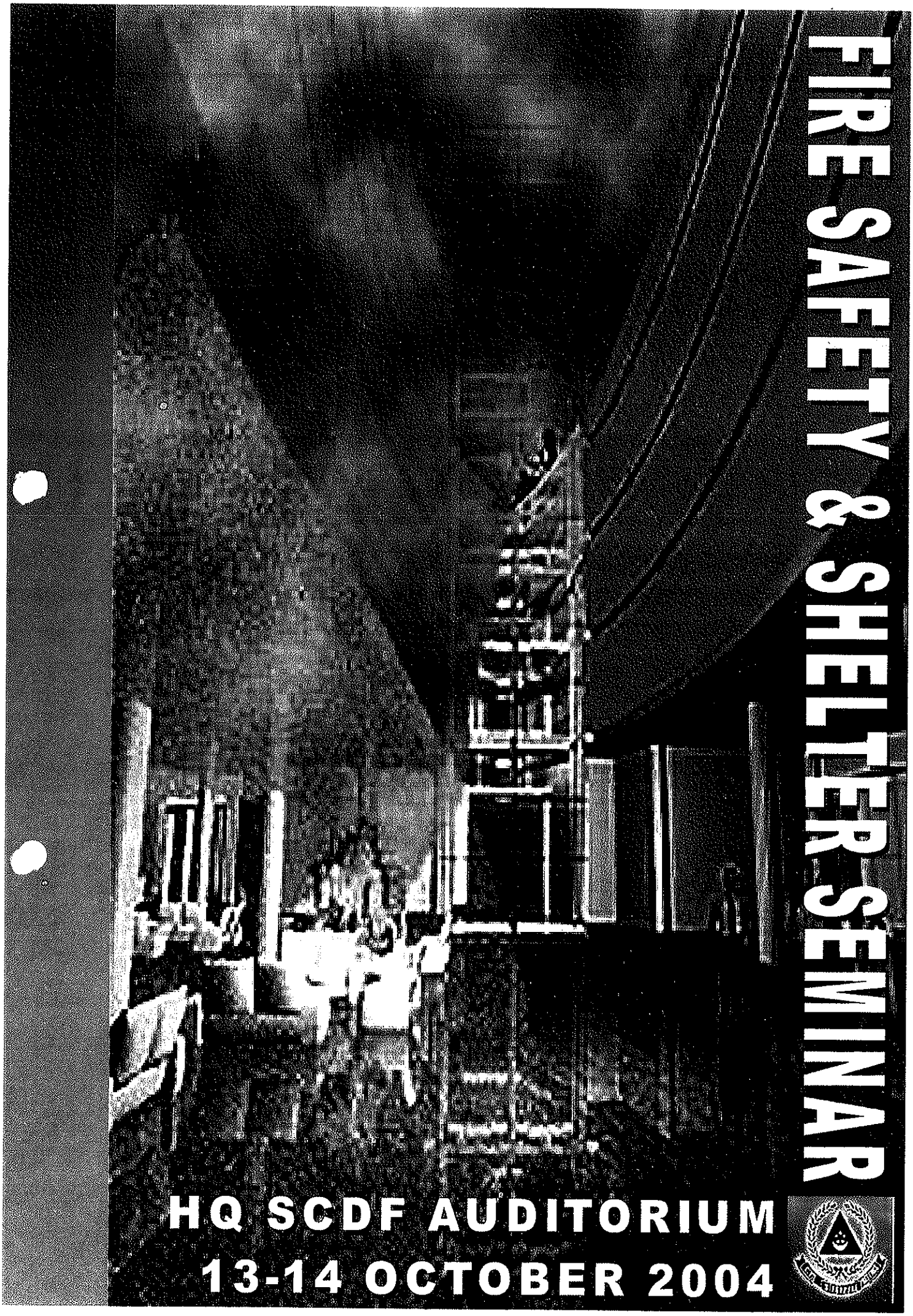

FIRE SAFETY & SHELTER SEMINAR
HQ SCDF AUDITORIUM
13-14 OCTOBER 2004

Programme for Fire Safety & Shelter Seminar
(13 &14 Oct 2004)

Session One (13 Oct, AM)	
0830 hr	***Registration***
0925 hr	*Participants to be seated*
0930 hr	*Design Requirements for Staircase Storey Shelter*
0950 hr	*The Electronic Way – Corenet E-submission System (ESS)*
1010 hr	*Performance-Based Fire safety Engineering Design – Tools and Examples*
1030 hr	***Refreshment***
1100 hr	*Technical Guidelines on Fire Safety requirements of Chemical Warehouse*
1120 hr	*Technical Guidelines on Fire Safety Requirements for Petroleum Service Station and Proposed Technical Guidelines on Fire Safety Requirements for Hydrogen Fuel-Cell Vehicle Refueling Facilities and Hydroegn Fuel-Cell Vehicle Maintenance Workshop.*
1140 hr	*Building Structural Design Under Fire Conditions*
1200 hr	*Questions & Answers*
1230 hr	*End*

Session Two (13 Oct, PM)	
1345 hr	***Registration***
1430 hr	*Building Structural Design Under Fire Conditions*
1450 hr	*The Electronic Way – Corenet E-submission System (ESS)*
1510 hr	*Design Requirements for Staircase Storey Shelter*
1530 hr	***Refreshment***
1600 hr	*Technical Guidelines on Fire Safety requirements of Chemical Warehouse*
1620 hr	*Technical Guidelines on Fire Safety Requirements for Petroleum Service Station and Proposed Technical Guidelines on Fire Safety Requirements for Hydrogen Fuel-Cell Vehicle Refueling Facilities and Hydroegn Fuel-Cell Vehicle Maintenance Workshop.*
1640 hr	*Performance-Based Fire safety Engineering Design – Tools and Examples*
1700 hr	*Questions & Answers*
1730 hr	*End*

Session Three (14 Oct, PM)	
1345 hr	***Registration***
1430 hr	*Design Requirements for Staircase Storey Shelter*
1450 hr	*The Electronic Way – Corenet E-submission System (ESS)*
1510 hr	*Performance-Based Fire safety Engineering Design – Tools and Examples*
1530 hr	***Refreshment***
1600 hr	*Technical Guidelines on Fire Safety requirements of Chemical Warehouse*
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1700 hr	*Questions & Answers*
1730 hr	*End*

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2.	The Electronic Way – Corenet E-Submission System (ESS)	Ms. Chantel Chew
3.	Performance-Based Fire Safety Engineering Design – Tools & Examples	EO Edmund Choo
4.	Technical Guidelines on Fire Safety Requirements for Chemical Warehouse	Cpt. Alice Seto
5.	Technical Guidelines on Fire Safety Requirements for Petroleum Service Station and Proposed Technical Guidelines on Fire Safety Requirements for Hydrogen Fuel-Cell Vehicle Refueling Facilities and Hydrogen Fuel-Cell Vehicle Maintenance Workshop.	Cpt. Aidil Arshad
6.	Building Structural Design Under Fire Conditions	Assoc. Prof. Tan Kang Hai

Design Requirements for Staircase Storey Shelter

By

Maj. Ng Shu Herng

AD Shelter Operations & Management Branch

Fire Safety & Shelter Department

DESIGN REQUIREMENTS FOR STAIRCASE STOREY SHELTER

INTRODUCTION

With the implementation of the Civil Defence Shelter Act on 1 May 1998, all new residential developments (public and private housing) must be provided with either household or storey shelters. While household shelters have to date been the more popular option adopted by developers, the recent trend of designing dwelling units that are smaller in sizes prompted the development of the design requirements for the construction of storey shelters in fire escape staircases. Because of space constraints, developments with small flats are more likely to encounter layout difficulties when incorporating household shelters in these units. For such developments, the primary advantage of adopting storey shelters (SS) instead of household shelters (HS) is that there can be greater flexibility in the design and layout of the dwelling units, now that the required shelter berths are to be provided on common spaces on that storey instead of within the confines of the individual units.

