Defence Works Functional Standards

Guide to World War II Hangars

02 - Type T2 Hangar

DEFENCE ESTATE ORGANISATION (WORKS)
MINISTRY OF DEFENCE

DEFENCE WORKS SERVICES
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Defence Works Functional Standards

Guide to World War II Hangars

02 - Type T2 Hangar

MARCH 1995

COMPILED BY AIRFIELDS & BULK FUELS GROUP (ABFG)
DEFENCE WORKS SERVICES

Acknowledgements

Defence Works Services would like to express their thanks to the British Constructional Steelwork Association Limited (BCSA) for their permission to reproduce tables from the Historical Strucural Steelwork Handbook. DWS would also like to extend their gratitude to the British Standards Institution for permission to reproduce the UK map of wind speeds.

Foreword

This Standard was prepared under the patronage of HQ STC.

This document is intended for use by Project Sponsors, Property Managers (PROMs), Establishment Works Consultants (EWCs), Works Services Managers (WSMs), Project Managers (PMs) and any other MOD staff using the Type T2 hangar or engaged in duties connected with the hangar.

MOD addressees should ensure that designers and contractors employed for works connected with the Type T2 hangar are advised of the Functional Standard.

Amendments to this Functional Standard will be advised by DWS Technical Bulletin and it is the responsibility of the reader to check with the PM or Project Sponsor if amendments have been issued. A sheet is provided to record amendments.

A Change Suggestion Form is included at Annex A for feedback on suggested changes and development of the Functional Standard. All readers of the document are requested to send the form to the DWS Technical Authority giving details of any suggestions they may have.

In making reference to any publication mentioned in this Functional Standard, readers should check the latest edition from its publisher.

Any reference to works or project in this Functional Standard should be interpreted to mean either "works services" with estimated cost currently below £300k overall or "project" with estimated cost above £300k overall (NB inclusive of professional fees and VAT).

The DWS Technical Authority on hangar buildings is:

Structures Section
Airfields and Bulk Fuels Group
P O Box 1734
Sutton Coldfield
West Midlands B75 7QB

All enquiries in connection with drawings and requests for copies of drawings should be addressed to:

The Library
HQ DWS
P O Box 1734
Rectory Road
Sutton Coldfield
West Midlands B75 7QB

Every care has been taken in the preparation and presentation of this document, but the information provided is for guidance only and it must be verified and checked for each individual project.

Amendments

Amendments	Page No	Date	Inserted By

Abbreviations

BS	British Standard
DCI	Defence Council Instruction
DWS	Defence Works Services
EWC	Establishment Works Consultant
HQ STC	Headquarters Strike Command
JSP	Joint Services Publication
MHE	Mechanical Handling Equipment
MOD	Ministry of Defence
PM	Project Manager
PROM	Property Manager
TB	DWS Technical Bulletin
WSM	Works Services Manager
pc	permissible axial stress in compression
pt	permissible axial stress in tension
pbc	permissible bending stress in compression
pbt	permissible bending stress in tension

CONTENTS

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1.0 INTRODUCTION

This Functional Standard is a guide to the Type T2 hangar, for use by all those from within MOD or from external organisations, engaged in works or duties connected with the hangar.

The Type T2 hangars are in active use on the MOD estate. Many of these hangars are subject to maintenance, repair and refurbishment works depending upon the condition of a particular hangar, its current and future use and predicted life span.

In this Functional Standard the term Type T2 is used as a generic term for all hangars within the Type T2 group. The Functional Standard describes the typical Type T2 hangar, how it can be identified, its typical structural form and features. There are a number of variations within these types of hangars, the most common being the 'standard' Type T2 (23) comprising 23 bays of the lattice steel portal frame and this is given detailed consideration in the Functional Standard. The Functional Standard records the Archive Drawings available on microfilm and the new Typical Drawings that were prepared illustrating the 'standard' Type T2 (23) hangar.

The long held view within MOD is that wartime hangars have inherent weaknesses in their structural strength, particularly the lightweight hangars such as the Type T2. In view of this, an in-depth analysis of the Type T2 (23) structure was carried out to determine its strength. The results of the structural appraisal confirmed that there existed some deficiencies in the strength of the hangar, in that it fell below current standards for design and loadings. The degree of shortcomings in the hangar's strength depended on its location within UK as this determined the wind and snow loadings applied to it.

This Functional Standard explains how the 'standard' Type T2 (23) structure was appraised, the design philosophy adopted and findings of the analysis. The historical design codes and steelwork stresses and the current loading criteria are covered. The significance of dominant openings in a hangar building due to door and window openings and the building's permeability is also explained.

Due to concerns about weaknesses in the structural strength of wartime hangars, operational constraints had to be put in force. These constraints in the main required hangar doors to be kept shut and the structure put under observation during adverse weather conditions of snowfall and high winds.

The Functional Standard covers general hangar refurbishment and the common work items which a PROM or Project Sponsor would be involved with, e.g. roof and wall re-cladding, doors, floors, etc. Guidance is given in respect of MOD policy, working practices and any other standards or codes that are applicable, depending upon the particular work item under consideration. Typical solutions are given with illustrations for strengthening the Type T2 structure.

MOD Fire Standards directly applicable to hangars are explained, including MOD policy on their application during refurbishment works. The application or otherwise of Building Regulations can in certain circumstances be difficult to interpret, and suitable guidance is given to overcome ambiguity. During major refurbishment works on a hangar, Project Sponsors may be compelled to upgrade the hangar in order to comply with statutory requirements, i.e. structural safety, fire regulations, etc.

Any planned hangar works cannot be analysed without an estimate of costs. Limited information is available on cost estimates during refurbishment works, including costs for strengthening of structure, re-cladding, etc. In selecting the most economical option during hangar works, the option of a new build alternative should not be ignored. Cost estimates of a new build hangar are also given, enabling comparisons to be made.

In selecting the option of whether an existing Type T2 hangar is refurbished or demolished and a new hangar built, it is realised that capital costs for the latter are higher than for the refurbishment option. A site specific structural appraisal is recommended with all the options for a project being considered according to their particular circumstances. An investment appraisal should be carried out based on cost estimation using risk analysis. The professional judgement for the safety of structure and its economic viability, taking into account factors such as predicted future uses, projected life span requirement and the operational consequences of a hangar being out of use during construction works, should be given due consideration. A well balanced and measured approach can then be taken for a project's viability.

Where a hangar is in its original state i.e. without having been strengthened, re-clad or refurbished, the choice between upgrading the existing hangar and a new build hangar is a simple one, largely dependent upon a site specific investment appraisal. Given equal considerations, this is likely to lead to the fact that refurbishment is a cheaper option. However the new build has the advantage of incorporating current user requirements as against making impromptu arrangements. The maintenance, repair and running costs will also prove to be lower.

When a hangar has already been refurbished and its cladding renewed, the choice between upgrading the hangar in view of any structural weakness and new build can be difficult, in that despite major expenditure the operating restrictions on the use of the hangar during adverse weather conditions will continue to remain in force unless the structure is strengthened and this is not easy particularly when new cladding is in place. The investment appraisal using risk analysis then becomes a much more demanding and sensitive exercise. It should however be understood that the operating restrictions on the use of a Type T2 hangar are not as rigid as, for example, a Bellman hangar.

2.0 BACKGROUND

It is estimated that there are in excess of 100 Type T2 hangars throughout UK. The hangars were built around World War II, during late 1930s to early 1940s, and are still in use on the MOD estate. The Type T2 hangars were often referred to as "transportable sheds" due to the fact that their modular design meant that they could be dismantled and transported to a new location for reuse.

Many of the wartime hangars were erected as temporary structures in anticipation of a short design life. They were produced in order to provide a fast, economical solution to a need for hangars before and during World War II. They were built hastily and over a short period of time, with many 'enjoying' emergency relaxation of design standards. The envisaged short term exposure to wind and snow loading would have allowed smaller loadings to be considered than is the case for long term exposure as the magnitude of the design load is dependent upon the life of the structure.

It is believed that Type T2 hangars were built at locations as listed below. The list is not authentic and it is given for information only, subject to confirmation. It is noted that a number of the stations listed below may have closed. Also some Bellman hangars at the respective locations may be permanently out of use or they may have been demolished.

RAF Alconbury	RAF Acklington
RAF Barkston Heath	RAF Benson
RAF Bentwaters	RAF Bedford
RAF Biggin Hill	RAF Bovingdon
RAF Burwell	RAF Brawdy
RAF Ballykelly	RAF Boscombe Down
RAF Chelveston	RAF Chilton
RAF Church Fenton	RAF Coningsby
RAF Foulsham	RAF Greenham Common
RAF Gaydon	RAF Henlow
RAF Honington	RAF Hemswell
RAF Honeybourne	RAF Knettishall
RAF Lakenheath	RAF Llanbedr
RAF Molesworth	RAF Mona
RAF Milfield	RAF Northweald
RAF Oakington	RAF Pershore
RAF Raydon	RAF Rattlesden
RAF St Mawgan	RAF Stradishall
RAF Sculthorpe	RAF Swanton Morley
RAF Sydenham	RAF Scampton
RAF Strubby	RAF Saltwick
RAF Stornoway	RAF Syerston
RAF Tockwith	RAF Valley
RAF Wethersfield	RAF Wyton
RAF Watton	RAF Wattisham
RAF Waterbeach	RAF Woodhall Spa
RAF Wymeswold	

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3.0 GENERAL ARRANGEMENT

3.1 IDENTIFICATION AND DESCRIPTION

In dealing with any hangar works, it is vital that the hangar type is correctly identified. Some hangars have only minor differences between them and any doubts about identification of the Type T2 hangar can be clarified with the DWS Technical Authority.

At first glance the Type T2 and Bellman hangars appear very similar. They are both lightweight structures made from steel lattice portal frames but the doors of the Bellman run level with the top of the side panelling, whereas T2 hangars have panelling above the doors before the roofing commences. See photos 3.1 and 3.2.

Another distinction between the Type T2 and Bellman is the lattice arrangement of the portal frame units. The Type T2 is a Warren type i.e. with all internal web bracing members as diagonals whereas for the Bellman the internal web bracing members are similar to the Type T2 but with additional vertical members (NB horizontal in columns) at each node. See photos 3.3 and 3.4.

Each gable end has six sliding doors allowing an opening the full width of the hangar to be formed. Some hangars may now have operational doors on one end only, the other end with doors permanently locked. There is a top guide track and the doors slide on a roller track bottom.

The most common of the Type T2 hangars is the 'standard' Type T2 (23), which denotes 23 bays of the portal frame along the length of the hangar. The frame centres are at 3.175m giving an overall building length of 73.025m, and a width of 36.833m. The overall height of the hangar is 11.909m and the eaves height is 8.839m giving a clear height of 7.620m.

Two basic units were used to form the Type T2 structure, these being the column and rafter standard units approx 3.658m long and 1.041m wide comprising 2 No toe to toe angles as boom members and pressed metal channels or 2 No welded toe to toe angles as ties/diagonals. The pressed metal channels as internal web bracing were used on earlier buildings whereas the later buildings used rolled steel angles. Both types of internals however gave almost identical load capacities. The eaves units which are of slightly heavier construction than the standard units form a corner unit at the head of the columns. The eaves units join the columns to the rafters, the latter consisting of 8 standard units, 4 in each half of the portal frame. The columns comprise 2 No standard units each. The connections of the internals have a standard 2-bolt connection detail and the units were connected by bolts.

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Photo 3.1 External View of Type T2 Hangar

Photo 3.2 External View of Bellman Hangar

Photo 3.3 Lattice Portal Frame of Type T2 Hangar

Photo 3.4 Lattice Portal Frame of Bellman Hangar

Longitudinal stability of the hangar is provided by bracing the frames at roof level and in the side walls at three locations, one at each end and one in the middle of the building. The secondary members consist mostly of angle sections for the purlins, sheeting rails, rafter bracing and vertical wind bracing. All connections are bolted together to form the structure.

The original roof covering was corrugated steel sheeting but some hangars are known to have been re-clad using pressed and profiled metal sheeting possibly using insulation.

The hangars have a concrete floor and the foundations are of a simple pad type base for each column.

DWS Drawing Nos D/DWS/H1/002/001B & 2B show basic details and dimensions of the 'standard' Type T2 (23) hangar and reduced size copies are included in this chapter.

There are basically five variations to the Type T2 hangar, namely T2, T2 HD, TFB, TFBHD and T2 MCS. Each of these variations in turn have further variations within the respective type. For example Type T2 (26), T2 (18), T2 HD (46), TFBHD (26), etc. The number in the brackets denotes the number of bays formed by the portal frame. The abbreviation HD refers to a heavy duty structure where frame centres are halved for additional strength.

