The Council on Tall Buildings and Urban Habitat

Comments

on the

"Structural Fire Response and Probable Collapse Sequence of World Trade Center Building 7 August 2007"

Prepared and Issued by
The National Institute of Science and Technology (NIST)
as a Draft Report for Public Comment

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1. Introduction

In August 2008, NIST issued their report on the Structural Fire Response and Collapse Sequence of World Trade Center Building 7, for Public Comment.

This brief report contains feedback from the Council on Tall Buildings and Urban Habitat on the NIST report. The Council's key interest in the NIST study is an understanding of the collapse sequence and one of NIST's key objectives, which was to "identify, as specifically as possible, areas in the current building and fire codes, standards and practices that warrant revision."

The Council believes that the NIST report is a responsible attempt to find the cause of the failure, and finds that the report has investigated many of the probable causes. The Council has several technical questions about details of the modeling; but we would not expect that to change the conclusions: that the floor beams failed due to fire, which led to buckling of the internal columns resulting in global failure.

However, the Council feels that the report does not adequately investigate the implications that this failure has on the design practice for tall buildings, as per Objective No. 4 in the NIST report. Although the NIST report clearly identifies factors that could have mitigated the structural response (Chapter 14.6), it does not investigate how effectively changes to design practices could have improved performance.

The NIST report recommends that in the future, buildings should be designed so that they do not collapse, even in an extreme fire, and even if the sprinkler system fails or is overwhelmed by the fire. The approach recommended by NIST is essentially a performance-based approach which explicitly checks the performance of structure in fire. This approach is becoming commonplace for some buildings which are considered special due to their extreme height or complex design. However, such an approach is less common for more typical high-rise buildings.

The Council supports the use of Performance-Based Design (PBD) for tall buildings. However, within the industry there is a lack of knowledge and consensus about how PBD should be implemented and there is a need for the industry to share knowledge and develop an understanding. The Council does encourage NIST to set an example in this respect and hypothesize a performance-based approach to WTC 7 and identify what specific structural changes would have made this building perform to an "acceptable" level.

There is a common premise that in order to achieve the necessary level of fire resistance, every structural element must equally conform to the minimum fire protection requirements. This is a convention that is not necessarily required by building codes, which only ask that the fire resistance be achieved, and do not specify exactly how this is done. Many PBD studies have demonstrated that varying the fire protection regime across the structural elements of a building can enhance the performance in fire, without additional cost, and often at a reduced cost.

The Council does not agree with the NIST statement that the failure was a result of the buckling of Column 79. We believe that the failure was a result of the collapse of the floor structure that led to loss of lateral restraint and subsequent buckling of internal columns.

The Council would like to make it clear that it sees no credibility whatsoever in the 911 'truth movement' and we believe, with the vast majority of tall building professionals, that all the failures at the WTC (WTC 1, 2, 5, 6 and 7) were a direct or indirect result of the planes that were flown into the two towers. We have carefully looked at the evidence that the 911 'truth movement' presents and we cannot see any credible scientific evidence of a controlled demolition on WTC 7 or any of the other WTC buildings. The Council considers that the 'truth movement' is a distraction and should not obfuscate the performance issues which should be at the center of the debate about how best to continue to improve and develop fire and life safety in tall buildings.

2. Background

The National Institute of Science and Technology (NIST) issued its draft report on the fire and collapse of World Trade Center 7 in August 2007, and was issued for public comment. Our report contains the formal response by the CTBUH that has been compiled by the Council's Fire & Safety Working Group, led by Simon Lay, Daniel O'Connor, and David Scott.

The Council has solicited technical discussion through an online forum located at www.ctbuh.org. Tower 7 collapsed as a result of the fire that was ignited during the 9/11 terrorist attack. The report concludes that the collapse was solely a result of the fires that started on ten levels following the initial attack. The failure occurred approximately eight and one-half hours after the first attack. The collapse of WTC 1 and 2 severed the water mains, reducing the capacity for suppression by sprinklers and consequently the firefighting effort was abandoned after the collapses of the twin towers.

NIST notes that the structural failure was caused by the effects of thermal expansion. Fire engineers are well aware that the effects of thermal expansion and thermal contraction (during the cooling phase) are often substantially more significant than the effects of heat reducing the strength of materials. This understanding needs to extend to architects and engineers who are involved in the high-rise industry and an introduction to the subject is described in the paper David Scott presented at the NIST national workshop on Prevention of Progressive Collapse, July 2002. The paper – "Fire Induced Progressive Collapse" – authored by Scott, Lane and Gibbons can be found online and on the CTBUH website.