2 Responding to the feedback from the building industry in 2003, SCDF and BCA have reviewed and adapted the Storey Shelter (SS) technical requirements to allow the fire escape staircase to be configured to serve as storey shelters in a war emergency. The staircase SS is an additional option which developers of new flat developments may adopt in lieu of, or in combination with the provision of household shelters (HS). Compared to the normal SS design option which has been available since1997, the new staircase SS design is attractive to developers because it incurs less additional GFA by making use of existing space of the fire escape staircase to double up as shelter space.

3 For the purpose of obtaining feedback and comments from the industry, the draft design requirements for Staircase SS was tabled for presentation at the FSSD Standing Committee Meeting in May 04 as well as at the FSSD Dialogue Session in Jun 04. The finalised requirements were subsequently issued for implementation via circular on 14 Jul 2004.

CONCEPT OF STOREY SHELTER

4 As mentioned earlier, the normal SS was introduced as an alternative to the HS since the inception of the CD Shelter Act. The design requirements for SS are stipulated in the document "Technical Requirements for Storey Shelters 1997".

5 Unlike a HS which is built within an individual dwelling unit, an SS is located in a common area on the same storey as those dwelling units which it serves. Figure 1 is a typical floor plan of a development incorporating an SS. In terms of size, an SS is also larger than a HS, since the former is meant to cater to the occupants of two or more dwelling units on that particular storey. The maximum allowable size of an SS is $32m^2$.

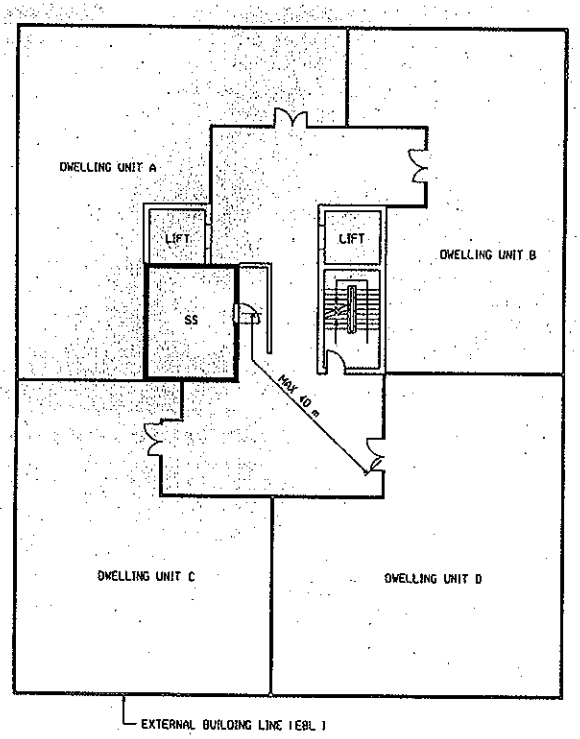


Figure 1 – Typical Floor Plan of Development Incorporating SS

6 In order to ensure the SS can perform its intended function of offering quick access to protection, the travel distance between the shelter entrance and the exit door of any dwelling unit (at the same storey as the shelter entrance) served by the SS shall not exceed 40 m. If the dwelling unit has more than one exit door, the travel distance is

measured between the shelter entrance and the nearest dwelling unit exit door at the same storey as the shelter entrance.

7 Just like for HS, SS are stacked one on top of another forming an SS tower that extends down to the foundation of the building. Besides having a steel blast door, thickened walls, floor and ceiling slabs, an SS also derives its protection from having its walls setback from the external façade of the building. The setback distance requirements decreases the likelihood of the SS being hit by weapon effects, thereby increasing the survivability of the shelterees within. An additional feature that an SS is required to incorporate in view of its larger sheltering capacity (compared to HS) is the rescue hatch and cat ladder setup, meant for rescue/emergency escape. The positioning of the rescue hatch on the floor and ceiling slabs of an SS is illustrated in Figure 2.

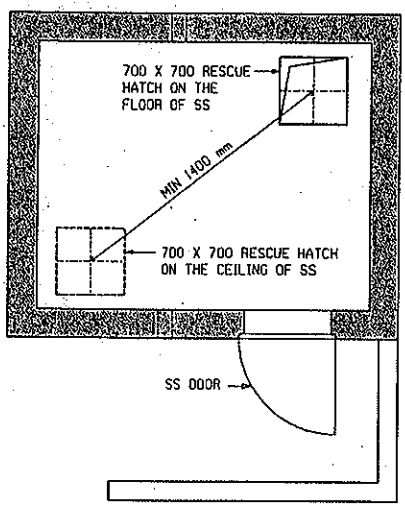


Figure 2 – Rescue Hatch in SS

DESIGN REQUIREMENTS FOR STAIRCASE SS

8 The staircase SS is an adaptation of the normal SS, in which a fire escape staircase is configured to double up as storey shelters during a war emergency. Because of the setback distance requirements, only internal exit staircases can be considered. Also, since the staircase space has to be transformed into air-tight enclosures when converted for use as SS, naturally ventilated staircases would not be appropriate. As such, only

mechanically ventilated staircases would be suitable for adaptation into staircase SS. The following sections presents the salient design requirements for staircase SS, illustrating how a staircase that has to comply with fire safety requirements can be adapted for the dual purpose. (Note: For the full set of requirements, please refer to the circular "Design Requirements for Staircase SS" issued on 14 July 2004.)

Blast Hatch for MV Shaft Opening

9 For peacetime ventilation purpose, openings for entry of ventilating air via mechanical ventilation (MV) shaft are permitted. These MV shaft openings have to be designed such that they can be closed and made airtight by BCA-approved blast hatches when the staircase shaft is converted for use as SS. The height of these opening shall be between 600-700mm, whereas its width shall be between 500-700mm. With respect to the arrangement of the blast hatch protecting the MV shaft opening into the staircase SS, the 3 different layouts that can be adopted are as follows:

a Horizontal blast hatch

The blast hatch in this arrangement is configured similar to the rescue hatch in a normal SS. For inspection and maintenance of the blast hatch, there shall be reinforced concrete or steel nib provided around the MV shaft as shown in Figure 3. The MV shaft walls at each storey other than the portion that is common with the staircase shaft are deemed as the SS walls i.e. bounds of protection of the SS.

b Vertical blast hatch swinging into MV shaft

The bottom edge of the opening in the SS wall shall be 900 mm above the finished floor level of the landing slab. For inspection and maintenance of the blast hatch, there shall be reinforced concrete or steel nib provided around the MV shaft as shown in Figure 4.

