 years ago.

With regards to Ontario, a report published by the Ontario Auditor General in 2004 indicated that for that year, approximately 32% of the province’s bridges needed to be rehabilitated or replaced within five years (the same period of reference used in Québec to classify a bridge in the “deficient” category).[20] The situation in Ontario is therefore better than in Québec but not as good as in the U.S.

Notwithstanding the caution that should be exercised when making this type of comparison, it is nevertheless clear that Québec’s bridges are in much worse shape than those in Ontario and the United States.

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[17] National Bridge Inventory and 2004 Status of the Nation’s Highways, Bridges and Transit: Conditions & Performance, US Department of Transportation, Federal Highway Administration – Report to Congress. These two documents are available on: www.fhwa.gov.dot/bridge/ .

[18] U.S. Department of Transportation, Federal Highway Administration. 2006. *Bridge Inspector’s Reference Manual*, volume 1, Publication No. FHWA NHI 02-001, Section 4: Bridge Inspection Reporting System, Topic 4.2: Condition and Appraisal, Page 4.2.12.

[19] The average age of bridges for all of the U.S. was 42 years in 2006.

[20] This percentage pertains to the 2,800 provincial jurisdiction bridges whose average age is 37 years. Ontario also has between 12,000 and 13,000 municipal jurisdiction structures at an average age of approximately 55 years.

7.4 Bridge rehabilitation: a national priority

The need for a broadbased bridge rehabilitation programme gradually became apparent as the Commission's work revealed mounting, irrefutable evidence. The Commission itself, as well as the organisations it consulted, are convinced of the urgency to act in this regard.

Ontario, where 68% of bridges are in good condition, wants to see this figure reach 85% by 2021. In the U.S., where 75% of bridges are in good condition, the improvement initiatives undertaken in the mid-1990s continue. Québec needs to not only follow their lead but also set ambitious goals and find the means to achieve them. A tremendous, sustained effort will be required.

The Commission recommends the implementation of a programme at the end of which the proportion of bridges in good condition will increase from their 2005 level of 53,6% (for PRN bridges) and 51% (for MUNRN bridges) to 80% for both networks. In fact, this 80% target should apply to all 12,000 bridges in Québec. The Commission is of the opinion that a ten-year period at the very least will be required to reach this objective.

The Commission heard representations by various groups that all agree on the need for rehabilitation but disagree on how to go about it. For example, the *Association professionnelle des ingénieurs du Gouvernement du Québec* are calling for a bolstering of the role of the *ministère des Transports* by making it the prime actor of a major rehabilitation programme. For its part, the *Coalition pour l'entretien et la réfection du réseau routier du Québec* would like to see the creation of a parapublic company responsible for maintaining, repairing and improving the road network, including the bridge network. The *Ordre des ingénieurs du Québec* recommends creating a public agency with a mandate to oversee the implementation of action plans that all infrastructure managers, including municipalities and government departments, would be required to have.

The Commission will not express an opinion in this regard since it is of the opinion that elected officials have the responsibility to determine such fundamental issues that are at the core of the organisation of the State. The Commission did not conduct the research required for it to acquire detailed expertise in this regard.

However, based on its work and consultations, the Commission is in a position to recommend conditions it considers essential for the success of the proposed programme.

7.4.1 A targeted programme, managed as a major project

Regardless of the approach selected by the government (management by the MTQ, by a newly created parapublic or government agency, with or without the involvement of the private sector, including public private partnerships), the scope of this programme is such that it must be managed as a major project using the best governance and project management practices, rather than be subjected to the constraints of a regular government programme.

A massive effort will be needed. The size of the budget and amount of work required, combined with the specialized engineering and construction resources that will have to be mobilised and coordinated, are such that the proposed programme can easily be compared, in terms of complexity, scope and duration, to the largest projects ever carried out in Québec.

A project of this magnitude must fulfill its long-term objectives and take place under stable, predictable conditions in order to avoid a scattered execution. This means multi-year budgeting and planning without the uncertainties associated with annual budgetary reviews that would only reduce the programme's efficiency and even compromise its success.