The standard portal frames are used for all the T2 and T2 HD variations by changing the total number of bays and hence the overall length of building or halving the frame centres for the heavy duty types. For the TFB (Flying Boat Hangar) and TFBHD, the standard portal frame is used but with an additional standard lattice frame unit to give a clear door height of 35' 0" (10.668m). The T2 MCS (7) (Marine Craft Shed) is a smaller building with 7 bays achieved using lesser standard frame units in the columns and rafters.

Details of all the variations within the Type T2 group of hangars and their dimensions are given in Table 3.1. In order to illustrate the variations and provide an "at a glance" impression of the hangars, simple sketches of each variation are given in Figure 3.2.

The frames of the Heavy Duty hangars are so close that the typical pad foundations merge into a continuous strip.

3.2 DRAWINGS

Archive Drawings of the Type T2 hangar are available on microfilm including some as prints. There are no records of site specific as-built drawings, unless these are available from a PROM or Project Sponsor at the particular site. The Archive Drawings appear to be authoritative records of the Type T2 hangar, as seen during site inspections.

A range of Type T2 drawings were examined and a list of those drawings appertaining to the Type T2 (23) hangar was selected. These drawings are listed in Table 3.3. The full list of drawings is available from the Library at HQ DWS. It cannot be confirmed whether the drawings list is 100% complete i.e. representing all the drawings as originally produced. The drawings give an outline of the structure and its component parts. The quality of the microfilming is poor in some cases and the extent of the drawings is not comprehensive enough to fully define the structure. The drawings on microfilm can be viewed on a projector, subject to prior arrangements with the Library at HQ DWS, at the address given in the Foreword to the Functional Standard.

Hangar Type	Frame Centres (mm)	Overall Length (mm)	Clear Door Opening	
			Width (mm)	Height (mm)
T2 (23)	3175	73025	34595	7620
T2 (26)	3175	82550	34595	7620
T2 (18)	3175	57150	34595	7620
T2 (17)	3175	53970	34595	7620
T2 (14)	3175	44450	34595	7620
T2 (13)	3175	41275	34595	7620
T2HD (46)	1587.5	73025	34595	7620
T2HD (26)	1587.5	41275	34595	7620
TFB (24)	3048	73152	34595	10668
TFBHD (46)	1524	70104	34595	10668
TFBHD (26)	1524	39624	34595	10668
T2MCS (7)	3175	22225	16535	5791

Table 3.1 Variations of Type T2 Hangars

The examination of microfilmed drawings and collation of information obtained from site inspection has enabled two Typical Drawings to be produced, showing the structural form of the Type T2 hangar. The general arrangement of steelwork and foundations are detailed in Drawing Nos D/DWS/H1/002/001B and 002B. The Typical Drawings were produced in AutoCAD form at A1 size. A reduced size copy of each of the Typical Drawings is included at the end of this chapter. These drawings form the basis of the assumptions made in the structural appraisal of the Type T2 (23) hangar, assisted by Archive Drawings as listed in Table 3.3 where appropriate.

The Typical Drawings convey DWS' understanding of the Type T2 hangar. If an on-site inspection reveals any deviations from the Typical Drawings, then suitable allowances should be made to the guidance and recommendations in the Functional Standard in line with the nature and scale of deviations.

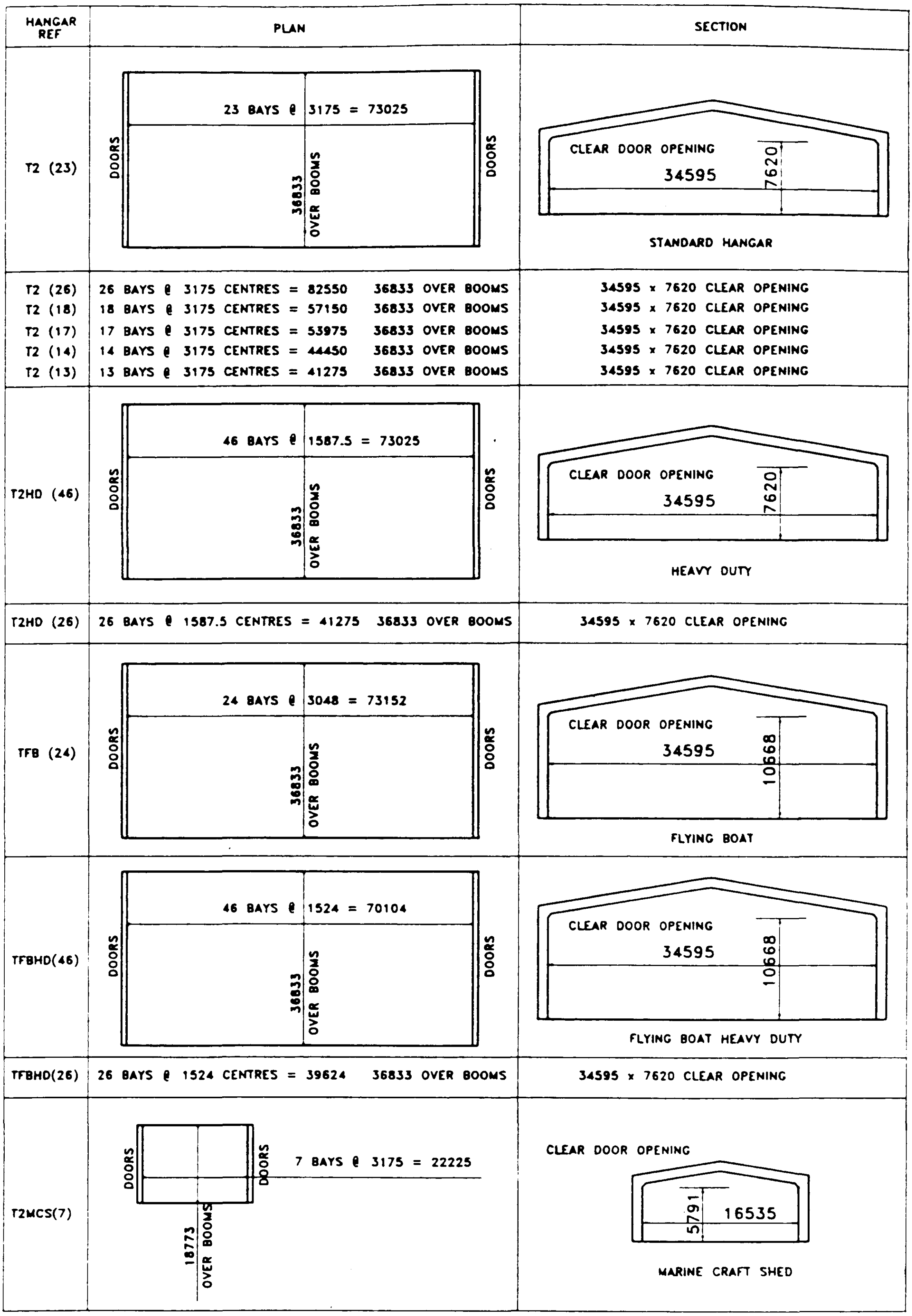


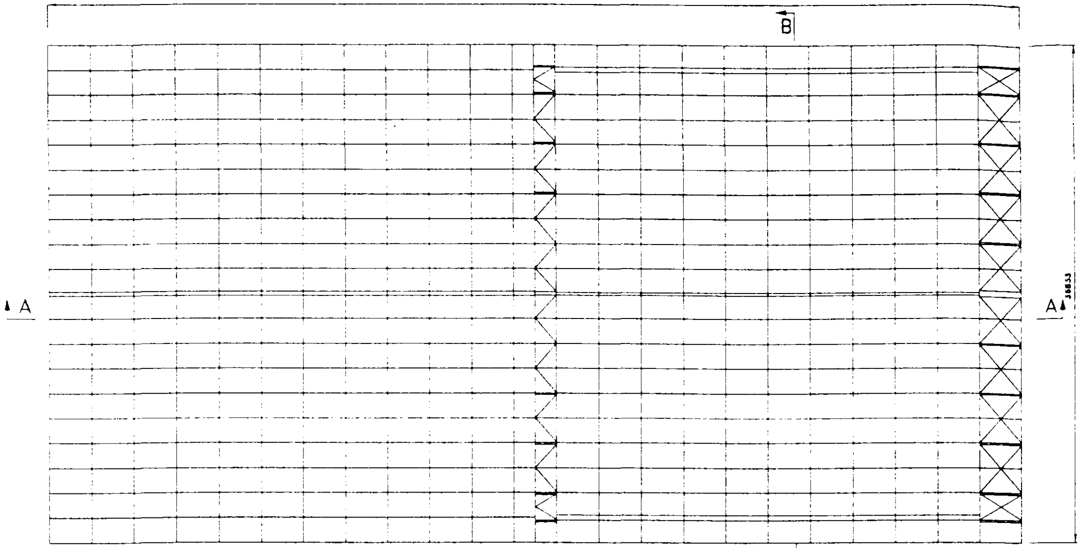
Figure 3.2 Sketch of Type T2 Hangar Variations

Drawing Title	Drawing Number	Microfilm Number (Cat No)	Location	Storage Media
Foundation Plan	3657/42	0353050 (65)	DWS HQ	Microfilm
General Arrangement	3653A/42	0353032/33 (49)	DWS HQ	Microfilm
Standard Units	3654/42	0353035 (50)	DWS HQ	Microfilm
Standard Units	3654/42	0353047 (62)	DWS HQ	Microfilm
Standard Units	3277/43		Imphal Barracks	Print
Gable Units & Tops Door Guides	8257/40	0352989 (5)	DWS HQ	Microfilm
Gable Frame & Canopy	8263/40		Imphal Barracks	Print
Sliding Doors	8258/40	0352990 (6)	DWS HQ	Microfilm
Door Wheels & Runners	3672/42	0352107 (76)	DWS HQ	Microfilm
Wicket Doors & Frames	1695/44	0352110 (150)	DWS HQ	Microfilm
Levelling Top Door Tracks	1149/44	0352112	DWS HQ	Microfilm
Roof Sheeting	3658/42	0353051 (66)	DWS HQ	Microfilm
Side Sheeting	3659/42	0353039 (53)	DWS HQ	Microfilm
	3659/42	0353052 (67)	DWS HQ	Microfilm
Gable Sheeting	3660/42	0353040 (54)	DWS HQ	Microfilm
	3660/42	0353053 (68)	DWS HQ	Microfilm
Stormwater Drainage	4203B/81		Imphal Barracks	Print
Deflection Calculations	7937/41	0353026 (43)	DWS HQ	Microfilm

Table 3.3 List of Archive Drawings for Type T2 (23) Hangar

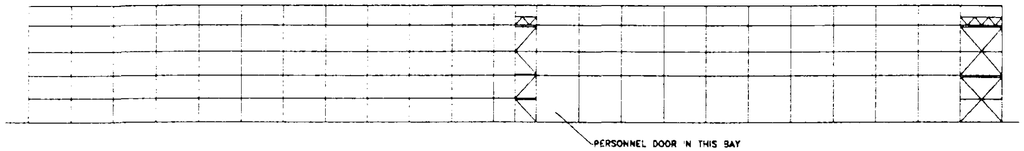
Do not scale: Contractor to check dimensions and report any omissions or errors

"THE INFORMATION SHOWN ON THIS DRAWING HAS BEEN PREPARED FROM ORIGINAL AIR MINISTRY "TYPE DRAWINGS" OF VARIOUS SOURCES, AND THEREFORE ITS RELEVANCE TO ANY SPECIFIC HANGAR MUST BE CONFIRMED BY A SITE SURVEY. THE ORIGINAL DRAWINGS WERE PREPARED IN IMPERIAL UNITS AND DURING THE PROCESS OF METRICATION SOME ROUNDING ERRORS MAY HAVE OCCURRED."