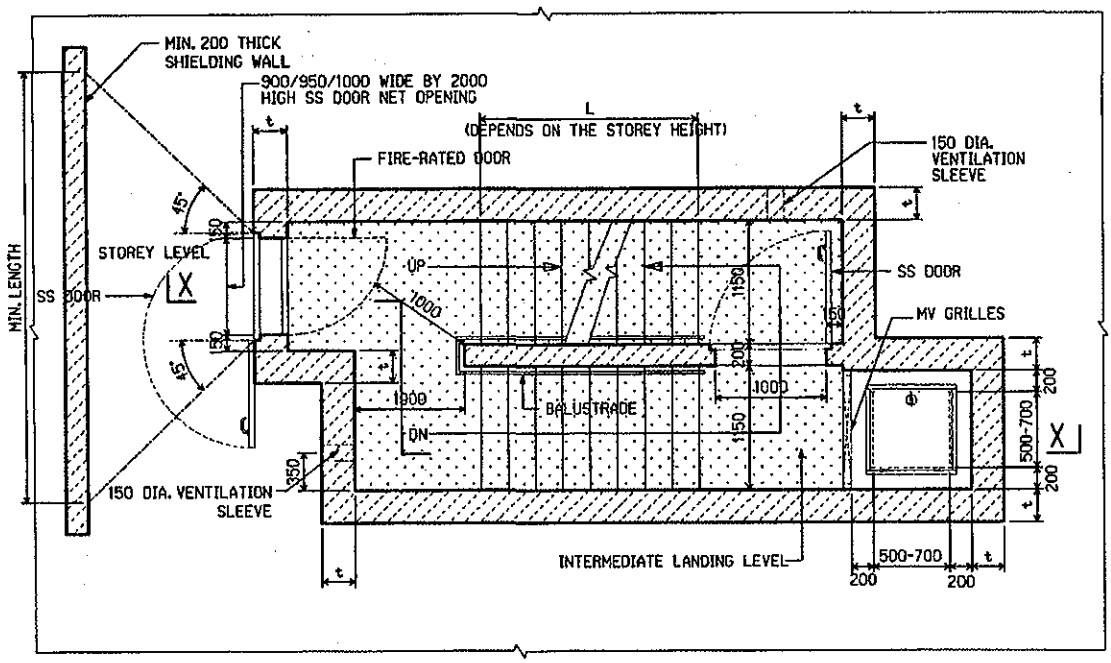


Figure 3 – Horizontal Blast Hatch Configuration

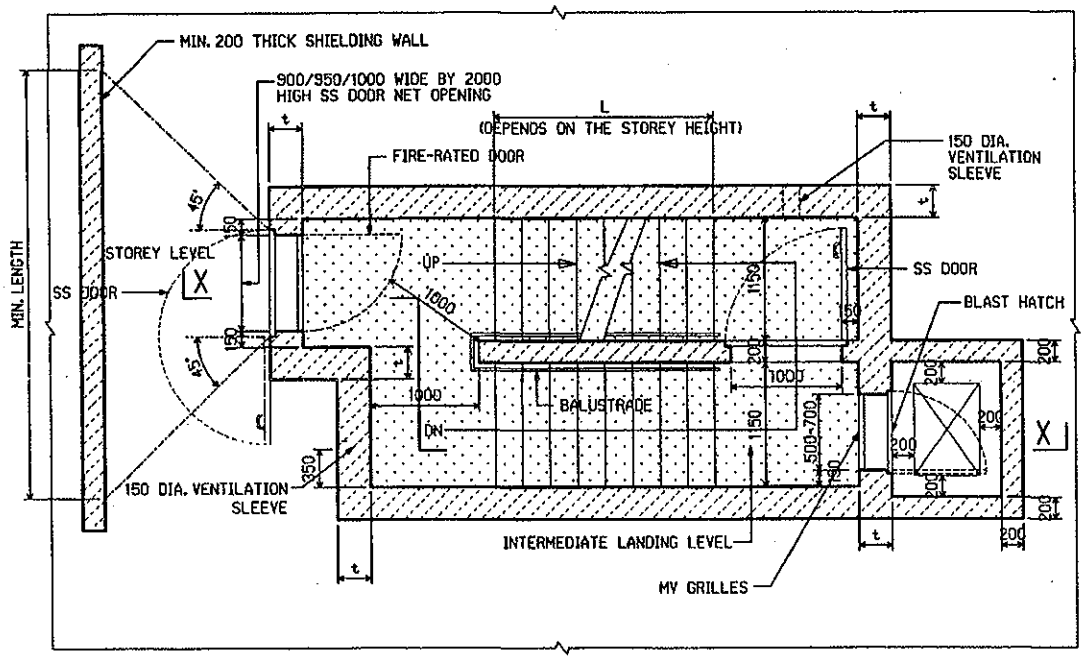


Figure 4 – Vertical Blast Hatch Swinging Into MV Shaft Configuration

c Vertical blast hatch swinging into staircase shaft

The bottom edge of the opening in the SS wall shall be 900 mm above the finished floor level of the landing slab. Inspection and maintenance of the blast hatch can be performed from within the staircase shaft. The MV shaft walls at each storey other than the portion that is common with the staircase shaft are deemed as the SS walls i.e. bounds of protection of the SS.

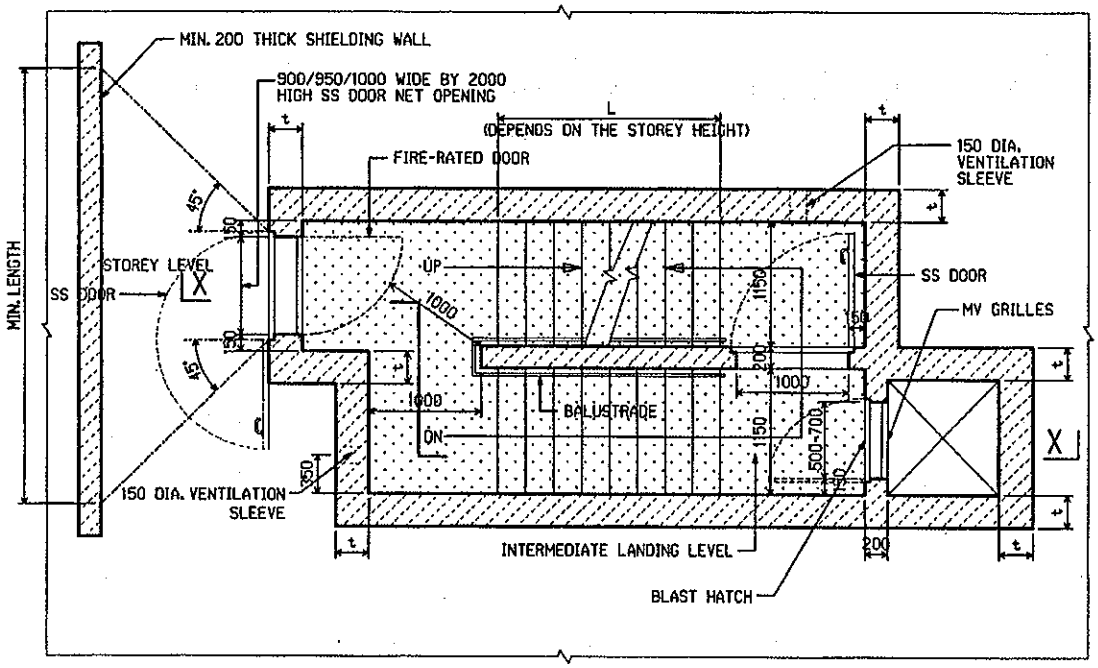


Figure 5 – Vertical Blast Hatch Swinging Into Staircase Shaft Configuration

SS Door at Shelter Entrance

10 At every storey, one SS door with removable door kerb[1], swinging outwards and left permanently open during peacetime, is to be provided at the shelter entrance (see Figure 6). As the swing of this SS door is against the direction of exit travel, it shall not double up as the peacetime fire-rated door. Hence, a separate peacetime fire-rated door swinging in the direction of exit travel is required.

[1] For CD operations, the SS door's lower edge has to be supported by a door kerb for resisting blast and maintaining air tightness. For peacetime use of the staircase, the kerb has to removed to avoid obstructing smooth traffic flow during fire evacuations.