Such an initiative will be best served with a dedicated team whose sole and long-term focus is the project. Because the project will attract quality human resources, turnover will be minimised, favouring the development of a qualified workforce and the formation of highly competent teams.

With regards to governance, the Commission recommends that independent experts be regularly solicited for advice and recommendations on how to improve management and quality control. This can be done by setting up independent audit groups comprised of specialists and practitioners from various disciplines.

7.4.2 The investments required

The Commission was unable to accurately determine the investments required to bring the condition indicators back to an acceptable level within the next decade. The Commission has not been able to conciliate the bridge rehabilitation figures in the MTQ's documents with those in other government documents.

Still, the Commission did notice the significant increase in the budgets recently allocated to structure maintenance and repairs.

With regards to the PRN structures, the revised plan approved in July 2007 by the *Conseil du trésor* indicates that the FCARR will contribute $540 million in 2007-2008. It should be noted, however, that once professional fees and administrative expenses are taken into account, the actual amount is $457.5 million. Last year's budget was $252 million budget, already a substantial improvement over the $151 million average spent in the last ten years. In February 2006, the MTQ estimated that at least $386 million would be needed each year for the next five years to carry out the work required, under current standards, over that period. In other words, the indicators will not improve under the current budget unless it is maintained over the long term.

As for the bridges in the MUNRN, whereas the average actual investments were $9 million per year between 1996 and 2007, they will increase to $30 million this year. This amount is still insufficient. In its 2005 report on the condition of Québec's structures, the MTQ estimated that, under current standards, $74 million per year would be needed each year for the next five years to carry out the work required. In short, this year's increase will not halt the deterioration of MUNRN structures and certainly will not reverse the trend.

While incomplete, this data leads the Commission to conclude that the government must plan a budget of at least $500 million per year for the next 10 years if it is to raise the condition indicator of PRN and MUNRN bridges to an acceptable level.

If the government chooses this direction, it will have to more accurately calculate the investment required to rehabilitate Québec's bridges. A financial effort of this magnitude requires a commitment from government. However, to ensure the smooth operation of the bridge and overpass rehabilitation programme, the following conditions are essential:

- Make a clear, firm commitment to provide, over a 10-year period, a steady, predictable budget dedicated solely to the rehabilitation of bridges and overpasses;
- Establish a clear distinction between the protected $500 million annual budget dedicated exclusively to the rehabilitation of existing structures and amounts allocated for new infrastructure or large projects such as major works on the St. Lawrence River bridges or the reconstruction of the Turcot interchange in Montréal;
- Ensure that the authority responsible for the programme manages it by following clearly established and publicly announced long-term priorities – the first being the safety of the population – and by developing a predictable multi-year plan for the work.

Fulfilling these conditions does not alter the accountability of elected officials, which will remain intact. They will determine the content of the bridge rehabilitation programme and the long-term financial commitment required to sustain it. They will keep all their prerogatives with regards to possible additions to the road network. Although not involved in the day-to-day management or in determining the most vulnerable structures, they will nevertheless be involved in setting the programme's priority objectives in accordance with their socioeconomic development policy. For example, they could decide to give priority to the rehabilitation of structures on roads used for export or on inter-regional links.

The Commission reiterates the need to establish and maintain stable, long-term financial and operational planning, impervious to cyclical or situational fluctuations. The Commission also insists on making public safety the first priority.

Ensuring the programme's long-term predictability and stability will also allow consulting engineering firms and the construction industry, as well as the MTQ, to better plan their human resources needs and to develop on a solid footing. It merits repeating that bridges are complex structures that call for special expertise. Following the example of Hydro-Québec, which contributes to the development of expertise in the electrical industry by keeping it informed on the volume of work and how it will be spread out over time, the approach proposed by the Commission will allow both the companies concerned and the MTQ to build strong, experienced teams. Besides guaranteeing better work quality, this approach will further Québec's development because these companies will then be able to export the expertise built in this specific area.