This CTBUH report contains various technical comments on specific chapters of the NIST report. However, the primary focus is the NIST recommendations and the NIST objective – namely, to identify what parts of current practice need to be reviewed and improved.

The NIST report has identified a series of complex structural effects which led to the collapse of WTC. The Council believes that these mechanisms can be adequately understood and predicted using information and design methods that are available today, even if these are not currently found in many building codes. The Council considers that fire and structural engineers do have the capacity to design safe, tall buildings.

3. Initiating Event Hypothesis (Chapter 8)

This section summarizes CTBUH comments on Chapter 8 of the NIST report. Several conclusions drawn in the NIST report on the contribution of structural components in failure initiation are unexpected and have raised concerns within the Council. These conclusions involve the role of both shear studs and local global buckling of the floor beams in failure initiation. The Council believes that the local connection performance was a significant part of the global failure and would like to have seen a more explicit analysis of the connection failure. (See also comment on Chapters 11-13.)

The NIST analysis (p. 353), shows that shear studs and the bolts holding the primary Column 79 failed before the temperature of the steel reached 200˚C. This implies a fundamental weakness that would be picked up by a conventional PBD analysis. These temperatures are very low compared to a fire protection test that assumes that steel loses strength at 550˚C.

The failure of shear studs is surprising, and has been modeled in a very simplistic way, which may overestimate the failure of this element. Prior studies and real fire cases have not previously identified shear stud failure as a significant possibility.

Perhaps the temperature regime of the slabs may have impacted on the stud failure prediction. If the top of the slabs were modeled as being hotter than the underside of the slabs, that might cause an upward bow, against the typical downward deflection of the steel deck, adding stress to the shear studs.

Adequately designed shear studs can play a significant role in the stability of the structure under fire conditions, and the NIST study should not be taken to indicate that failure of shear studs is likely, only that this was an assumption within the model. It is unclear what the effect of a more accurate shear stud model would have produced in the NIST study, and in the somewhat extreme case of WTC 7 (given the multiple fire floors) it is unlikely that a significantly different overall conclusion might be reached. However, in more typical fire scenarios, shear studs can still provide a significant benefit.

It is difficult to understand why the top bolts of the girder would fail at connection to Column 79. Such failure would mean the slab had moved relative to Column 79.

The finite analysis model applied was limited (Fig 8-22), and this may have restricted the ability of the model to pick up all the local effects around Column 79.

One important question that should be addressed is “Did NIST review and evaluate any cooling cycle effects?” If cooling had started after the bolts connecting to Column 79 had failed, would the connection be stable?

It is surprising to see in-plane buckling of the beam as being a key generation of the initial failure, since it would be expected that the floors would bend out of the way on their major axis, combined with a local buckling of the bottom flange, like those found in the Cardington Fire Tests.

On page 330, NIST states that "the challenge was to determine if a fire-induced floor system failure could occur in WTC 7 under an ordinary building contents fire." But we cannot identify where in the report they address this challenge. The studies of the fire spread, without the initial structural damage, still assume fire spread on multiple floors, which is, in itself, a consequence of the initiating terror attack.

The report is rather confusing because the floor analysis is considered in Sections 8, 11 and 12. It would be better if there was a complete reconciliation of the analysis models.

4. Fire Analysis and Simulations (Chapter 9)

Critical to the implementation of PBD is the establishment of reasonable and justified criteria on which the performance of a developed design can be based. This section of the NIST report identifies fire intensities and extents that are assumed to have existed within WTC 7 prior to its collapse. However, the Council has found it unclear how these assumed conditions relate to NIST recommendations for PBD of tall buildings in the future. The Council believes it is important for NIST to explicitly discern the facets of the WTC 7 study that it recommends for inclusion in PBD of other structures. Discussed below are specific assumptions whose applicability to general structural design has been called into question.

NIST estimated a combustible fuel load of 20kg/m^2 for open plan office areas and 32kg/m^2 for areas with a cubicle layout. Are these the fuel intensities that NIST would recommend for a PBD and how are these values justified?

The NIST report proposes a very intense fire 250MW under Level 13, the floor that lasted for 2 hours. Is this a design intensity that NIST would recommend for offices?

It appears that the fire on Level 12 had passed its peak in the area of Column 79. Is it possible that failure occurred as part of the cooling cycle?