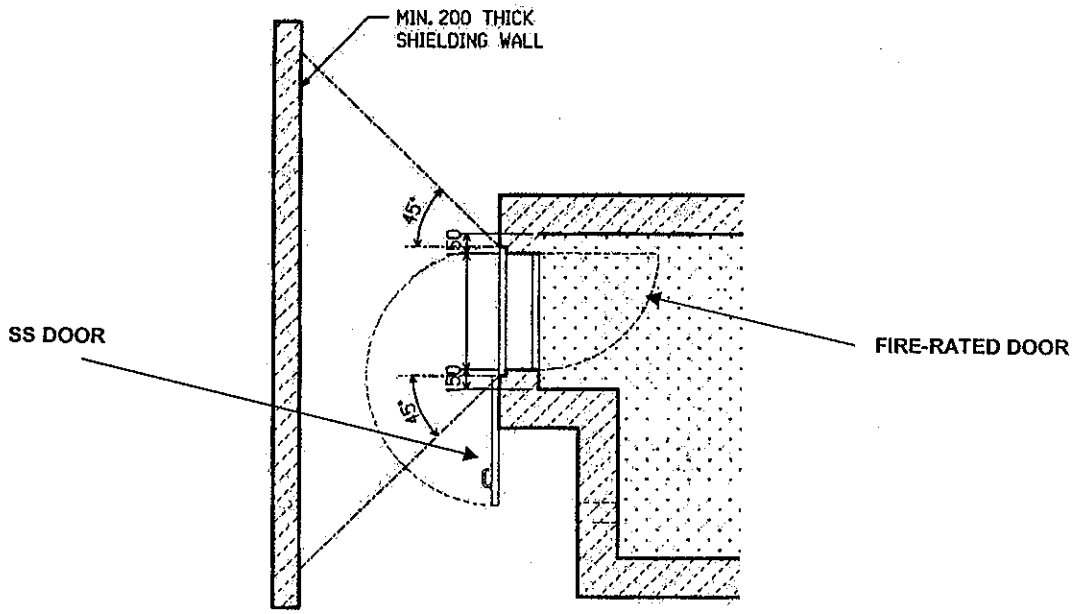


Figure 6 – SS Door at Shelter Entrance

11 Similar to the normal SS, to protect the SS door against fragmentation effects, it has to be shielded by a full-height reinforced concrete (RC) wall. The shielding wall, with a minimum thickness of 200 mm, has to be positioned such that it is not more than 4000 mm from the SS door .

Internal SS Wall and SS Door

12 Like the normal SS, the staircase SS serves those dwelling units on the same storey. In order to compartmentalise the staircase shaft into a series of SS, each serving one storey, there has to be a RC internal wall of minimum 200 mm thickness running the full height of the staircase shaft. Also, at every storey, one SS door swinging in the direction of exit travel, with removable door kerb, is to be provided either at the staircase entrance landing or at the intermediate landing (See Figure 7). Like the SS door at the shelter entrance, this SS door has to be kept permanently opened during peacetime. (Note: As all the SS inside the staircase shaft are interconnected, rescue hatches and cat ladders required for a normal SS are not needed.).

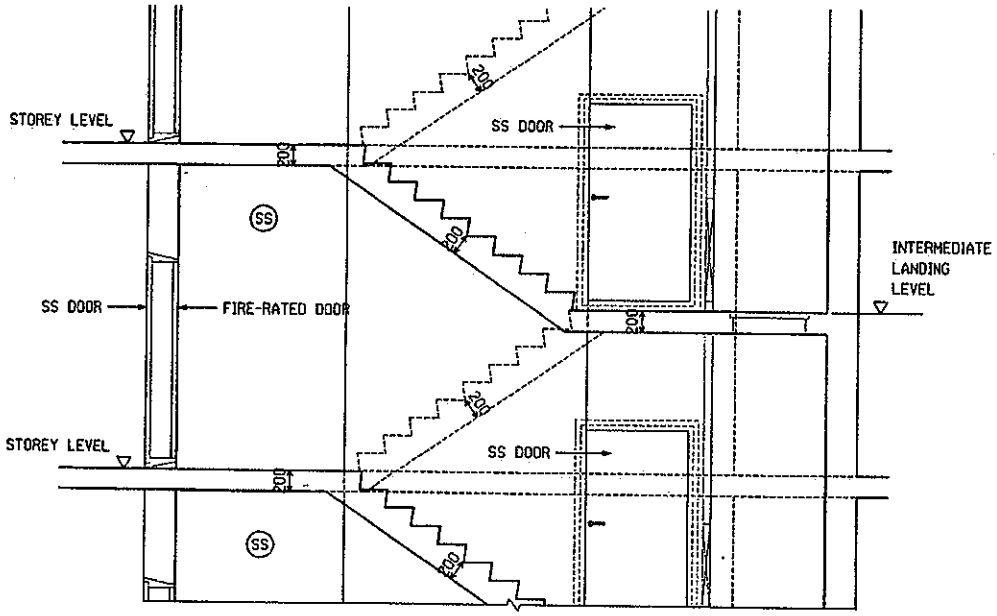


Figure 7 – Positions of SS Doors in Staircase SS

13 The SS door net opening dimensions shall be:

a Door width – 1000 mm (Note: The minimum clear opening of the door way shall be 970 mm measured between the face of the door and the face of the door stop with the door open at 90°).

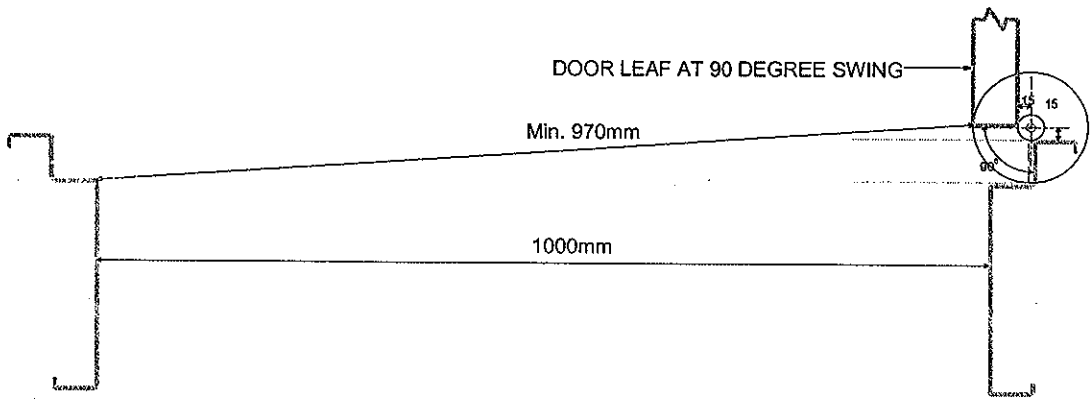


Figure 8 – Clear Opening for Intermediate Landing SS Door

b Door height – 2000 mm.

Staircase SS Area and Volume

14 The aggregate planar area of the staircase entrance landing, intermediate landing and the staircase treads (excluding the over-lapping tread at each riser and area taken up by the internal SS door) of each storey is taken as the internal floor area of the staircase SS. The required minimum internal floor area of the staircase SS is the product of 0.6 m^2 and the nominal occupancy of all the dwelling units served by the staircase SS at that storey. The product of the internal floor area of the staircase SS and its internal height (measured from the finished floor level to the soffit of the ceiling slab) is taken as the internal volume of the staircase SS. The required minimum internal volume of the staircase SS is the product of 1.8 m^3 and the nominal occupancy of all the dwelling units served by the staircase SS at that storey. The nominal occupancy of various sizes of dwelling units used to calculate the required minimum internal floor area and volume is given in Table 1. The maximum length of staircase SS shall be 8000 mm.

Gross Floor Area (GFA) of Dwelling Unit (m^2)	Nominal Occupancy of Dwelling Unit (No. of Persons)
GFA ≤ 45	2
45 < GFA ≤ 75	3
75 < GFA ≤ 140	4
GFA > 140	5

(Note: The GFA of the dwelling unit excludes the area of balconies that are open on at least two sides to make the balconies conducive for sky-rise gardening in accordance with URA guidelines.)