7.4.3 Funding

Besides the *Fonds de conservation et d'amélioration du réseau routier*, other funding sources exist for infrastructure rehabilitation. Two that immediately come to mind because they are widely used around the world are a special tax on gasoline and selective road tolls. These two options offer a threefold advantage: they are a source of stable and relatively predictable revenue; they are visible to taxpayers, and they create a "user-payer" relationship. Future legislative provisions should, however, assure taxpayers that these revenues will be entirely channelled to rehabilitating and maintaining of the structures, thus insuring the permanent character of the programme.

The Government of Canada periodically sets up infrastructure spending programmes. If the Government of Québec creates a programme with a systematic plan to rehabilitate all infrastructures giving priority to work related to public safety, it could justify a federal government participation in Québec's long-term programme.

7.4.4 Private sector involvement in financing and operations

The Commission is aware that there is sometimes reticence to involve the private sector in the financing and operation of public services. However, a public private partnership (PPP) does have its merits. When it entails managing or leasing a publicly-owned infrastructure equipment, a PPP must comprise very specific contractual conditions as regards performance objectives and returning of the structure in excellent condition at the end of the term.

The global private capital market often looks for safe, long-term investments with stable returns. Infrastructure financing offers an attractive opportunity in this regard.

Moreover, the private sector long ago proved its ability to adapt and be flexible when complex programmes are involved, and demonstrated its expertise in executing major projects.

The Commission has also noticed that private road construction using revenue-sharing formulas such as tolls is being successfully employed around the world. Still, the Commission understands that it is difficult to solicit private investment to rehabilitate aging structures whose level of deterioration can be hard to establish and that as a result, pose a challenge for financial institutions seeking to assess the risk. It appears easier to attract the private sector when new or replacement infrastructures are involved.

Given that the priority is to make Québec's infrastructures safe for the long term, the Commission believes that pragmatism should prevail over ideology. If, for some projects, the private sector can help improve the condition indicator within a reasonable timeframe and at lower cost, the government should not deprive itself of this resource. It must, however, ensure that public imperatives such as structure safety and quality at the end of the contract are fulfilled by establishing an effective accountability plan with the requisite sanctions. Using this financing and operating model would encourage our companies to participate in similar projects elsewhere on the continent.

Recommendations of the Commission

17. The Commission recommends that the Government make bridge rehabilitation a national priority based on the following principles:

- Adopt the principle of a bridge and overpass rehabilitation programme for Québec's PRN and MUNRN networks with the goal of bringing the condition indicator up to a level comparable to that of neighbouring provinces and states.
- Make this programme a Major Project and ensure that it is managed according to best governance and management practices regardless of the organisation and financing methods selected, with or without private sector involvement.
- Dedicate a protected budget of at least $500 million per year for 10 years exclusively to the rehabilitation or reconstruction of existing structures.
- Ensure the programme is managed based on long-term priorities – the first being public safety – that are clearly defined and publicly announced by the appropriate authorities, according to a predictable, multi-year work plan.
- Establish sources of financing that will provide stable, predictable revenues which taxpayers can easily identify by establishing the principle of "user-payer".
- Systematically call upon independent experts to recommend measures to improve the framework of management activities and quality control.
- If the Government chooses to involve the private sector, either in terms of financing or management, the participation should be conditional to the achievement of specific performance objectives and to the return of the structure in excellent condition, failing which clearly defined financial sanctions would apply

CONCLUSION

ASSESSMENT

In order to determine the circumstances and causes of the collapse of part of the de la Concorde overpass, the Commission considered and analysed extensive evidence consisting of testimonies, documents and expert reports, all aimed at uncovering the truth. To this end, it established the facts, which it then evaluated and interpreted in order to draw conclusions. The Commission also formulated a series of recommendations aimed at strengthening the management of Québec's bridges with a view to improving public safety. The Commission hopes that its work provided answers to the questions of thousands of citizens still reeling from this unexpected, incomprehensible and troubling event.