HALF PLAN ON TOP OF ARCH RIBS
SHOWING PURINS
(76x63x6.2RSA's)

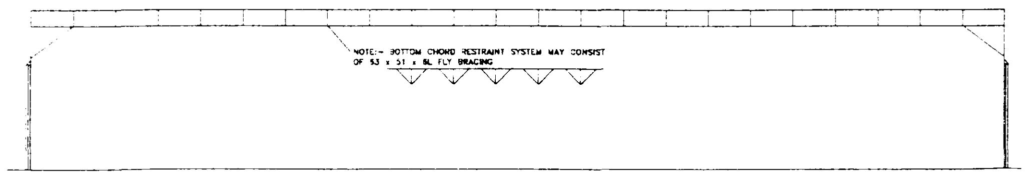
HALF PLAN ON BOTTOM BOOM OF ARCH RIBS
SHOWING LONGITUDINAL PURLIN ANGLES & BRACING
(76x63x6.2RSA's)



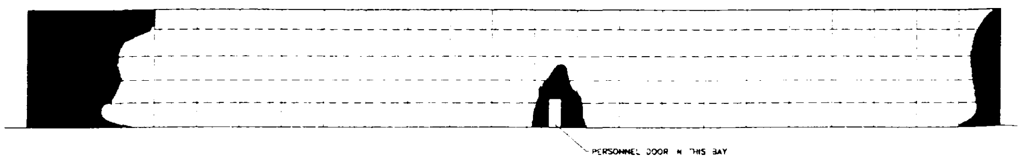
SIDE ELEVATION OUTER BOOM

SIDE ELEVATION INNER BOOM

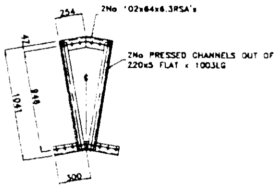
SIDE PURLINS JOINTED EVERY 3175
ROOF PURLINS 76x63x6.2RSA's x 3169LG & 6344LG
AS SHOWN ON ABOVE KEY PLAN



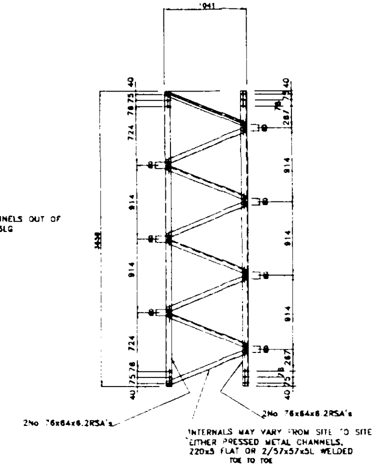
LONGITUDINAL CROSS SECTION A - A



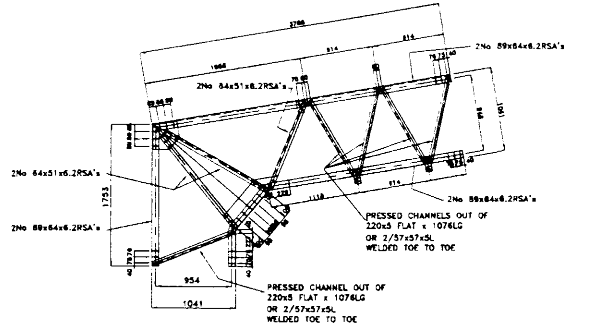
SIDE ELEVATION



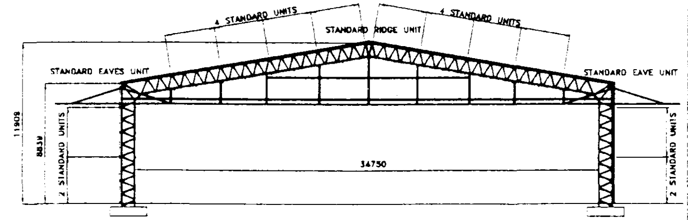
STANDARD RIDGE UNIT



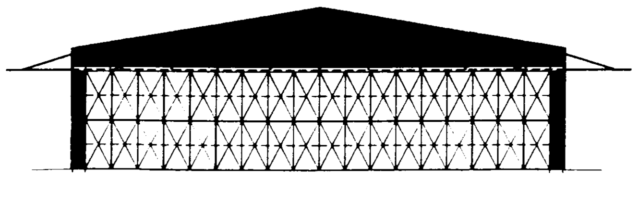
STANDARD UNIT



STANDARD EAVES UNIT



CROSS SECTION B - B



GABLE ELEVATION

Issue	Date	Change No.	Issue	Date	Change No.
B	19.7.94	WS 41/026			

Revisions

DWS
Defence Works Services

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West Midlands B75 7QB

Technical Authority: STRUCTURES SECTION / ABFG

	Company	Contract No.	Signature	Date
Drawn:	WHITE YOUNG	WS 41/028	PF	NOV 93
Design:	WHITE YOUNG	WS 41/028	KA	NOV 93
Checked:	WHITE YOUNG	WS 41/028	DJB	DEC 93
Approved:				
Date:				

Security Classification: UNCLASSIFIED

DWS File Ref: D/DWS/C1/03188

Facility / Location Name: TYPE T2 (23) HANGAR

Associated Dwg. Nos.: DWS/H1/002/002, DWS/H1/002/003

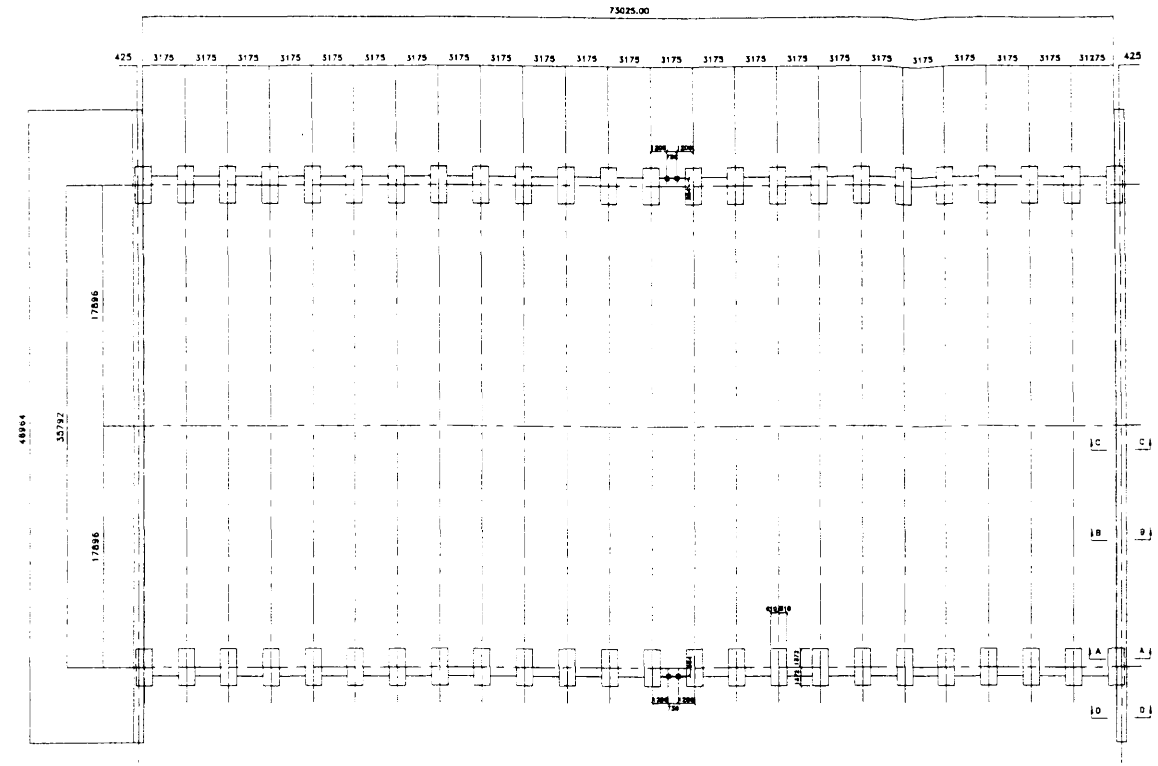
Drawing Title: DETAILED G.A. STRUCTURAL STEELWORK.

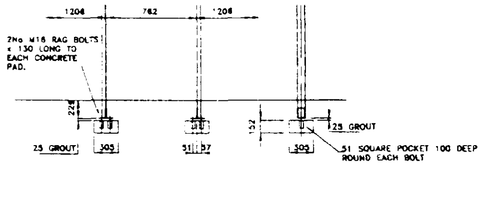
DWS Drawing No.: DWS/H1/002/001

Rev.: B

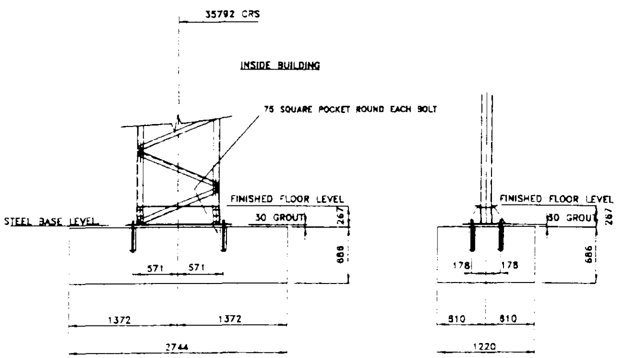
Do not scale. Contractor to check dimensions and report any omissions or errors

"THE INFORMATION SHOWN ON THIS DRAWING HAS BEEN PREPARED FROM ORIGINAL AIR MINISTRY "TYPE DRAWINGS" OF VARIOUS SOURCES, AND THEREFORE ITS RELEVANCE TO ANY SPECIFIC HANGAR MUST BE CONFIRMED BY A SITE SURVEY. THE ORIGINAL DRAWINGS WERE PREPARED IN IMPERIAL UNITS AND DURING THE PROCESS OF METRICATION SOME ROUNDING ERRORS MAY HAVE OCCURRED."

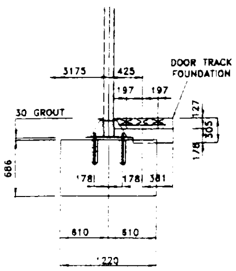




DETAILS OF FOUNDATION FOR PERSONNEL DOOR FRAME

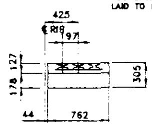


DETAIL OF MAIN BASE SECTION

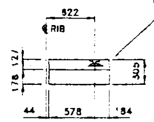


SECTION AT A – A SHOWING JUNCTION OF MAIN BASE & DOOR TRACK FOUNDATION

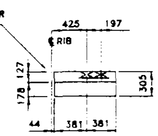
FOUNDATIONS OF DOOR TRACKS LAID TO LEVELS SHOWN



SECTION D – D DOOR TRACK FOUNDATION



SECTION C – C DOOR TRACK FOUNDATION



SECTION B – B DOOR TRACK FOUNDATION

Issue	Date	Change No.	Issue	Date	Change No.
B	19.1.96	WS41/026			

Revisions

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Drawn:	WHITE YOUNG	WS 41/028	PF	Nov 93
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Approved:				
Date:				

Security Classification: UNCLASSIFIED

DWS File Ref.: D/DWS/C1/03188

Facility / Location Name: TYPE T2 (23) HANGAR

Associated Dwg. Nos.: DWS/H1/002/001, DWS/H1/002/003

Drawing Title: DETAILED G.A. OF FOUNDATIONS.

DWS Drawing No.: DWS/H1/002/002

Rev.: B

4.0 STRUCTURAL APPRAISAL

The Structures Section, ABFG undertook a structural appraisal of the Type T2 hangar in order to determine its capacity. The most common hangar structure, Type T2 (23) was selected for the appraisal. The design philosophy adopted, the design and loading codes used and the results of the structural analysis are discussed in this chapter. The assumptions made for the appraisal may vary from site specific conditions of a particular hangar, including the environmental conditions, predicated future uses, projected life span, etc. It is recommended that suitable allowances are made for deviations from assumptions made in this Functional Standard and that a site specific analysis is always considered before drawing any firm conclusions.

4.1 DESIGN PHILOSOPHY

There is no absolute measure of adequate safety and even less of serviceability. There does however exist a generally accepted level of safety provided by design and construction practice in accordance with current regulations and codes of practice. It is recommended that these levels of safety should be taken as datum. Whilst assessing an existing structure, sound engineering judgement is to be exercised in the degree of application of these standards and this should take precedence over compliance with detailed clauses of codes.

There are two extant British Standards which can be used in the design of steel frame buildings: namely BS 5950 and BS 449. Great debate exists as to which of these two codes is more appropriate for the analysis of historical structures and the final selection should be based upon professional judgement dependent upon the particular circumstances of the structure in question. After discussions with British Steel and others, the design work undertaken for this Functional Standard has been in accordance with the current edition of BS 449 incorporating Amendment No 8, December 1989 (AMD 6255). It is recommended that future design work should adopt this approach. However, if it is thought more appropriate to use BS 5950, then great care must be taken in the selection of appropriate yield strengths.

4.2 DESIGN AND LOADING CODES

4.2.1 Wind Loading - Dominant Openings

Wind loading on a large lightweight structure such as the Type T2 hangar is of great significance and care should be taken to ensure that all of its effects are appreciated. Wind loads should be assessed by using BSI CP3: Chapter V: Part 2: 1972 as revised up to Amendment No 5 dated 15 September 1993. In addition the effects of dominant openings allowing increased internal pressures to occur should be taken into account, affecting loading on external walls and roof. The internal pressure is primarily controlled by the size of all openings which connect the inside to the outside of the building and the permeability of the building.