Table 1 - Nominal Occupancy of Dwelling Unit

Setback Distance and Thickness of SS Elements

15 The setback distances and thickness of the staircase SS walls have to comply with Table 2 and Table 3_respectively. The minimum setback distance of the SS wall where the SS door is located shall be 4000 mm.

Storey Height (mm)	Min. Setback Distance of any 1 Wall (mm)	Min. Setback Distance of Remaining 3 Walls (mm)
$2500 \leq SH \leq 2650$	2200	4000
$2650 < SH \leq 3000$	2400	4000
$3000 < SH \leq 3500$	2600	4000
$3500 < SH \leq 4000$	2800	4000

Table 2 - Storey Height and Minimum Setback Distances

SS Clear Height (mm)	Setback Distance of SS Wall (mm)	SS Wall Thickness (mm)
$2400 \leq Ht \leq 3400$	< 6000	300
	≥ 6000	250
$3400 < Ht \leq 3900$	< 6000	325
	≥ 6000	275

Table 3 - SS Clear Height and Minimum SS Wall Thickness

16 The minimum thickness of staircase waist and landing slab shall be 200 mm. The minimum thickness of the ceiling slab of the top-most staircase SS as well as that of the floor slab of the bottom-most staircase SS shall be 300 mm. Where there are Non-Shelters (NS) interspersed within the staircase SS tower, the provision of SS doors at the intermediate landings, as well as blast hatches shall be as shown in Annex D.

Ventilation Sleeves on SS Walls

17 Two ventilation sleeves of diameter 150mm are to be provided in the SS wall at the staircase entrance landing or intermediate landing at each storey. Both openings are to be closed with steel cover plates as in the case of a normal SS. No fire rating requirements need be applied for these steel cover plates. To facilitate the carrying out of inspection as well as future upgrading/installation works, the position of the ventilation sleeves shall comply with the following:

a The height of each opening, measured from the centre of the opening to internal FFL shall be between 1900 mm and 2600 mm;

b The ventilation sleeve shall be positioned such that there is sufficient clear space in the wall around the opening. The clear space around it shall be a circular area of at least 700 mm diameter, measured concentrically from the centre of the opening;

c Where the ventilation sleeve is placed above or adjacent to the SS door, the centre of the opening shall be at least 275 mm from the nearest edge of the door frame; and

d The shortest distance between the centres of the two openings shall be at least 1000 mm.

Fixtures in Staircase SS

18 At each staircase entrance landing or intermediate landing, a TV/radio point shall be provided. One power point shall be provided in the vicinity of the TV/radio point and additional two power points (either 1 twin gang or 2 single-gang) at every staircase landing shall be provided for other appliances such as fan, etc. A telephone point shall also be provided at either the staircase landing or intermediate landing for every storey. The telephone point at each storey shall have its own independent line. Luminaires shall be

mounted on the soffit of the staircase SS ceiling slab with screws and non-metallic inserts. Luminaires shall not be wall mounted.

Other Requirements

19 Wherever applicable, other requirements stipulated in the "Technical Requirements for Storey Shelter 1997" such as commissioning of the SS, and supplementary technical requirements with respect to NS wall shall apply to the staircase SS. In addition, other statutory requirements (such as building control and fire safety requirements) governing the design and use of the staircase shall be complied with.

CONCLUSION

20 By allowing fire escape staircases to be doubled up as SS, architects and developers now have greater flexibility in the design and layout of their developments. This new concept is especially advantageous for developments with small studio apartment units. As at end Sep 2004, 17 developments have decided to adopt or have indicated interested in adopting the staircase SS concept in their design. Some of these developments are designed with staircase SS solely, while others incorporate a combination of staircase SS and HS.

Prepared by : Maj Ng Shu Herng
Assistant Director (Shelter Operation & Management)
Fire Safety & Shelter Department
Singapore Civil Defence Force

The Electronic Way – Corenet E-submission System (ESS)

By

Ms. Chantel Chew

Technical Consultant

Building & Construction Authority

CORENET E-SUBMISSION SYSTEM (eSS)
FREQUENTLY ASKED QUESTIONS

1. SETTING UP FOR CORENET E-SUBMISSION

1.1. What are the set-up requirements?

You should take note of the following requirements:

- E-Submission Applicants should have the following hardware
  - ⇒ Pentium III with 500 MHz and above
  - ⇒ Minimum 128MB RAM
  - ⇒ ADSL (Highly recommended) modem
  - ⇒ Hard disk with sufficient capacity of minimum 1 GB
  - ⇒ Netrust Smartcard Certificate Version 3
  - ⇒ Smartcard Reader

- E-Submission Applicants should install the following software on the PC
  - ⇒ Supported Operating System
  - ⇒ Windows 98 (Second Edition)
  - ⇒ Windows 2000
  - ⇒ Windows NT 4.0
  - ⇒ Windows ME
  - ⇒ Windows XP (Home/Professional)
  - ⇒ Microsoft Internet Explorer Browser Version 6.0 and above
  - ⇒ Microsoft office applications
  - ⇒ Java Virtual Machine
  - ⇒ Volo View (if no CAD software)
  - ⇒ *McAfee Anti Virus 7.0 is not compatible with ESPro applications.*

- E-Submission Applicants who require to send applications to URA should also install the following software on the PC:
  - ⇒ EDAForm application (offline module)
  - ⇒ JRE 1.3 (this comes with the EDAForm application installation program).

1.2 Do I need to register with Netrust?

Qualified Persons (QP) who need to "sign" plans and documents for regulatory approval need to obtain a Netrust digital certificate. These include, but shall not be limited to, register architects, professional engineers and licensed tradesmen like electricians, plumbers and gas workers.

There would be cases where some forms require both the signature of owners / other party and qualified persons. If the owner / other party do not have Netrust digital certificates they can, through formal arrangement such as via letter of undertaking etc, appoint the qualified persons to act on their behalf. Such letter or equivalent document would have to be digitally sign by the qualified persons and submitted together with the plans for regulatory approval.

- Information about Netrust is available at www.netrust.net.

1.3 Do I require any licenses for the software?

The Internet Forms viewer requires a unique license key for each site license. The license is distributed by BCA. To encourage early adoption of the System, BCA would be absorbing the initial purchase cost (estimated to be $ 300) for one license per firm. The distribution of the licenses would be subjected to the availability of stock of the Internet Forms viewer. There is a recurrent cost of about $ 30 / year per license. The payment would be borne by the firm issued with the license.

To request for a new license, the firm has to write in to BCA System Administrator (Ms Irene Tan at Irene_Tan@bca.gov.sg) with the following information:

- Company's name
- Company's address
- Contact person
- Designation in the firm
- Professional registration number if any
- Reference number of project registered with the System (if any)

BCA will only issue new licenses to firms that have existing projects registered with the System.

1.4 What is the maximum file size for each submission?

It is advisable to keep in within 100MB

If you have more than 100MB of documents for submissions, you can send the files in 2 batches. First batch as a new submission (ES) and the second batch as a correspondence (CR).

1.5. Can eSS accept submission of all types of files?

No. Only selected files types are accepted.

Documents/Reports/Text	*.DOC, *.XLS, *.TXT, *.RTF, *.PDF, *.HTML, *.XFD, *.EDA
CAD Data Format	*.DXF, *.DWG, *.DGN, *.PDF
Image File	*.GIF, *.JPEG, *.TIFF, *.BMP, *.PDF

1.6. What is the payment mode for eSS?

Cash, Cheque & GIRO are allowed.