With regards to the circumstances of the collapse, the Commission can only describe them as violent and instantaneous. Given his functions and knowledge, the patroller reacted adequately before and after the collapse. The 9-1-1 service of Laval and the notification service of the *ministère des Transports du Québec* worked properly. Even before the arrival of emergency services, many citizens acted quickly and courageously to help victims trapped in their vehicles. Urgences-santé, police, firefighters, Laval's emergency services, and the Sûreté du Québec all responded in a timely and disciplined fashion.

As for the causes of the collapse, the Commission identified the main physical causes as well as secondary contributing causes. It examined the human behaviours and actions that played a part in the causes. It blamed the organisations and individuals who failed to live up to their responsibilities during the construction of the de la Concorde overpass. The Commission also analysed the MTQ's maintenance of the structure; while it deplores some specific actions taken by the *Ministère*, it blames above all the MTQ itself for systemic failures that spanned many years and that prevented it from understanding the growing deterioration of the overpass and for not taking the necessary actions to remedy the situation.

In the Commission's view, no single entity or person was responsible for the collapse of the de la Concorde overpass. No single defect or lapse identified in this report could have, on its own, caused the disaster, which, in fact, resulted from a sequential chain of causes. The Commission underlines that the tragic event of 30, September 2006, was the result of an accumulation of failures: that of applicable Code standards to the design of the bridge which today would be considered as faulty, and those of defects and lapses during the design and construction period of the bridge as well as its management during its useful life. This background is essential to understand and interpret the blames and reproaches contained in this report.

In addition to the anchoring details of the reinforcing steel creating the plane of weakness when the de la Concorde overpass was designed, confusing specifications led to the use of the wrong type of concrete, one that is not resistant to freeze-thaw cycles in the presence of road salts. Moreover, due to contractor negligence and extremely poor supervision during construction, the rebars were misplaced. All these factors resulted in an inherently weak structure.

The Commission also believes that the lack of shear reinforcement in the thick slab and the absence of a watertight membrane on the slab are secondary contributing causes.

Despite repeated inspections over nearly 40 years, the MTQ was unable to detect the fundamental weakness of the structure. When in 1992, the reinforcement steel was stripped as much of the deteriorated concrete was removed around the chair bearing support, the MTQ did not grasp the severity of the damage observed and did not evaluate the condition of the overpass. When in 2004 the engineer in charge of the bridge inspections became concerned about the condition of the de la Concorde overpass and requested the *Direction des structures* to provide technical assistance, it was not carried out rigorously.

The Commission makes a series of recommendations based on its findings. The tragedy of the de la Concorde overpass serves as a reminder of the need to exercise the utmost rigour when designing, building and managing bridges. It also highlights the importance of having a proper framework with standards, manuals and strictly implemented programmes to help inspection and maintenance personnel, and to encourage them to always be vigilant and conscientious when encountering problems on bridges under their responsibility. These recommendations are all the more relevant in a context of aging infrastructures.

LOOKING TO THE FUTURE

The Commission's mandate revealed the need to modernise our infrastructures, built largely in the 30 years following World War II. Québec is not alone; the situation is similar across all of North America. At issue is not only public safety but the ability to maintain first-rate infrastructures, which play a role in the quality of life of Québec's residents and in its economic development.

Bridge rehabilitation is just one of many modernisation projects Québec must undertake and one that should not be neglected because bridges are just as important to our quality of life as roads, waterworks and sewer systems, drinking water and wastewater treatment plants, public buildings, schools, hospitals, public transit systems and parks.

Hundreds of projects need to be planned and coordinated over many years in a context of limited financial resources. Hence the importance of making the right choices, sticking to them for the long term and maximising the impacts of such investments. This means adopting multi-year budgeting and financial planning, taking a major project approach, and using appropriate management methods. It is up to elected officials to determine what efforts must be made, to articulate the participation of the private sector and to enlist through consensus the commitment of the population and of institutions.

From a socioeconomic viewpoint, infrastructure rehabilitation offers our companies and workforce a good opportunity to advance provided we understand and leverage their potential. The massive and inevitable investment Québec must make is an excellent opportunity to master skills, further research, and develop cutting-edge technologies. These investments can boost local and regional development and with the participation of the private sector, make up a source of expertise and skill building and exports that will benefit all.

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