In determining the minimum size of a dominant opening, i.e. an opening large enough to allow internal pressures to be affected by the external pressure on a face of the building, Building Research Establishment (BRE) Digest No 346 should be followed. The empirically based definition for "dominant" openings is taken as "when the opening is twice as large as the sum of the permeability of the rest of the building". Openings of this size or larger should be taken as "dominant". For the Standard Type T2 (23) hangar, the dominant opening limit based on permeability of 0.1% of the total wall and roof area is 9.1m^2, which equates to a main gable door to be open only 1.2 metre wide. This is too small to classify all but personnel doors as non-dominant openings hence it can be assumed that the structure is subject to internal wind pressures due to a dominant opening in one of the gable ends.

Internal pressures in a hangar can result in reversal of stresses induced in the portal frame and also cause "uplift" of the whole structure including foundations.

4.2.2 Wind Loading - Geographical Distribution

An important factor to be considered when assessing the wind load on a structure is that of location. The basic wind speed, and hence wind load, varies with site location. Three different basic wind speeds were considered as follows:

a. Wind Speed less than 40 m/s.

b. Wind Speed greater than 40 m/s but less than 46 m/s.

c. Wind Speed greater than 46 m/s but less than 54 m/s.

The above groupings were chosen after consideration of the distribution of known Type T2 hangars in relation to "Map of United Kingdom Showing Basic Wind Speed" from CP3: Chapter V: Pt 2: 1972 which is reproduced at Figure 4.1 overleaf. If a hangar lies outside the limits of group c above, then the effect of wind must be considered accordingly.

The basic wind speed is the 3-second gust speed, at 10 metres above ground in an open situation, estimated to be exceeded on the average once in 50 years.

For the structural analysis of the typical Type T2 (23) hangar, the factors applied to the basic wind speed for determining the design wind speed were as follows:

Topography factor S1 = 1.0.

Ground roughness, building size and height above ground factor S2 as applicable, corresponding to ground roughness category (1).

Statistical factor S3 = 1.0.

Directional factor S4 = 1.0.

For map of the United Kingdom showing the Basic Wind Speed.
See the British Standard CP3: Chap V: Part 2: 1972. Fig 1.

Figure 4.1 Basic Wind speed in United Kingdom

It is important to note that the above factors will require to be verified or adjusted for each specific site appraised. The S3 factor of 1.0 is for a 50 year period of exposure to the wind. Where it can be confirmed that a hangar will be required for a shorter period, then an S3 factor of less than 1.0 may be used. However, experience has shown that MOD buildings are often retained long after their intended life span and therefore an S3 factor of less than 1.0 should only be adopted in exceptional circumstances and following careful consideration of the project.

4.2.3 Dead Loads

The dead load imposed on the structure should be assessed from the actual form of construction noted for a particular hangar. The dead load assumed in the appraisal is 0.34 kN/m². This figure includes 0.10 kN/m² for the use of modern lightweight cladding systems with integral insulation to give a 'U' value of 0.45 W/m²K. Depending on the type of cladding system used, the dead load assumed should be adjusted accordingly.

4.2.4 Service Loads

Adequate allowances should be made for the provision of services fixed to the roof of a hangar, such as lighting, heating and ventilation units. The requirements of each hangar should be assessed on a case by case basis, but unless advised otherwise by the Property Manager, a minimum loading of 0.15kN/m² should be allowed.

4.2.5 Imposed Loads

The imposed load upon the structure will be that due to snow loading. Snow loads should be calculated in accordance with BS 6399: Pt 3: 1988 "Code of Practice for Imposed Roof Loads". The code gives the map of UK showing the variation in basic snow load with location and this is reproduced as Figure 4.2. The snow load on the roof (s_d kN/m²) is determined by multiplying the estimated snow load on the ground at the site location and altitude (the site snow load s_o kN/m²) by a factor known as the snow load shape coefficient (u_l), i.e. $s_d = u_l s_o$. The site snow load s_o equates to the basic snow load s_b as per Figure 4.2 for sites whose altitudes are not greater than 100m.

After considering this distribution and the requirements of Clause 4.3.1 of the code, which states that a minimum imposed roof load of 0.6kN/m² must be allowed for access and maintenance, it is recommended that this value is used for the Type T2 hangar. In the majority of England and Wales, and the southern regions of Scotland, this minimum imposed maintenance load will produce the worst design case. However, in certain locations in the north of Scotland, higher snow loads may determine the minimum imposed load.

For map of the United Kingdom showing the Basic Snow Load on the Ground.
See the British Standard 6399: Part 3: 1988. Fig 1.

Figure 4.2 Basic Snow Load on the Ground

For the analysis of existing buildings the use of a minimum loading of 0.6 kN/m² is sometimes considered as excessive, and it has often been postulated that the basic snow load on the ground, modified by the appropriate factors in BS 6399 could be used. However, it should be remembered that where major refurbishment is being considered, and the Building Regulations invoked, the 0.6 kN/m² is a Building Regulations requirement. If a lesser figure is used, dispensation from a Building Control Officer will be required. It is therefore considered prudent and good engineering practice to use the value of 0.6 kN/m² as the starting point for all analyses, whether it is for routine appraisals or to support major refurbishment.

4.2.6 Steelwork Design Stresses

In the absence of original steel certificates or design calculations, the interpretation of permissible design stresses applied at the time requires sound engineering judgement coupled with knowledge of developments in iron and steel construction in UK and Europe from the turn of the century.

Invaluable data on steelwork properties is contained in "Historical Structural Steelwork Handbook - Properties of UK and European Cast Iron, Wrought Iron and Steel Sections including Design, Load and Stress Data since the Mid 19th Century", Publication No 11/84, published by The British Constructional Steelwork Association Limited, ISBN 0 85073 015 5.

The permissible axial stresses in tension (pt) and in compression (pc) for mild steel beams pre-1938 as quoted in Section 6 of the above handbook are as follows:

pt = 8.0 tons/sq inch (123.6 N/mm²)

pc = 8.0 tons/sq inch (123.6 N/mm², pc is based on a theoretical maximum for a slenderness ration of 0).

Table 6.4 in the Historical Structural Steelwork Handbook giving values of permissible stresses to BS 449 has been reproduced as Table 4.3 for reference.

During the period 1940-1945 revisions were issued to BS 449 for war time emergency relaxation of standards. These relaxations permitted axial compression (pc) with lateral restraint and bending stresses (pbt or pbc) to be increased to 10 tons/sq inch (154.4 N/mm²). This value was partly rescinded to 9 tons/sq inch after the war.

Where a BS 449 type approach is being adopted it is recommended that permissible stress values of 8 tons/sq inch are most appropriate to the Type T2 hangar unless other evidence is available to suggest that steel quality is higher for the particular structure being considered. As an example, such evidence may be from sufficient samples taken from the structure for testing, bearing in mind the inconsistency of steel quality achieved during the war.

WORKING STRESSES in tons/sq in to BS 449										
Year	**Steel Grade**	**Tension** Thickness (ins)	**Tension** Stress	**Compression (Maximum)**	**Bending** Thickness (ins)	**Bending** Stress (Maximum)	**Shear** Max Stress	**Shear** Thickness (ins)	**Shear** Average Stress	**Bearing**
1932	MS		8	8		8	5			
1935&37	MS		8	8		8	5			
	HY		12	12		12	7.5			
1939&40	MS		8	10		10	5			
(Amdts)	HY		12	12		12	7.5			
1948	MS		9	9*		10 (9.5)	6.5			12
	HY	≤1.75	13.5	13.5	≤1.75	15 (14.5)	9			18
		>1.75	11.5	13.5	>1.75	13 (12.25)	8			18
1959	MS	≤1.50	9.5	9.5	≤1.50	10.5 (10.0)	7.0	≤0.75	6.0 (6.0)	12.0
		>1.50	9.0	9.5	>1.50	10.0 (9.5)	7.0	>0.75	6.0 (5.5)	12.0
	HY	≤2	13.5	13.5	≤2	14.5 (13.5)	10.0	≤2	8.5 (8.0)	17.0
		>2	Ys	13.5	>2	Ys (Ys)	Ys	>2	- (7.0)	17.0
			1.63			1.52 (1.63)	2.2			

* for discontinuous angle struts; MS-6. HY-9   ( ) values refer to plated members

Note: This table cannot cover all the nuances of the standard, thus for detailed requirements reference must be made to the original text of BS 449.

MS refers to mild steel to BS 15   HY refers to high yield steel to BS 548 before 1959 and to BS 968 after 1959

TABLE 4.3 Extract from Historical Structural Steelwork Handbook

Column stress to BS 449 1937		
Slenderness ratio c = effective L / min.r	Axial stress pc in tons/sq inch	Axial stress pc in N/mm^2
20	7.17	110.7
30	6.92	106.9
40	6.64	102.6
50	6.30	97.3
60	5.89	91.0
70	5.41	83.6
80	4.88	75.7
90	4.33	66.9
100	3.81	58.8
110	3.34	51.6
120	2.93	45.3
130	2.58	39.8
140	2.28	35.2
150	2.02	31.2
160	1.81	28.0
170	1.62	25.0
180	1.46	22.5
190	1.33	20.5
200	1.21	18.7
210	1.10	17.0
220	1.01	15.6
230	0.93	14.4
240	0.86	13.3

Table 4.4 Extract from Historical Structural Steelwork Handbook

ALLOWABLE STRESSES IN RIVETS AND BOLTS in tons/sq inch						
Stress	Rivets			Bolts		
	Type	MS	HT	Type	MS	HT
1932						
Tension	Shop	5		≥0.75"Ø	5	
	Site	4		<0.75"Ø	0	
Shear	Shop	6		Turned	6	
	Site	5		Black	4	
Bearing	Shop	12		Turned	12	
	Site	10		Black	8	
1935 & 1937						
Tension	Shop	5	7.5	≥0.62"Ø	5	7.5
	Site	4	6	<0.62"Ø	0	0
Shear	Shop	6	9	Turned	6	9
	Site	5	7.5	Black	4	6
Bearing	Shop	12	18	Turned	12	18
	Site	10	15	Black	8	12
1948						
Tension	Shop	5	7.5	≥0.75"Ø	6	9
	Site	4	6	<0.75"Ø	5	7.5
Shear	Shop	6	9	Turned	6	9
	Site	5	7.5	Black	4	6
Bearing	Shop	12*	18*	Turned	12*	18*
	Site	10	15*	Black	8	12*
1959						
Tension	All	6.0	9.0	≥1.12"Ø	8.0	12.0
				≥0.87"Ø	7.0	10.5
				<0.87"Ø	6.0	9.0
Shear	Power Shop	6.5	9.0	Turned	6.0	9.0
	Power Site	6.0	8.5	Black	5.0	7.0
**	Hand	5.5	7.5			
Bearing	Power Shop	19.0	27.0	Turned	19.0	27.0
	Power Site	17.5	25.0	Black	12.5	+
	Hand	16.0	23.0			

* Increase by 25% when in double shear
** All values reduced by 20% when in single shear
\+ Value not given, approx 17.5 pro rata

Note: MS = Mild Steel
HT = High Tensile Steel

Table 4.5 Extract from Historical Structural Steelwork Handbook

The maximum value for permissible axial stress in compression must be amended to take into account slenderness of the sections. Table 6.7 in the Handbook is reproduced as Table 4.4, giving relevant allowable stresses for varying values of slenderness ratio. To this end the members should be analysed using BS 449 but replacing Table 17a of the BS code with Table 4.4.

It should be noted that as well as permissible stresses in pure tension or compression, BS 449 also stipulates that combined stresses due to bending, tension, shear and bearing must also be considered. In the case of the structure under consideration, which effectively acts as pin jointed trusses, only compression or tension forces are likely to predominate, hence the effects of shear etc can be ignored as they will not be significant.

With historical buildings the connections are often found to be weaker than the members themselves; particularly if bolted or rivetted construction is involved. The Historical Structural Steelwork Handbook gives invaluable advice on the strengths of bolts and rivets and lists the changes in design values over the years. Table 7.1 in the Handbook giving permissible stress values in bolts and rivets is reproduced as Table 4.5 for reference. An initial check on the capacity of a bolted or rivetted end connection will frequently provide the earliest indication of a structure's overall strength.

The stresses used in calculating the joint strength in mild steel black bolts (1935 and 1937) is recommended as follows, on the basis of Table 7.1 of the Historical Handbook:

Shear: 4 tons/sq inch (62 N/mm^2)

Bearing: 8 tons/sq inch (124 N/mm^2)

Tension: 5 tons/sq inch (77.5 N/mm^2)

4.3 STRUCTURAL ANALYSIS

4.3.1 Approach to Structural Analysis

It was not possible to locate any detailed calculations, steel certificates or record drawings concerning wartime hangars. Much of the information was therefore taken from fabricators' handbooks or historical textbooks covering that period. The appraisal of the Type T2 (23) hangar was on the basis of BS 449 incorporating Amendment No 8, using maximum permissible stress values of 8.0 tons/sq in (123.6N/mm^2) for axial tension and compression.