2. TRAINING AT CITI

2.1. Where can I go for the training?

Training will be conducted at Construction Industry Training Institute, BCA's training arm. Details are available on the CORENET web site, under IT Training and Promotion. The authority shall not be responsible for the training or support provided by other independent contractors or agency trainers.

2.2. Can I apply for any training subsidy or grant for attending the training? How do I go about applying for the grant or subsidy?

Trainees can apply for training grant of up to 70% of the training costs under the Initiatives in New Technologies (INTECH) offered by EDB and administered by BCA, subject to EDB's terms and conditions. The scheme is applicable to Singaporeans or Singapore Permanent Residents sponsored by the company in the private sector for the training. More details are available at CORENET web site, under IT Training and Promotion.

2.3. How do I register for the training?

Interested parties can either request for the registration forms to be sent or faxed to CITI (Application Form will be included in the Starter Kit).

2.4 If I need more information or have further queries, where can I obtain the information or whom can I contact?

More information can be found on CORENET's website or you can contact the following for further assistance:

For enquiry on INTECH training grant:

Building and Construction Authority
5 Maxwell Road
#16-00 Tower Block MND Complex
Singapore 069110

Catherine Wee-Loh (Mrs)
Tel: 6325 7720
Fax: 6325 4800
Email: bca_corenet@bca.gov.sg

For enquiry on training schedule:

Construction and Industry Training Institute
Supervisory Training Administration Department
200 Braddell Road
Singapore 579700

Kong Tak Chong (Mr)
Tel: 62489908
Fax: 6258 0558

2.5 Will I receive any certificate upon completion of the course?

Trainees will be presenting with a Certificate of Attendance upon successful completion of the training.

3. SITE SUPPORT

3.1 What is site support?

In any case if the problems encountered cannot be solved, CORENET-ESS helpdesk staff will provide complimentary assistance over the phone or on your site at your office.

3.2 Who should I contact for site support?

You could call CORENET eSS helpdesk at 6325 5901 to 6325 5906 during office hours.

4. NETRUST FOR CORENET E-SUBMISSION SYSTEM

4.1. Who to contact for enquiry or help?

Netrust Pte Ltd
10 Collyer Quay
#09-05/06 Ocean Building
Singapore 049315

Netrust Customer Service Hotline:

Tel: 6212 1388
Fax: 6212-1366

Email: infoline@netrust.net

Website: www.netrust.net

4.2. How much do I have to pay?

⇒ Netrust Digital Certificate: $50 (renewable annually)

⇒ Registration Fee: $10 (one-time cost)

⇒ Netrust-ready Smartcard: $25

⇒ Netrust-ready Reader: $55

⇒ GST: $4.20

Total with GST: ***$144.20***

Mode of payment:

- Cash
- Cheque
- NETS
- VISA
- MASTER upon collection

4.3. What do I have to bring?

- Identification document of Applicant – Identity Card, Passport or Work Permit (foreigners);
- Photocopy of front and back of identification document;
- Netrust Digital Certificate Application Form;
- *Original* or *certified true copy* of either one of the following if applicable:
- Practising Certificate from the Professional Engineers Board OR
- Practising Certificate from the Board of Architects;
- Letter of Authorization, authorizing the Applicant to apply for the card;
- *Original* or *certified true copy* of the RCB (Registry of Companies & Businesses) Certificate.

Performance-Based Fire Safety Engineering Design – Tools & Examples

By

EO Edmund Choo

Performance Based Plan Verification Section

Fire Safety & Consultation Branch

Fire Safety & Shelter Department

Performance-Based Fire Safety Engineering Design – Tools and Examples

I. Introduction

Fire safety engineering is a new and complex field of study, which may involve multi-disciplinary engineering knowledge and inevitably, computational tools are helpful to the fire safety engineer in generating, organizing and processing loads of data and information needed in the process of coming up with a suitable engineered fire safety solution for the particular building involved.

This paper provides an overview of the type of software tools that are available to the fire safety engineer, and the general underlying concepts behind some of these tools, and their limitations. The paper will also highlight the use of such tools in performance-based projects that have been implemented locally.

Modelling softwares have been employed to simulate

(i) fire and smoke spread and
(ii) occupant evacuation out of buildings

for performance-based submissions to SCDF.

II. Fire Modelling

Fire safety engineers are able to tap on the increasing power of today's computers to create mathematical representations of fire in the computational domain. Mathematical fire models predict the effects of fire in buildings, eg transport of smoke, temperature changes, visibility conditions. For most projects, mathematical modelling is much more practical and viable than setting a real fire in the constructed building, in terms of cost and time.

The dynamics of fire is extremely complex and mathematical models attempt to simplify the processes involved, in order to obtain reasonably accurate predictions of fire and its effects for practical engineering use and calculations. In the simplification process, assumptions are introduced and as such, users of fire modelling software must be aware of such assumptions to gauge the appropriateness of the software for the applied usage.

There are 2 types of fire modelling software:-
(i) zone models
(ii) field models, or computational fluid dynamics (CFD) model

In the following sections, we endeavour to introduce the general concepts behind the above-mentioned models, but do not propose to delve into the mathematical details.

A. Zone Models (2-Zone)

Zone models are simple programs used to model the effects of compartmental fires. These softwares are usually free or cheaply available, and some have been extensively validated for their accuracy.

The ability of zone models to incorporate multiple parameters such as extract/supply fans, detectors, sprinklers, opening and closing of vents etc, coupled with short simulation run times, make them very useful in establishing many possible fire scenarios for fire safety engineering analysis.

Zone modelling, as its name suggests, works on the concept that the buoyancy of the heated air due to the thermal effects of the fire leads to the formation of two distinct gas zones:-

(a) hot upper layer
(b) cold lower layer

The fire acts as a heat pump to inject mass and energy into the hot upper layer.

Zone models solve a set equations derived from conservation equations for energy, mass and momentum, and the ideal gas law in predicting variables such as temperature, pressures etc.

Major assumptions in zone models (2-zone) include:-

(i) Stratification of hot and cold layers with uniform horizontal interface

For most fires occurring in small compartments, this generalization is still valid within limits needed for engineering purposes.

However, uniform layering (2-zone formation) may not occur where for a small fire in a large room, ie the depth of the hot smoke layer may be substantially deeper in certain pockets of the compartment than others.

For a small fire in a very tall compartment, the hot smoke may not have sufficient buoyancy to reach the ceiling of the compartment, creating three zones instead of the assumed two. In this instance, use of zone models may not be appropriate.

(ii) Homogeneity across each layer

While gradations in temperatures, smoke and gas concentrations etc must be expected across a hot smoke layer in a real fire situation, and the horizontal interface between actual hot and cold layers may not be exact, however, it has been shown by comparison with actual fire testing data that this model simplification will still allow for reasonably accurate predictions of fire effects for most fire safety engineering purposes.

(iii) Rectilinear compartments

For non-rectilinear compartments, eg cylindrical or irregular spaces that are not in the shape of a rectangular box, fire safety engineers must exercise their judgement as to whether an approximation to an equivalent rectilinear volume would still allow the model to make reasonably accurate fire predictions.

(iv) No transport lag from fire to ceiling and across ceiling

The smoke appears instantaneously at the ceiling, ie no time lag accounted for the smoke plume to rise from fire to ceiling. At the same time, the zone model assumes that the smoke spreads instantaneously across the ceiling space of the compartment, ie no time lag accounted for the ceiling jet to traverse across ceiling.

Users of zone models must be aware that these assumptions impose a degree of uncertainty onto model predictions. Therefore, it is important that users of modelling software check that they are properly validated against experimental fire data, to ensure the reliability of the model predictions.

CFAST from the National Institute of Standards and Technology (NIST), BranzFire from BRANZ, New Zealand are some examples of zone models that are available in the market.