5. Structural Heating (Chapter 10)

Why was Floor 7 so hot when there was no floor or fire at Level 6. When NIST refers to Floor 7 do they mean the floor or the ceiling of the seventh floor?

After approximately two hours the floor slab temperature reached over 675°C. What was the distribution of heat through the concrete slab? The temperature distribution in the slab can often have a significant effect on the floor performance and the stresses on the shear studs.

In simulations A and B, the floors are subject to critical heat for less than an hour. Does this imply that the tower floors would have collapsed under a normal fire if the sprinklers did not work? If NIST is advocating that engineers analyze building performance as part of the normal design process, then surely they can answer the challenge they set normal designers. Did their analysis show that the building would fail under a normal contents fire?

6. Structural Analysis and the Cause of Failure (Chapters 11-13)

In these sections NIST states that the initial failure was caused by the failure of the floor system, in particular the connections to Column 79, that led to the column becoming excessively slender and buckling. These statements contradict the summary section 14.3.4 that identifies the initiating event as the buckling of Column 79. We strongly believe that the initiating event was the failure of the floor and the girder connections to the main column and that this should be documented in Section 14.3.4.

The report does not describe the detail failure mechanism of the girder connection to Column 79. Since this was critical to the failure we would expect to see diagrams of it, in its deflected, deformed shape immediately prior to collapse.

The connections models (e.g., Fig. 11-15) do not appear to reasonably reflect the important effect that the slab has on the connection performance.

7. Summary and Recommendations (Chapter 14)

The report says that improvements to the frame, connections, and long spans could have mitigated the collapse. The industry needs to understand the main characteristics of the building which led to the collapse, and needs to understand the types of details and configurations that create poor performance, and why.

The fire-induced failure of WTC 5/6 showed designers that short, slotted holes at the end of stub cantilever primary girder connections work under dead and live load conditions, but do not work in fire conditions, even if the beams are properly fire protected. What did the failure of WTC 7 show and what can be done to make a similar building perform better?

1) If the primary girder had shear studs would the floor have failed?
2) If the girders had fin plates or end plates would the building have survived?
3) Did the floors fail on the heating or cooling cycle, and theoretically which was worse?
4) How effective was the slab to tie the floors over the column, and what were the catenary forces and how effective was the reinforcement?

5) Normal fire codes assume a fire only occurs on one floor and much of the fire protection design is to stop flame spread between floors. WTC 7 started with fires on 10 floors and the report is vague about whether this had an impact on the failure.
6) Would the tower have failed if the fire was only at one level? The report is not clear on this issue.

NIST recommends a Performance-Based Design approach as a general standard on tall buildings. Can the issues above be verified by a simple performance-based design check, and if not, then surely NIST should qualify its recommendation for this approach as a basis for future design.

8. Performance Based Design

NIST is suggesting that the building community design all buildings by modeling fire performance. The implication is that this is not difficult and can be part of the normal process. The Council requests that NIST take the WTC 7 floor plan, model it in fire and change the design to make it work in a fire, showing the public what it takes and how easy it would be. In that way designers could see the type of changes that would need to be incorporated in the design.

Is it possible that small changes to connections or shear studs could have a major impact on the performance of the floor?

Normal codes assume that there is a fire on only one floor at a time. Does NIST recommend that all floors should be considered on fire? Based on the WTC 7 fire it could be assumed a maximum of 2 floors, but some other fires have had many floors on fire. What guidance would NIST give?

If we keep on adding up extreme approaches, we could get some extreme buildings. Is it appropriate to realistically consider the following assumptions simultaneously:

- The sprinklers do not work
- Fire fighting does not occur, and
- 2, 5, 10 levels are on fire simultaneously
- The fire lasts for 7 hours?

The Council agrees with NIST's support of performance-based design for tall buildings. Performance-based design can often lead to higher safety levels, more collapse prevention, and often results in more fire protection in some areas and less in others.

9. NIST Recommendations

The comments in this section refer to several of the NIST recommendations in Chapter 5, on the Final Report of the Collapse of World Trade Center Building 7, issued as a Draft for Public Comment.

General Statements

We do not agree that "The intent of current practice, based on prescriptive standards and codes, is to achieve life safety, not collapse prevention."

Traditionally, building codes have prescribed property protection, and minimizing the loss to the building and its contents is still a major consideration. Only in the last 50 years has there been more emphasis on "life safety." We would suggest that a better wording would be "The intent of current practice of all building codes is to achieve optimum levels of life safety and structural integrity."