Computations were carried out for the basic wind speed of 46 m/s which covers approximately 75% of the United Kingdom but omits areas such as the Pennines, the majority of Scotland, parts of Northern Ireland and the west coast of Wales. Additional computations were also carried out for a basic wind speed of 54 m/s although it could be that some Type T2 hangars in these areas are of the heavy duty type. It was assumed that a dominant opening existed in one of the gable ends.

The main frame was analysed using standard structural analysis computer software as a plane truss. The supports to the main frame can be considered either as a pinned footing with only one connection to the foundation unit, or as a rigid connection with each leg connected thereby forming a 'couple'. The latter is a more realistic approach to the behaviour of the structure but imports greater loadings to the foundations which cannot be resisted within the normal limits of structural adequacy. In such an instance the foundation cross member may deform and will then tend to allow the structure to behave as if only one leg of each column were connected to it. This has the effect of making the structure behave as if it were truly pinned at its base. The truth lies between these two extremes but it is recommended that for the refurbishment solutions the frame should be assessed as if only a pinned support exists at the inside face of the main columns. In this way the structural solution for the main frame will be strong enough to withstand the loads under consideration.

The secondary members such as wind bracing, purlins and sheeting rails were analysed using standard means. These members, apart from the door head units, consist of mainly rolled steel angle sections in varying states of repair. A similar approach to calculating their permissible stresses was used to that for the main frame.

4.3.2 Findings of the Structural Analysis

Main Frame

In discussing the results it should be noted that BS 449 assumes an elastic behaviour of the structure and uses a factor of safety of 1.7. Therefore, a structure may be overstressed theoretically and may deflect excessively but it will not actually yield or collapse until its weakest component is loaded in excess of 170% of its safe working load. Within this document the term overstressed is used for any component found to have a stress level of between 100% to 170% of its design working stress. The term yield refers to any member found to have a stress level in excess of 170% of its design working stress and which theoretically could lead to crippling and actual collapse of structure. Hence a failed member or joint refers to a situation of overstress and can include yield too, although the results show that the latter condition is not reached.

A graphical illustration of the failed members and joints is given in Figure 4.6.

For the dead plus imposed load condition, it is found that 16% of the main frame members fail. The members are overstressed from as little as 102% to as much as 167% of their safe working load. The frame can withstand the dead load and in addition take up an imposed load of 0.15kN/m² without causing overstressing in any of the members.

FAILED JOINTS AND MEMBERS
(Under Dead, Imposed and Wind Loads)

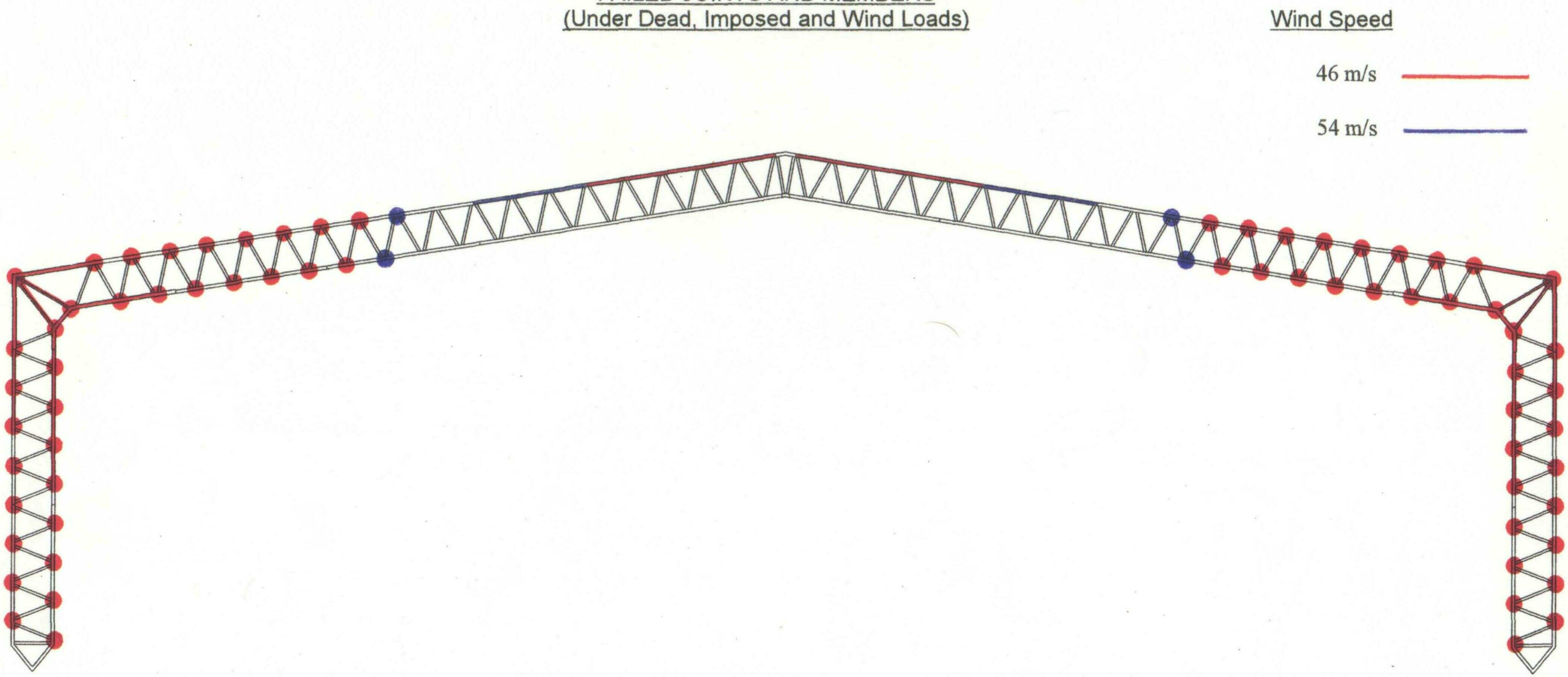

Figure 4.6 Type T2 (23) Hangar

(NB: Failures shown are additive)

For wind loading, only one member is overstressed to 107% at the basic wind speed of 46m/s. For a wind speed of 54 m/s, it is found by coincidence, that 16% of the main frame members fail. The members are not necessarily the same as for the dead plus imposed load case. Also, for this higher wind condition the stresses in the failed members are reversed i.e. the compressed members undergo tension and vice versa. The extent of overstressing ranges from as little as 102% to as much as 168%.

The induced loads from rafter and vertical bracing do not significantly affect the above results.

The joints comprise a standard 2 bolt connection and these are found to fail in 57% of the frame. Figure 4.6 gives an illustration of the failed joints.

Secondary Members

The purlins and side rails have been regarded as simply supported at the rafters and columns as many of these are single spanning with a single bolt end connection. The current practice is to span the purlins and side rails over two or three bays and stagger the joints with continuity provided by fish plates or cleats thus achieving a degree of fixity. This would allow the maximum bending moment of WL/10 to be applied. In view of the above and the general state of repair and corrosion seen on some sites, the maximum bending moment of WL/8 is used.

Table 4.7 gives values of purlin capacity and the loads applied. It is seen that for all situations of dead plus imposed load and dead plus wind loads at 40 m/s, 46 m/s and 54 m/s the purlins are of inadequate strength.

Load Condition	Purlin Loads		
	Capacity	Applied (kN)	% Overstress
Dead & Imposed	2.8	4.3	154%
Dead & Wind (40 m/s)	3.7	6.6	178%
Dead & Wind (46 m/s)	3.7	8.3	224%
Dead & Wind (54 m/s)	3.7	12.0	324%

Table 4.7 Details of Purlin Failure

Table 4.8 gives values of side rail capacity and loads applied. It is seen that for all three wind speeds considered, the side rails are of inadequate strength.

Load Condition	Side Rail Loads		
	Capacity	Applied (kN)	% Overstress
Dead & Wind (40 m/s)	3.7	6.0	162%
Dead & Wind (46 m/s)	3.7	7.9	214%
Dead & Wind (54 m/s)	3.7	10.9	295%

Table 4.8 Details of Side Rail Failure

In order to satisfy the existing capacities of the purlins and side rails, the maximum imposed load acceptable is 0.46 kN/m² and a maximum basic wind speed of 34m/s. It should be noted that the minimum basic wind speed in the United Kingdom is 38m/s.

The rafter and vertical bracings are found to be of adequate strength for the current loading conditions.

Foundations

The safety factor required for the uplift condition is 1.4 and this is achieved for the basic wind speed of 40m/s. For higher wind speeds, the foundations will require strengthening. At 46m/s the factor of safety attained is 1.0. The foundations local to the braced bays will have additional loads induced to them and therefore would require further enlargement.

5.0 OPERATIONAL REQUIREMENTS

The Type T2 hangar is subject to various operational requirements, some in the form of restrictions due to concerns about its structural safety and some in connection with hangar doors and periodic professional appraisal and inspection of hangar.

5.1 OPERATING RESTRICTIONS

The findings of the structural appraisal of the Type T2 hangar are of concern in that although members do not reach yield and lead to collapse of structure, the safety factors are greatly reduced in relation to requirements of design codes. Precautionary measures must therefore be taken by all those engaged in duties connected with a Type T2 hangar for reasons of safety.

DWS Technical Bulletin 39/94: Hangars - Safety of Structure - Recommendations for Users During Adverse Weather Conditions was issued in August 1994, for use in connection with any type of wartime hangar including the Type T2. The requirements of the safety notice should be observed at all times and are re-stated below.

During Snowfall:

When freshly fallen snow reaches a depth of 200mm, the Property Manager must advise the Commanding Officer of the possible dangers and that the hangar structure must be placed under observation. If excess deflection or other signs of structural distress are noted by the EWC, the occupants should be ordered to evacuate the hangar. Depending upon the level of risk attached to the dangers and the value of stores or aircraft inside the hangar, the Commanding Officer must decide if their removal is imperative.

During High Winds:

When high winds are forecast, the Commanding Officer must ensure that hangar doors are kept closed. There is a risk to the safety of the structure and damage to roof cladding. High winds for the hangars listed in this Bulletin can be considered to be gusts of more than 27 m/s (60 mph). (NB The wind speed stated is the gust speed as against a steady wind speed).

Emergency Action Plan:

For each hangar on the MOD estate, the Property Manager is to agree an Emergency Action Plan with the Commanding Officer, the EWC and the WSM. The Emergency Action Plan should give details of responsibilities of each MOD staff, the EWC and WSM, and their respective actions required to be taken during adverse weather conditions.

For ease of understanding the operating restrictions a flow chart is given at Figure 5.1 indicating steps that need to be taken. The flow chart is not an action plan to be followed during adverse weather conditions. For each MOD estate with a Type T2 hangar an Emergency Action Plan should be devised as explained above.

The operating restrictions must not be lifted for any Type T2 hangar until it has been appraised and cleared by a competent Chartered Civil or Structural Engineer experienced in this type of work.