B. Field Models (Computational Fluid Dynamics Models)

Field models, also known as Computational Fluid Dynamics (CFD) models, are sophisticated computer programmes that can be used to predict the effects of fire, such as smoke transport, visibility conditions, concentration of toxic gases etc.

Field models have their own niche in the domain of fire safety engineering, which is apart from zone models, because of their ability to incorporate important parameters to take into account turbulence, radiation and

combustion models, complex geometry etc that would otherwise not be possible with zone models.

In a field model, the enclosure space to be modelled is sub-divided into many smaller control volumes. Field models solve conservation equations for mass, momentum and energy that are applied to each of these smaller control volumes.

Today's field modelling softwares are coupled with excellent graphical interface which allows the data churned out by the software to be viewed in 2 or 3-dimensional format, in static mode or animated sequence. The superior graphical visualization of the modeling results allows users to better organise, analyse and interpret voluminous amount of data that is produced by the model.

Each field modelling software, due to the high level of individual sophistication, has its own specific set of limitations, which makes it difficult to generically categorise the limitations.

Examples of field modeling softwares include Fire Dynamics Simulator, CFX, FLUENT, JASMINE, SMARTFIRE.

At this juncture however, it is important to point out that the users of field modeling software or for that matter, any software, must have an adequate level of competence and understanding of the subject matter and the limitations of the concerned software.

Softwares are but only tools to assist the fire safety engineer. Software must not be taken as black boxes, for which the user neither comprehend the underlying working principles nor understand its limitations, because these must be used in their right context in order to have an assurance of the reliability of the output data, which are directly used to determine meeting of life safety criteria. Fire safety engineers thus have a responsibility to have a thorough understanding of the software that they use, and use them within their validated limits.

III. Evacuation Modelling

Occupant evacuation is another area where computational software has been developed to help the fire safety engineer in his engineering decision making. Evacuation models predict the time required for occupants to escape out of buildings before untenable conditions set in.

The older generation of evacuation models, known as hydraulic models, calculate egress times based on mechanisms similar to calculation of hydraulic

flow in pipes. Such models do not take into account aspects of human behaviour that may affect an occupant's decision-making in his escape out of the building. Example, an occupant after hearing the fire alarm sounding may hesitate, or take investigative actions before deciding to make his way out of the building. These pre-movement activities are not accounted for in hydraulic models.

Nonetheless, these hydraulic models are still useful to the fire safety engineer in estimating occupant escape times, provided that the fire safety engineer adequately addresses the aspect of pre-movement times, and other factors that may be critical in the overall consideration for a realistic estimation of actual time required by occupants to escape out of a building.

The newer generation of evacuation models are entity-based. In entity-based models, each individual (entity) simulated in the model can be assigned values for free walking speed, age, fitness, familiarity and association with other individuals etc. These assigned values, and the modelled interactions between individuals simulated in the evacuation model will ultimately determine the speed at which each individual moves out of the building. In short, entity based models aspire to simulate the human reactions and interactions that take place in the course of an actual evacuation process. By doing this, entity-based models attempt to tackle the impact of human behaviour and their interactions have on predicted escape times.

As with fire models, evacuation models must also undergo rigorous validation with real-life evacuation cases in order to establish the credibility of the underlying algorithms of the software in accurately predicting occupant escape times for all possible envisaged scenarios.

IV. SCDF Requirements for Use of Modelling Software

In this section, we will outline the important aspects in the submission of a computer modelling simulation to SCDF:-

(i) Show evidence that the software has been adequately validated for its reliability against actual test data.

(ii) Check that the software is appropriate for the intended use, ie that it is not used outside its limits of validation.

(iii) Consult and seek SCDF's agreement on your proposed input parameters for the software model prior to setting up and running the model, and arrive at acceptance criteria against which to determine the acceptability of the proposed fire engineering solution.

(iv) Analyse output data from modelling software, and organize the information for discussion with SCDF on whether pre-determined acceptance criteria for the fire safety engineered solution has been met as demonstrated by computer modelling.

(v) Provide SCDF with all the programme inputs (geometry set-up, selected turbulence or radiation models, boundary conditions etc), ie everything that is required for the Peer Reviewer or SCDF to check that all necessary parameters are taken into account in arriving at a realistic model.

V. Practical Examples

Case 1 : Smoke Reservoir

The project involves major extensions to the sides of the building. This has affected the sizing of the original smoke reservoirs such that they have exceeded the maximum allowable limits as spelt out in the Fire Code.

The fire safety engineer proposed to demonstrate, through the use of field modelling, that in spite of the exceeding of smoke reservoir sizing limits, the smoke layer will still maintain its buoyancy indefinitely, ie smoke layer kept above 2.5m from floor level, for the anticipated fire size.

The fire safety engineer had preliminary discussions with SCDF to establish the acceptance criteria for the proposed fire modeling. The modeling must demonstrate that the buoyancy of the hot smoke layer is maintained at a clear height of more than 2.5m from floor level, temperature, visibility and toxicity limits are not breached to allow occupants ample time to evacuate the building.

Modelling requirements such as acceptability of proposed software, grid density, fire size and location, duration for the simulation run were discussed and agreed upon before the FSE proceeded with the setting up and running of the fire model.

The fire modelling results showed that the hot smoke layer was able to remain buoyant at a height of more than 2.5m for the stipulated duration, and tenability criteria were also met.

The project was subsequently granted approval to allow the extended size of the smoke reservoirs.

Case 2 : Evacuation in Office Building

The building under consideration is a multi-storey office block, with certain floors being fitted out for a tenant. The issue arising out of the tenant's business operation requirements is the exceeding of maximum allowable occupant loading on certain floors. The occupant distribution for affected floors are as given:-

Floor	Code Requirement	Proposed Occupant Load	Status
F4	240	170	OK
F3	240	170	OK
F2	240	341	Exceeded
F1	240	291	Exceeded

Note : *Floors F1 to F4 are intermediate floors in a multi-storey office building.*
F1 is the lowest affected floor (there are floors below F1)
F4 is the highest affected floor (there are floors above F4)

The maximum allowable occupant loading of 240 is exceeded on floors F1 and F2. The proposed solution is to introduce protected transfer stairs, in addition to the exit staircase, on floors F1 and F2 that lead into the exit staircase on the lower floor.

The QP and his appointed Fire Safety Engineer consulted SCDF regarding the proposal. The following acceptance criteria was given by SCDF to be met by the proposed design in order for it to be accepted and approved:-

(i) 2 separate evacuation simulations are to be conducted

(a) Base case

All floors above F1 is loaded to 240 occupants each, including floors higher than F4, up to the highest floor level of the building.

(b) Proposed case

Floors F1 to F4 are loaded as in the above table. Floors above F4 up to the highest floor of the building are loaded to 240 occupants per floor.

(ii) FSE to show that the time for all the occupants to evacuate to floor below F1 must be shorter for the proposed case than the base case.

(iii) Evacuation model used for the simulations must have been extensively validated for use in applied situation.

Major Assumptions:-

(i) Pre-movement time is assumed to be the same for both cases and thus taken out of the equation. Occupants are taken to evacuate simultaneously.

(ii) Floors below F1 are not simulated as it is assumed, everything being equal for both cases, that occupants on these floors would have taken the same time to evacuate to ground level.

The resulting timings for the above 2 scenarios are as shown below:-

Scenario	Total Evacuation Time (min)
Base case	17:18
Proposed case	16:28

The results show that the proposed case with additional transfer staircases will enable occupants to evacuate out of the lowest simulated floor F1 in a shorter time period than the base case.

It was also taken into consideration that it was also advantageous to introduce additional transfer stairs, in that occupants will have an additional exit point should a fire occur at one of the exit locations.