Buildings should not collapse in infrequent (worst-case) fires, without sprinklers

While in principle the Council agrees with "the key premise of NIST's recommendations is that buildings should not collapse in infrequent (worst-case) fires that may occur when active fire protection systems are rendered ineffective, e.g., when sprinklers do not exist, are not functional, or are overwhelmed by the fire," there are several factors that need to be considered.

From a historical perspective, sprinklers and fire fighting have been incredibly effective at preventing collapse of tall buildings and preserving life safety. It should be recognized that WTC 7 was subjected to extreme events of failed sprinklers, extensive impact damage, no firefighting and simultaneous fires in ten floors. Is it reasonable to consider that this extreme event be considered a design case? It would be useful if NIST could document what "performance" the WTC 7 floor would give under a normal design fire.

We recognize that it is becoming increasingly common for designers of tall or iconic buildings to design these buildings using a performance-based approach, and frequently part of the performance requirement will be to prevent collapse prevention under a full flash-over fire without sprinklers. However, this is rarely combined with structural impact damage or multiple level fires.

We do not believe that it is reasonable to require all buildings to perform with extreme fires without sprinklers. There may be better value solutions for different building types and forms. For many buildings, duplicate fire risers and/or back up water supplies may well be an acceptable alternative. We should also expect that as performance-based design becomes more common, the lessons learned from it will start to be applied to other buildings. Once performance-based design becomes an industry norm, we would agree that it would be appropriate to apply it to all buildings

Increased Structural Integrity to Prevent Progressive Collapse

NIST recommends the development of codes and standards to prevent progressive collapse of structures of buildings subject to multiple hazards.

There has been an extensive debate about the appropriate level of design of buildings to mitigate the potential of progressive collapse. It is not possible to design buildings to withstand all potential combination of all extreme events. Based on discussions, most of the Council prefers to see a performance-based design approach for mitigation of progressive collapse.

The Government Services Agency (GSA) has introduced onerous requirements for progressive collapse mitigation (Progressive Collapse Analysis and Design Guidelines for New Federal Office Buildings and Major Renovation Projects, June 2003). It is not clear if these GSA measures, which are very severe, would have prevented the WTC 7 collapse, since even the GSA rules do not require consideration of fire conditions.

We do not agree with the NIST comment which links design for progressive collapse mitigation and the design for fire-induced progressive collapse mitigation. These issues are quite different and it is misleading to connect them. Normal progressive collapse design does not consider performance in fire conditions. Only Performance-Based Fire Design looks at potential progressive collapse under fire conditions.

Enhanced Fire Endurance of Structures
NIST recommends that all buildings should be enhanced to avoid collapse in worst-case fires without sprinklers, and are suggesting that a performance-based design approach would be able to do this.

The Council would like NIST to show the industry what changes to WTC 7 would have resulted in an improved and acceptable performance. This investigation would help the industry understand what NIST is recommending. In particular, the Council is interested to see if some simple changes to the floor structure and detailing could have improved performance considerably, and from experience on other projects, this is often the case.

NIST has recommended improvement to connections and framing systems to improve performance and we agree that this issue needs to be better understood. The Council is of the view that this issue needs to be addressed in more detail in the NIST report.

If NIST were to improve the design of WTC 7 up to a level that they deemed acceptable, then such an exercise would be an example to the industry of what NIST is recommending for future design. If NIST expects the industry to do this work, it should not be enormously difficult to do.

10. CTBUH Conclusions

The Draft NIST Report on World Trade Center 7 is a comprehensive assessment of the events that led to its collapse.

The Council does not agree with the NIST statement that the failure was a result of the buckling of Column 79. We believe that the failure was a result of the collapse of the floor structure that led to loss of lateral restraint and then buckling of internal columns. This is an important distinction, as NIST appears to be seeking improved performance from floors rather than columns.

The Council would like to know if there are any simple changes to the floors and connections that would have resulted in a better performance than occurred.

The Council would like to understand how the floors would have performed in an analysis of a design flash-over fire, without sprinklers. This would correlate a real failure with a normal performance-based analysis, and help to increase the understanding of performance-based design procedures.

NIST has suggested some comprehensive changes to the design process that they recommend for consideration in future codes development. These changes need considerable work prior to being incorporated in any codes or standards. However, the Council agrees that performance-based design methods should be the method of choice for large and complex buildings, and these methods also allow both typical fire safety and more extreme events to be studied..

These comments are made by The Council on Tall Buildings and Urban Habit as part of the NIST public consultation process. The Council hopes that these comments will assist NIST in improving and developing the draft version of the report.