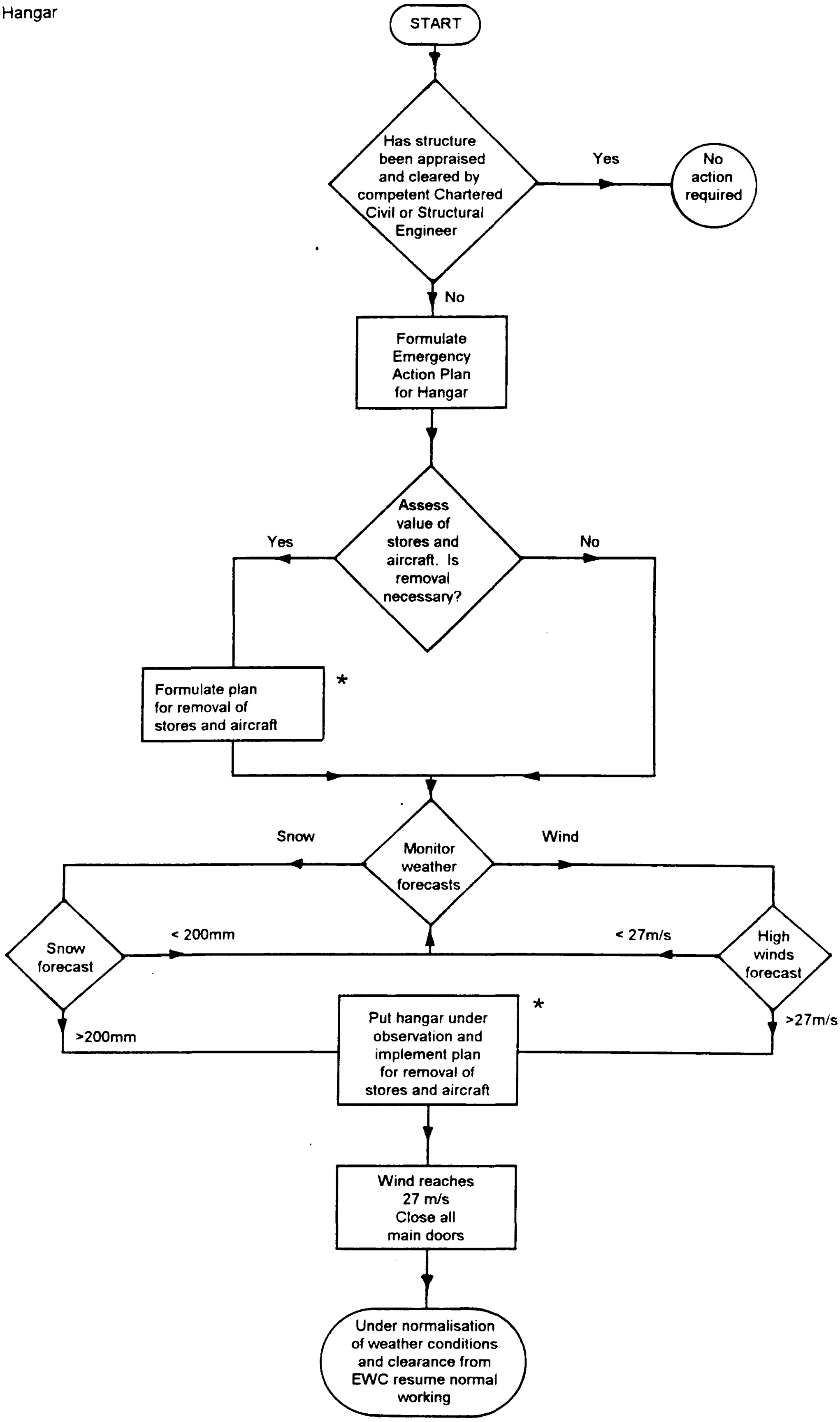

Figure 5.1 Operating Restrictions During Adverse Weather

5.2 HANGAR DOORS

In August 1994 DWS issued Technical Bulletin 40/94: "Hangars and Industrial Buildings - Inspection, Maintenance, Adjustment and Use of Large Sliding and Folding Doors". This TB is particularly relevant to the Type T2 hangar doors, defining among other items the roles and responsibilities of the User, the EWC, the WSM and the Project Manager in connection with activities related to hangar doors. Information on the safe use and maintenance of doors and their fixtures was given for the benefit of all those engaged in duties connected with hangar doors.

5.2.1 Statutory Requirements

a. Health and Safety

To comply with the Health & Safety at Work etc Act 1974 and its subordinate legislation, an assessment of the risks associated with the inspection, maintenance, adjustment and use of doors must be carried out, all hazards identified and any significant risks noted.

Those carrying out work in connection with doors must be made aware of the hazards (eg access to and working height) and should provide written safe systems of work. Only competent persons suitably trained on any equipment to be used and familiar with the safe system of work should be engaged for working at height.

The safe system of work should show how it is intended to gain access to the various parts of the doors and associated fixtures and fittings, also any safety precautions necessary to reduce or eliminate the risks to their employees.

As part of the Property Management system, records should be kept of the inspection and of the wear on doors and their components and it is recommended that an individual check list be drawn up.

5.2.2 MOD Requirements

a. DWS Specification 005

The current DWS Specification 005 Issue No 002, June 92: Property Management of the Defence Estate specifies mandatory requirements for the WSM and EWC. It is important to note that reference is made to the latest edition of DWS Specification 005. The mandatory requirements are as follows:

(I) Maintenance, inspection and adjustment of doors every 6 months by the WSM as stipulated in Schedule 6B Task No 052 of the Specification.

(ii) Regular inspections by EWC as stipulated in Schedule 6A Task No 051 of the Specification. The intervals are every 6 months, extended to every 12 months for Ascension Islands and Falkland Islands.

(iii) At the time of inspection, the EWC is to arrange for the WSM and WSM Specialist Maintenance Contractor to be available for repairs, as per tasks 051 and 052.

b. Operation of Doors - User Tasks

The User should be responsible for the day to day operation of the doors. He must ensure that:

(I) Bottom tracks are kept free of debris.

(ii) Excessive force is not used to open, close or move doors. Doors which are difficult to move may be obstructed or in need of repair.

(iii) In the event that doors cannot be opened or closed freely or appear out of alignment, the PROM is informed of the situation as a matter of urgency.

(iv) Tractors or other Mechanical Handling Equipment (MHE) are not used to operate doors, as they could force the wheels off the tracks. In addition , they could damage end stops or the carriages and wheel mechanisms.

c. Maintenance of Doors - WSM Tasks

(I) The maintenance tasks must include cleaning and lubrication of wheels, rollers, guides, runners, springs, winding gear, ropes and chains. Where available the manufacturer's instructions must be followed.

(ii) Doors must be checked for correct opening and closing and left in correct working order following any maintenance work.

d. Inspection of Doors - EWC Tasks

(I) Recommend inspection of doors, particularly the vulnerable parts at more frequent intervals where certain circumstances necessitate, for example where:

- Doors are subjected to high use or susceptible to damage.

- The environment is hostile (eg high winds or high corrosion rate).

- This is stipulated by the door manufacturer.

(ii) The following list covers checks and items for inspection. The list below is not exhaustive as the EWC may find it necessary to cover additional checks:

- Alignment and condition of upper and lower tracks and guides. Uneven wear on wheels. Doors designed to be top supported are not to bear on the bottom guides and similarly doors designed to be supported from the bottom are not to be supported by top guide wheels.

- Condition of wheels, rollers, guides, runners and springs. (Metallic parts such as wheels and rollers are to be "rung" with a hammer as a means of detecting cracks).

- Bearings, circlips and bearing retaining nuts. (Excess play in bearings should be noted and more detailed examination carried out where appropriate. This may involve removal and dis-assembly of the bearing).

- Condition of door stops and buffers. (Deformed or cracked items should be replaced and metallic stops should be rung. Particular attention should be paid to upper stops, checking tightness of bolts and soundness of welds).

- State of door frames and sheeting and the maintenance of adequate clearance between door leaves.

- Condition of winding gear, ropes and chains. (The condition and existence of detachable winding handles should also be checked).

- Ensure that the doors are prevented from lifting off the top tracks and moving sideways.

- Ensure that damaged and loosened components (eg wheels, stops, etc) cannot fall from top tracks and cause injury.

- Correct opening and closing of doors after every inspection.

e. Modifications to Doors

(I) The User is not permitted to modify doors as this could be detrimental to their operation. For example:

- Additions of any kind must not be made to doors as this could cause eccentricity or overloading on the door supports (eg brackets, insulation, additional linings, etc).

- Doors which are designed to be separated into a number of leaves must not have their leaves connected together to facilitate opening and closing.

(ii) Proposals for modifications can be made where there is an advantage in improved safety or functioning of the doors. For example:

- To prevent sideways movement of doors when they become lifted from top tracks.

- Replacing cast iron with mild steel wheels which have wider flanges.

- Introduction of compression springs, where none exist, in order to keep the wheels in contact with the bottom track.

(iii) The EWC must inform the PROM of any proposals for modifications to hangar doors and the reasons with estimated costs why this is considered to be necessary. Following the PROM's instruction to proceed, the WSM must arrange for a competent, suitably qualified engineer to design the modifications. This must include the preparation of full documentation including calculations, drawings, specifications and a method statement. In certain circumstances to comply with the Building Regulation, approval will have to be obtained and the design checked by an independent person as required by Schedule 7 of DWS Specification 005.

f. Project Handover - Project Manager Tasks

(I) At handover of a project involving hangar doors, the Project Manager is to ensure that the doors are left in safe working order without any significant snagging defects outstanding.

(ii) As part of the Operations and Maintenance manual, all available details of the door should be included such as drawings, specifications, calculations and availability of replacement parts. Any manufacturer's recommendations or guarantees relating to maintenance or inspection is to be passed via the PROM, to the EWC/WSM, particularly where this includes maintenance to be carried out by the manufacturer as part of the defects liability period or where the frequency of inspections exceed those of DWS Specification 005.

5.3 PROFESSIONAL APPRAISAL AND TECHNICAL INSPECTION

The EWC must carry out a Professional Appraisal of the hangar at 5 yearly intervals and a Technical Inspection at 2 yearly intervals, in accordance with Tasks 582 and 584 of DWS Specification 005. The above tasks are currently being reviewed by DWS and a revised specification is expected to be issued later this year.

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6.0 REFURBISHMENT WORKS

6.1 ROOF AND WALL CLADDING

One of the most common works items during major refurbishment of a hangar is renewal of roof and wall cladding. This could be for various reasons, e.g. unsatisfactory or irreparable water proofing, better thermal insulation for energy conservation as per MOD policy, uneconomical repair and maintenance costs, etc.

Roof cladding as originally used on Type T2 hangars was in the form of corrugated steel sheeting. Being a light-weight hangar, re-cladding will have a major effect on the Type T2's structural behaviour, for example:

a. Change in permeability of the cladding has major effects of loading transferred to the hangar structure.

b. Change in fixings and cladding stiffness has major effects on the structural restraint that cladding provides to the hangar.

c. Change in dead load; an increased weight of cladding will adversely affect the steel frame, whereas reduced weight cladding will increase the likelihood of an "uplift" problem.

The provision of thermal insulation in itself for refurbishment works will not fall under the control of Building Regulations. However, total re-cladding of a hangar may be considered to be a "material alteration" if it adversely affects the existing building in relation to compliance with requirements for structure. Further information on the application of Building Regulations is given in Chapter 9.1.

As a general rule, Building Regulations require the maximum 'U' value for roof and wall cladding to be 0.45 W/m^2K except where a low level of heating output not exceeding 50 watts per square metre of floor area is installed, when there is no requirement for insulation. It is recommended that, as Building Regulations requirements are minimum standards, they should be applied to that element undergoing refurbishment. This would also support MOD policy on energy conservation.

The Building Regulations for England and Wales Part L has been revised and the new standard will take effect on 1 July 1995. It has a higher requirement than the current document in relation to glazed areas, doors and roofs, and it is advisable that this later standard is followed.

6.2 STRENGTHENING OF STRUCTURE

The appraisal of the Type T2 hangar showed that it is deficient in several areas when compared against current standards and regulations. If major refurbishment is considered the main frame will require strengthening, the purlins and sheeting rails replacing, and the foundations enlarging. The following suggestions are developed for costing purposes only and should not be considered as standard or ideal solutions. Steelwork designers and contractors may have alternative economical solutions and these should be duly considered.

6.2.1 Main Frame

The main frame consists of a pin jointed truss to all intents and purposes, hence it can be strengthened by adding cross-sectional area in the form of welding plates to those members which fail and by strengthening weak joints. After consideration of the extent of failure and its nature it is thought prudent to plate up the main chords and the internal members and weld the joints due to the inadequate bolts now in use. The strengthening would only need to be carried in the failed members and joints. Some typical details of proposals for strengthening the standard portal frame unit are given in Figure 6.1.

6.2.2 Secondary Steelwork

Purlins and Sheeting Rails

The purlins and side rails fail for the dead plus imposed load and dead plus wind load conditions. Three options exist as regards rectifying this situation, these being: propping, inserting extra rows of purlins and rails and installation of a new system of cold rolled elements. The two former options, as well as being labour intensive, will also rely on the continued use of the existing purlins and rails. Evidence gained during site inspections showed many of these to be corroded. It is thought that these two options will be compromised by this fact and that the third option is the most prudent to choose. Therefore the option of installing a new system is likely to be the most cost effective as its expected life will be in excess of any of the refurbishment options.

6.2.3 Foundations

The examination of the foundations showed that problems exist with uplift of the structure when large openings exist during wind speeds higher than 40m/s. In order to allow the use of the hangars in all wind loading conditions it is necessary to add extra dead load to the foundations. Three options exist in order to overcome this situation: these being: adding kentledge, enlarging existing foundations using dowelling or encasement and using a dado wall on a strip footing which can also act as a security wall.

6.3 DOORS

During major refurbishment works covering renewal of roof and wall cladding, it would be reasonable to renew cladding on doors. Refurbishment works can also involve other items such as structural repairs to the door frame where necessary, replacement or repair of the tracks, guides, wheels, etc.

Existing cladding provides a stiffening function to doors whereas re-cladding with a light-weight material may not provide the same degree of support and could result in unsatisfactory door performance. Replacing cladding with a composite material may not be practicable as the cladding will be too thick to permit doors passing over one another.

If a hangar is no longer in use as an aircraft hangar, the large sliding doors may be permanently welded or fixed to the gable-end structural steelwork. Smaller doors could then be re-introduced within the fixed large doors. It should be ensured that both design and modification works are fit for the purpose, such that the modifications remain permanent for the remaining life of the building. If the doors continue to be supported in full or in part by mechanical fixtures such as wheels, tracks, rollers, rails, etc then the statutory and MOD requirements for maintenance and inspection as discussed in Chapter 5.2 will remain obligatory.

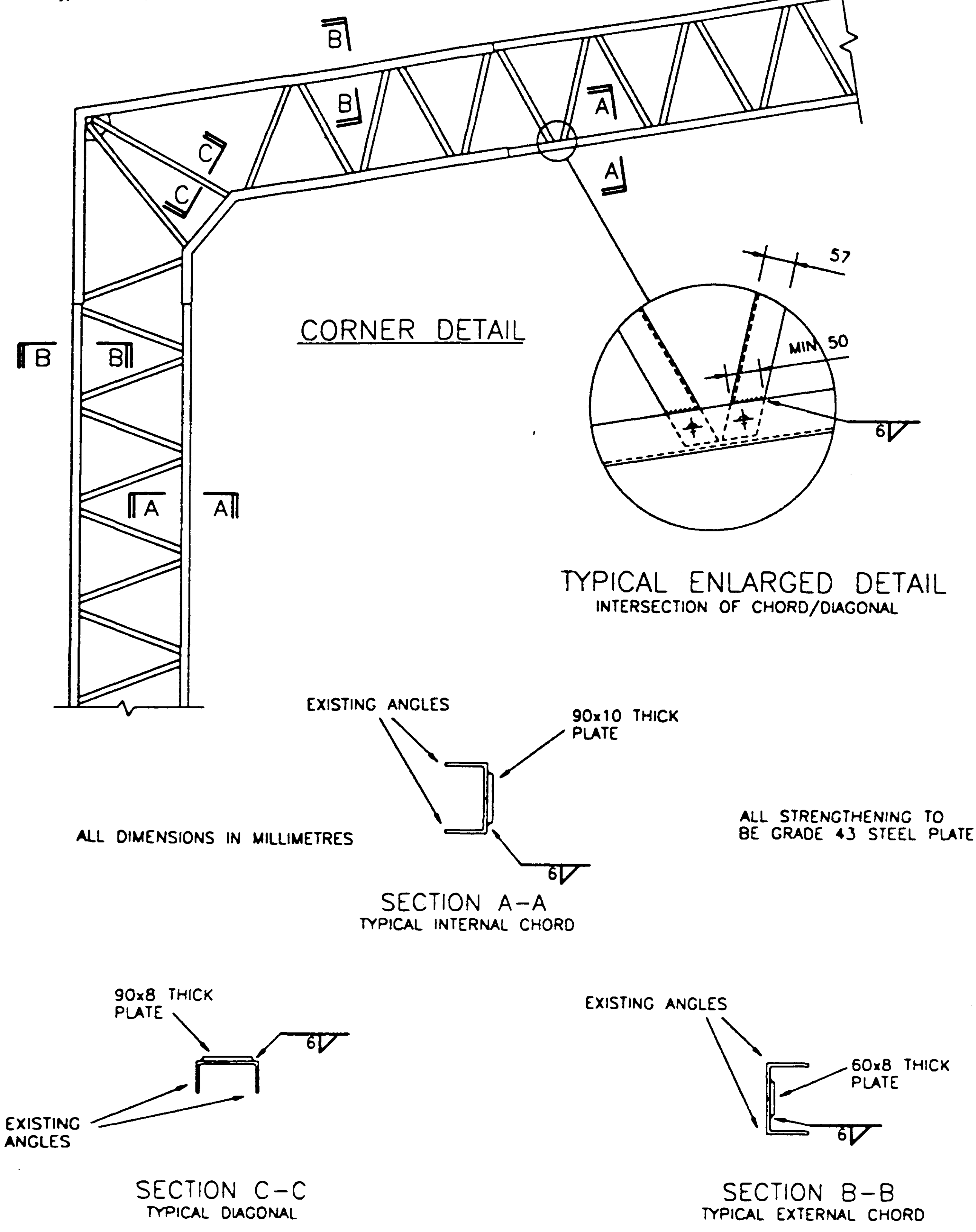

Figure 6.1 Typical Details for Strengthening of Type T2 Hangar Main Frame

6.4 FLOORS

The repair, upgrade or renewal of a hangar floor during refurbishment would depend on the particular site, i.e. the condition of the floor, its functional requirements and most importantly economic considerations.

Repairs to floors and application of numerous types of floor toppings and finishes is now commonly considered a specialist works item, carried out by specialist contractors. Depending on particular problems with a floor, a contractor specialising in such works should be engaged. The specialist contractor or designer should survey the floor, carry out tests, diagnose any problems and their causes and recommend solutions.

In view of the above and the wide range of problems associated with a hangar floor, recommendations are not made in this Functional Standard for specific solutions. As a guide however, the following is a list of some of the items which can be of concern to a PROM or Project Sponsor:

Load capacity
Flatness
Aesthetics (colour, appearance)
Hardness
Dust proof
Abrasion resistance
Chemical resistance (impermeable to oils and fluids)
Waterproof
Slip resistance
Cracking
Spalling
Osmosis
Joints (uneven joints, requirement for seamless floor, joint sealants, etc)
FOD (Foreign object damage)

Most of the above characteristics can be met by laying a new screed and coating, on the existing slab unless the sub base or soil conditions are such that the specialist contractor advises a total renewal of the floor.

Defence Works Functional Standard 06: Guide to Airfield Pavement Maintenance published by HMSO ISBN 0 11 772730 X contains advice on concrete floors and it is suggested that reference is made to this document.

6.5 DRAINAGE

Rainwater gutters and downpipes must be inspected for leaks and renewed if necessary. If slate or other cement-based roof cladding is being replaced by metal clad sheeting, then faster run-offs will be expected. Hence larger capacity guttering and downpipes may be required.

6.6 ROOFLIGHTS, LIGHTING AND HEATING

If natural lighting is required, then this should be specified by the user in full knowledge of the extra initial and running costs this may incur. Any natural light system should be professionally designed to give a uniform distribution of light to a minimum daylight factor of 7%. This will require rooflights equivalent to approximately 10% of the floor area evenly distributed throughout the roof. If natural daylight is not a user requirement then it is recommended that rooflights are not installed during refurbishment.

With modern high efficiency lighting units any extra energy which will be required to light the building will be compensated by the increased thermal efficiency of the hangar without rooflights. Disadvantages of rooflights include:

a. high initial cost over cladding.

b. high cleaning and maintenance costs.

c. more frequent replacement than cladding.

d. can cause glare within the hangar.

e. lower thermal resistance and prone to condensation drip.

f. difficult to achieve current or future blackout requirement.

Guidance on suitable levels of lighting is available in the Lighting Guide No 1 "The Industrial Environment" 1989, Chartered Institute of Building Services Engineers (CIBSE).

The requirements for heating are given in the appropriate Scales in the Services Accommodation Code, JSP 315. They should be checked and agreed with the PROM or Project Sponsor, depending on the specific use of a hangar. Minimum levels of heating are to be provided in compliance with the Health & Safety Regulations.

6.7 PHYSICAL SECURITY

During any refurbishment project, the Project Sponsor must give consideration to physical security. The Secure Building Specification for Industrial Type Buildings as approved by MOD Security Directorates, reference D/DSy(A)/121/1/2 dated 3 February 1994 should be followed. The full specification is available from:

DOE Special Services Group
Security Advisory Branch
St Christopher House
Southwark Street
London
SE1 0TE

Tel: 0171 921 4928
Fax: 0171 921 3802

Guidance to Project Sponsors, PROMs and security officers on the methods of obtaining security assistance and advice for works services is given in DCI GEN 125/94.

During recladding works on industrial type buildings such as hangars, the specification requires a dado wall of 2.7m minimum height above ground level with sheet cladding above to be constructed. The wall should be of masonry cavity construction with insulation between two skins of minimum 100mm thick brickwork or blockwork. If insulated metal cladding is used as the outer skin, the minimum thickness of the internal skin should be 150mm. If the hangar is used to store large classified equipment or vehicles, then the minimum height of masonry wall must be increased to 3.15m above ground level. In this situation the internal skin should be minimum 150mm thick or 180mm thick if the outer skin is insulated metal cladding.

Figures 6.2, 6.3 and 6.4 give illustrations of typical details of the dado wall. The wall height and thickness shown are minimum. The wall should be designed for structural stability depending upon site and environmental conditions. For example, it may be useful to consider masonry buttresses or tie beams at the top of the wall. Suitable details to prevent the penetration of rain should follow the principles given in Building Research Establishment Report 143: Thermal insulation: avoiding risks 1989 ISBN 0 05125 3830 (BRE).

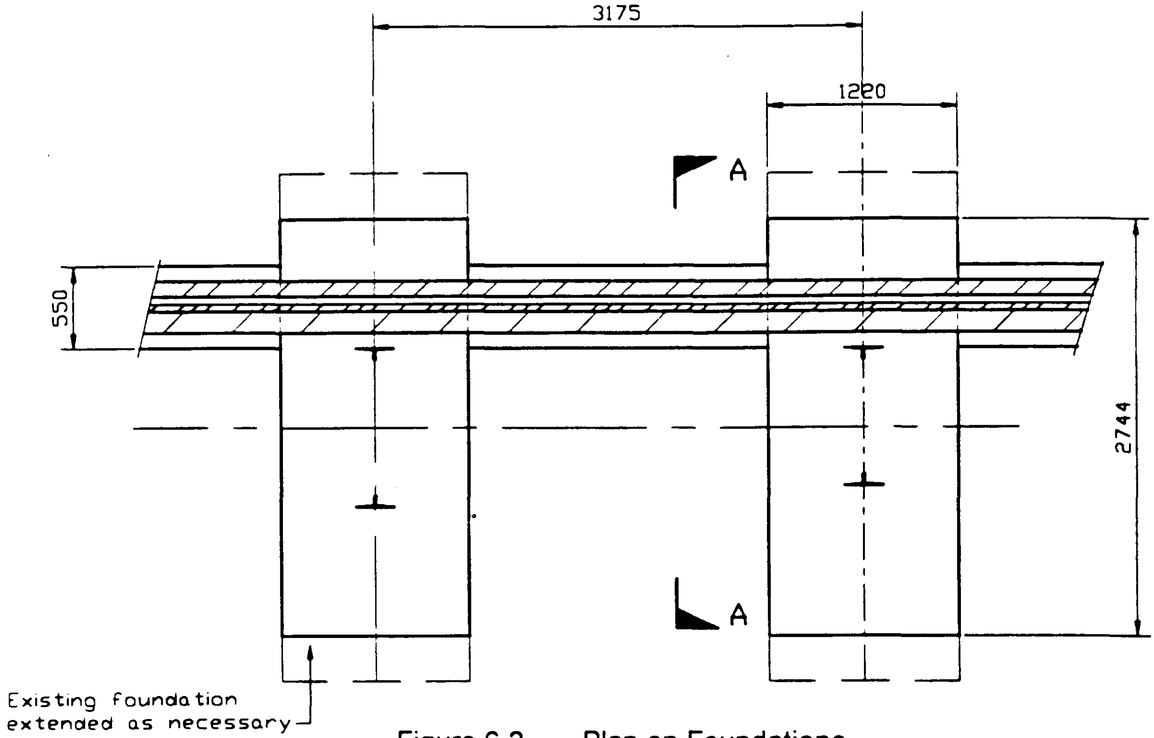

Figure 6.2 Plan on Foundations

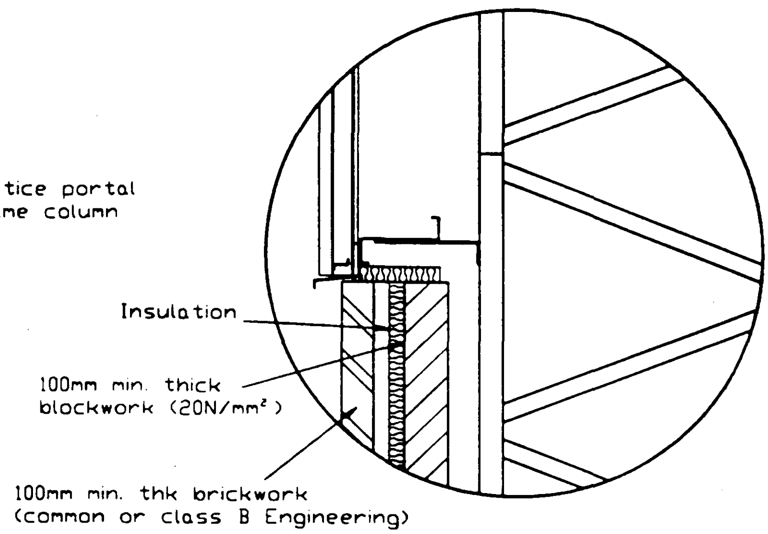

Figure 6.3 Enlarged Detail at Top of Wall

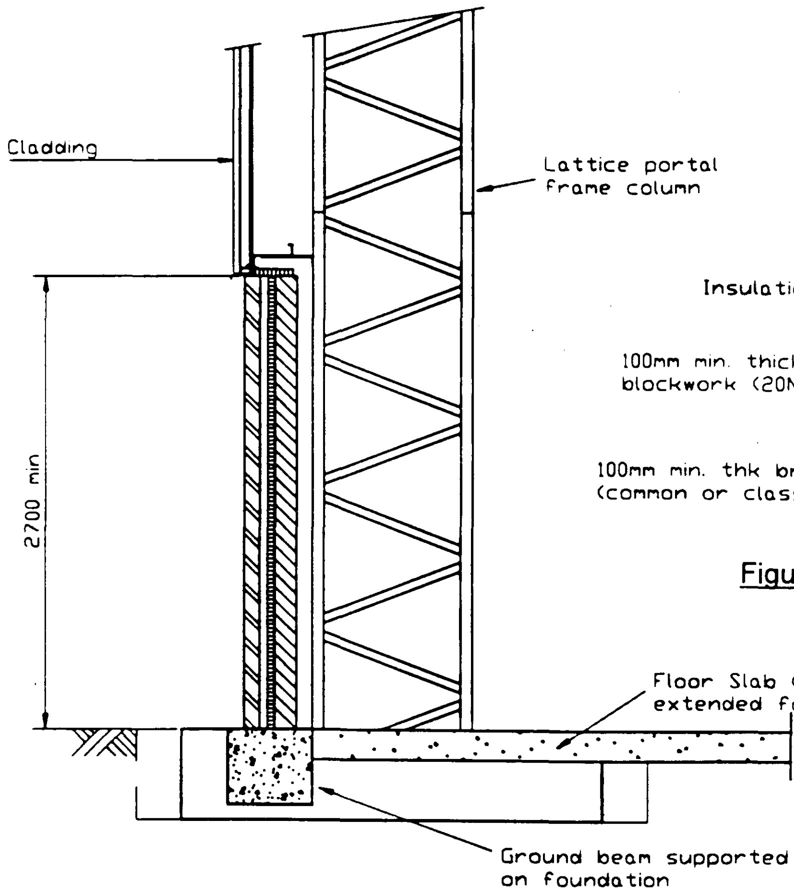

Figure 6.3 Section A-A

7.0 NEW BUILD ALTERNATIVE

An option study on any project should include a new build alternative besides the refurbishment option. A new build hangar as a "like for like" alternative was considered in order to perceive its structural form using modern higher quality steelwork and also to help give an estimate of its costs. In reality, the replacement structure is likely to be different in view of a Project Sponsor's current operational needs and use of different physical dimensions to give greater economy in construction.

The latest editions of all relevant British Standards should be used in the design of a new hangar. As part of the study a new steel portal framed building was analysed using BS 5950 design principles and current loading codes. The frame layout was matched as near as possible to an existing Type T2 (23) structure. The frame centres however were increased to approx 6.10m using 13 frames in total. Hence the advantage of modern cladding support systems was taken. The clear heights at the eaves below the haunch and the rafter heights were maintained.

The main members for the portal frame and foundation sizes were calculated as follows for a basic wind speed of 46 m/s:

Columns:	610 x 229 x 113 UB
Rafters:	610 x 229 x 101 UB
Foundations:	3.0 x 2.5 x 1.0m

For a new hangar, the designer must ensure that MOD policy and specifications for a building of this kind is complied. As a reference, the list below states MOD publications for use in the design and construction of a new hangar. The latest revisions to these publications should be checked.

- Air Publication (AP) 3384 Vol 1 (4th Edition) - Safeguarding Criteria and Movement Area Specifications for Permanent Aerodromes.
- MOD Publication JSP 318A - Military Air Traffic Services (Chapter 23 + for AGL) (Movement Area Floodlighting).
- Relevant Sections of PSA's M&E Guide (MEG) and CU (M&E) Drawings.
- AP 100D-20: Precautions Against Electric Shock in Electric Hazard Areas of Electrical and Electronic Maintenance Facilities.
- AP 113A - 0201-1 : Earthing of Aircraft and Ground Support Equipment.
- PSA Publication : A Guide to Airfield Pavement Design and Evaluation (ISBN 0 86177 127 3).

- Fire Standard D6 : "Fire Alarm Systems - Automatically Operated", April 1987.
- Fire Standard E4 : "Office Buildings", April 1987.
- Fire Standard E9 : "Garages, Vehicle Workshops, Vehicle Storage and Car Parks in Buildings", April 1987.
- Fire Standard E10 :·"Aircraft Hangars", November 1993.
- Fire Standard E11 : "Storage Premises", April 1987.

8.0 COST COMPARISONS

No option for a solution can be given full consideration without some idea of cost implications. Technical solutions on their own to overcome a problem do not carry any merit unless they can be proven to be economically viable.

Budget cost estimates are therefore given in this chapter for the basic work items in connection with a typical Type T2 (23) hangar, and a new build alternative. All costs are base estimates, in that they are 'raw' costs without inclusion of risk additions, preliminaries, VAT or professional fees. A site specific investment appraisal of the various options should take all such factors into account.

The base estimates in the Tables 8.1 and 8.2 are on the basis of 2Q 1993. All estimates will require validation for a particular project and updating to current price levels. They provide a rough guide for budgeting and comparison purposes.

Work Item	Estimated Cost (£)
Strip Cladding	19,000
Remove Purlin & Rails	3,500
Strengthening Steelwork	38,000
Strengthen Foundations	10,000
Fix New Purlins	9,000
Fix New Side Rails	7,500
Reclad	133,500
Flashings,.fixings, gutters, down pipes	6,500
Services	65,000
TOTAL	292,000

Table 8.1 Base Estimates (£) for Refurbishment of Type T2 (23) Hangar

If a 2.7m high brick dado wall is built around the perimeter of the building, then an extra over cost of £30,000 will be incurred.

The costs for the new build hangar are for a "like for like" alternative to enable comparisons to be made. As stated in Chapter 7.0, in reality the Project Sponsor's requirements may vary as per current operational practice. The new hangar has been costed for construction on the same site as the existing hangar. If a green field site were chosen, the cost of site preparation and laying new services may vary, depending on site specific conditions. The new build costs include for providing a replacement ground slab. If this were omitted and the existing ground slab used and patch repaired where necessary, then the total cost would reduce although some repairs and cutting out of the existing slab would become necessary.

Work Item	Estimated Cost (£)
Demolish and clear site	13,000
Foundations and Floor Slab	100,000
Steelwork	85,000
Purlins and Side Rails	25,000
Cladding	135,000
Flashings, fixings, gutters, etc	6,500
Doors (Roller Shutter)	10,000
Services	65,000
TOTAL	439,500

Table 8.2 Base Estimates (£) for New Build Type T2 (23) Hangar

The costs for refurbishment appear cheaper but a new build hangar will have a longer design life and can be designed to require much less maintenance than a refurbished hangar. Also a new hangar can be designed exactly to present day operational needs and thus running costs can be reduced. All such factors including any other indirect costs over the life of the two options should be taken into account in an investment appraisal.

For hangars which are heated, the use of modern insulated cladding panels would give an estimated saving of £12,000 per year for heat loss assuming a 'U' value of 0.45 W/m^2K.

9.0 STANDARDS

It is Government Policy that although the Crown is exempt from the provisions of the various Building Acts and Regulations all construction carried out on behalf of Government Departments is to comply with the substantive requirements of the relevant Acts of Parliament and Statutory Instruments, and that this compliance can be demonstrated.

9.1 BUILDING REGULATIONS

The application of Building Regulations is not retrospective but where major refurbishment works are carried out to the structure or cladding, these may be considered to be a "material alteration" and the refurbishment work will then be subject to the Building Regulations.

An alteration is material for the purposes of the Building Regulations if the work, or any part of it, if carried out by itself would adversely affect the existing building in relation to compliance with requirements for structure, means of escape in case of fire, internal or external fire spread, the provisions for disabled people, etc.

The requirement is in compliance with Part A of the Building Regulations 1991 for England & Wales, Part C of the Building Standards (Scotland) Regulations 1990 or Part C of the Building Regulations (Northern Ireland) 1994, and including all current amendments. The appropriate Regulations will be determined by the location of the works.

Further advice on compliance with Building Regulations is available from:

Building Control Officer
HQ DWS
P O Box 1734
Rectory Road
Sutton Coldfield
West Midlands
B75 7QB

Tel: Sutton Coldfield Mil Extn 2185
Fax: Sutton Coldfield Mil Extn 2187

9.2 MOD FIRE STANDARDS

MOD Fire Standards and in particular Fire Standard E10 - "Aircraft Hangars" are mandatory for all new build hangars and they are to be applied, so far as is reasonably practicable, when major refurbishment or modernisation of hangars is carried out. The MOD Fire Standards are not however retrospective and, where for example only limited renewal works items such as roof cladding are carried out, then only that element of the works is required to comply with the Standard.

It should be noted that the relevant MOD Fire Standard to be applied is determined by the proposed use of the hangar building and not by what it was built for originally. Therefore MOD Fire Standards E9 - "Garages, Vehicle Workshops, Vehicle Storage and Car Parks in Buildings" or E11 - "Storage Premises" may be the relevant Fire Standard.

Further advice on compliance with the respective Fire Standards is available from:

Senior Fire Prevention Officer
HQ DWS
P O Box 1734
Rectory Road
Sutton Coldfield
West Midlands
B75 7QB

Tel: Sutton Coldfield Extn 3634
Fax: Sutton Coldfield Extn 2187

ANNEX A

Change Suggestion Form

	Defence Works Services **Airfields and Bulk Fuels Group** **P O Box 1734** **Rectory Road** **Sutton Coldfield** **West Midlands** **B75 7QB**	**Guide to World War II Hangars** **02-Type T2 Hangar** **Change Suggestion Form**
Originator:		Date: Ref:
Change Suggestion		
Section:		Page:
Change Detail: Continuation Sheet included ? Y ❑ N ❑		
Reason: Continuation Sheet included ? Y ❑ N ❑		
DWS Review		
Action:		Ref: Action Date: Approved: Actioned:

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REFERENCES

1. BS 449: Part 2: 1969: Specification for the Use of Structural Steel in Building, incorporating Amendment No 8 (AMD 6255, December 1989).

2. BSI CP3: Chapter V: Part 2: 1972 - Code of Basic data for the design of buildings Chapter V: Loading, Part 2: Wind loads ISBN 0 580 074536.

3. BS 5950: Part 1: 1990: Structural use of steelwork in building.

4. BS 6399: Part 1: 1984 Code of Practice for Dead and Imposed Loads, Part 3: 1988: Code of Practice for Imposed Roof Loads.

5. Building Research Establishment Digest 346 December 1990 ISBN 0 85125 473 X.

6. Historical Structural Steelwork Handbook Publication No 11/84, The British Constructional Steelwork Association Limited, ISBN 0 85073 015 5.

7. Health and Safety at Work etc Act (1974), HMSO.

8. DWS Specification 005 Issue No 002, June 1992: Property Management of the Defence Estate.

9. DWS Technical Bulletin 39/94: Hangars - Safety of Structure - Recommendations for Users During Adverse Weather Conditions, August 1994.

10. DWS Technical Bulletin 40/94: Hangars and Industrial Buildings - Inspection, Maintenance, Adjustment and Use of Large Sliding and Folding Doors, August 1994.

11. Defence Works Functional Standard 06: Guide to Airfield Pavement Maintenance, HMSO ISBN 0 11 772730 X.

12. Lighting Guide No 1 "The Industrial Environment" 1989, Chartered Institute of Building Services Engineers (CIBSE).

13. Services Accommodation Code, Joint Services Publication (JSP) 315.

14. Secure Building Specification for Industrial Type Buildings, DOE Special Services Group.

15. MOD Fire Standard E10 - "Aircraft Hangars", November 1993.

16. MOD Fire Standard E9 - "Garages, Vehicle Workshops, Vehicle Storage and Car Parks in Buildings", April 1987.

17. MOD Fire Standard E11 - "Storage Premises", April 1987.

18. Building Regulations 1991 for England and Wales.

19. Building Standards (Scotland) Regulations 1990.

20. Building Regulations (Northern Ireland) 1994.

21. Building Research Establishment Report 143 : Thermal insulation : avoiding risks : A guide to good practice in building construction 1989 ISBN 0 85125 3830 (BRE).

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