SCDF approved the fire safety engineered proposal, as the fire safety engineer was able to show that the design met with SCDF's acceptance criteria.

VI. Conclusion

Tools such as fire and evacuation modelling softwares can be useful for the fire safety engineer in establishing the workability of the proposed alternative solution, ie performance-based solution. It is the responsibility of the fire safety engineer to appreciate and understand the underlying principles of the tools employed so that these are applied in the appropriate context.

Prepared by : EO Edmund Choo
Performance-Based Plan Consultant
Fire Safety Consultation Branch
Fire Safety & Shelter Department

Technical Guidelines on Fire Safety Requirements for Chemical Warehouse

By

Cpt. Alice Seto

Consultant

Fire Safety & Consultation Branch

Fire Safety & Shelter Department

TECHNICAL GUIDELINES ON FIRE SAFETY REQUIREMENTS FOR CHEMICAL WAREHOUSE

INTRODUCTION

1. Chemicals have a wide range of properties and hazards which must be identified and understood if the conditions of "safe warehousing" are to be achieved. A complete understanding of the hazards also requires an assessment of the container and packaging systems and storage arrangements.

IDETIFICATION of CHEMICALS

2. Whether the warehouse is in the planning stage or a fully operational facility, chemical identity is usually the first of many considerations in a comprehensive risk assessment. Any chemical deemed to come under DOT's hazardous materials regulations, is assigned to the following hazard class:

Class	Description
1	Explosives
2	Flammable gases
3	Flammable liquids
4	Flammable solids
5	Organic peroxides
6	Poisonous material
7	Radioactive material
8	Corrosive material
9	Miscellaneous

FIRE SAFETY REQUIREMENTS for CHEMICAL WAREHOUSE

Size Limitation

3.1 For chemical warehouse, the maximum floor area per compartment shall not exceed the following:

Table 1

Fire Hazard	Fire Compartment Area (m^2)				
	K1	K2	K3	K4	K5
S4/3, L4/3, OA4/3	≤50	≤200	≤300	≤600	≤900
S2/1, L2/1, OA2	≤100	≤400	≤600	≤2400	≤3600
S0, L0	≤400	≤1600	≤2400	≤4800	≤7200

FOOTNOTE: Refer Annex A for classification system

Table 2

K1	Structural •Small compartment
K2	Surveillance •Fire compartments •Automatic fire detection with link to DECAM
K3	Surveillance with company fire brigade •Fire compartments •Automatic foam sprinkler •Automatic fire detection with link to DECAM
K4	Extinguishing systems •Fire compartments •Automatic foam sprinkler •Automatic fire detection with link to DECAM
K5	Extinguishing system with company fire station (CERT) •Fire Compartments •Automatic foam sprinkler •Automatic fire detection with link to DECAM

3.2 The storage of flammable liquids, flammable gas and oxidizing agent shall be located only at the ground floor, storage height to 18m (single-storey warehouse), 15m (1st storey within multiple-storey warehouse).

3.3 Solids materials can be located either at 1st storey or upper floor, but less than 24m, storage quantity limit to 1,200kg/m²

3.4 Flammable solids - Class 4.2 and Class 4.3 shall be located at ground floor.

3.5 No compartment to comprise more than one storey.

Provision of Fire Protection System

4.1 Automatic alarm shall be provided where the total floor area is exceeded 50m². (Refer Table 1)

4.2 Automatic foam sprinklers over the whole storage area shall be required where the total floor area is exceeded 200m². (Refer Table 1)

4.3 Other types of fire suppression systems, such as carbon dioxide, foam, powder or other approved system to be provided where water sprinkler system is not applicable

Provision of Accessway

5.1 For buildings under purpose groups V1 and VIII, accessway shall be provided for fire fighting appliances. The provision of accessway shall be calculated based on the following gross cubical extent of the building as follows:

Minimum	1/6 perimeter (min 15m)
>14,200m³	¼ perimeter
>28,400m³	½ perimeter
>42,600m³	¾ perimeter
>56,800m³	island site access

5.2 Access road shall be positioned and fronting at least one wall of the compartment on external façade of the building.

5.3 Access opening (door or window) shall be provided along the external walls of buildings and placed not more than 15m apart.

Water Supply for Private Hydrant

6.1 Provision of water supply for private hydrant system where required shall comply with the following:

(I) PUB fed hydrant - K1, K2 (without sprinkler protection)
(II) Pump fed hydrant - K3, K4, K5 (sprinkler protection)

6.2 The storage and pumping arrangements of water supply shall comply with Table 4.4.2 of fire code.

6.3 The retention basin for fire fighting water for warehouse storage hazardous substances shall be complied in accordance to NEA code of practice on pollution control.

Minor Storage

7 Any storage of flammable or combustible liquids in quantities not exceeding those listed in Annex B classified as being minor storage.

Storage Cabinets

8 Any storage in a storage cabinet shall comply in accordance with SS CP 40.

Package Storage and Tank Storage

9 The package storage and tank storage shall comply with the requirements in SS CP 40.

Standards and Codes

10 The following standards and codes shall be complied with:

(a) CP 10:	Code of Practice for the Installation and Servicing of Electrical Fire Alarm System
(b) CP 29:	Code of Practice for Fire Hydrant Systems and Hose Reels
(c) CP 40:	Code of Practice for the Storage of Flammable and Combustible Liquids
(d) CP 52:	Code of Practice for Automatic Fire Sprinkler System
(e) CP 55:	Code of Practice for Use and Maintenance of Portable Fire Extinguishers
(f) NFPA 16:	Foam-Water Sprinkler and Spray Systems
(g) NFPA 70	Electrical Apparatus for explosive Gas Atmosphere
(h) SS 286	Classification and class labels for hazardous substances

This is only a proposal that will be discussed with the professional institutions. Your comments or suggestions are welcomed.

Annex A – Classification System

Hazard Category		Grade of Hazard				
		4	**3**	**2**	**1**	**0**
Solid Materials	S	Ignites very easily and burns rapidly	Ignites and burns rapidly	Readily combustible	Moderately combustible	Combustible only with supporting fire
Liquids	L	Class I Flash point < 23° C	Class II Flash point 23 - 61° C	Class III Flash point 61 - 150° C	Flash point > 150° C	Only burns with supporting fire
Oxidizing Agent	OA	Vary strong oxidizing agent	Strong oxidizing agent	Weak oxidizing agent	NIL	NIL

Annex B – Minor Storage

Location	Class of liquid			Manufactured Products
	Flammable		Combustible	
	PG1 or PG II	PG III	C1, C2	
Residential buildings of any type				
-Within a dwelling	5L	25L	50L total C1 and C2	50L
-In a garage attached to a dwelling with a 60/60/60 FRL rating separation wall	25L	50L	100L total C1 and C2	250L
-Outdoors, or in a shed or garage, separated from the dwelling or any other building by 1m space	100L	250L	500L total C1 and C2	250L
-Outdoors, uncovered, or in a shed or garage, separated from the dwelling or any structure or boundary by either 3m of space or a wall having an FRL or 180/180/180	250L	250L	500L total C1 and C2	250L
A supply tank for domestic oil-fired appliances installed in accordance with AS 1691 is excluded from any calculation of the quantity stored on the premises				

Commercial building	10L per $50m^2$ of floor space, but 5L for any tenancy of less than 50 m^2 area	25L per $50m^2$ of floor space, but 25L for any tenancy of less than 50 m^2 area	500L total C1 and C2 per $50m^2$ of floor space but 500L for any tenancy less than 50 m^2 area	The limit for any manufactured product is the same as for a liquid of the same class
Hospitals	10L per $50m^2$ of floor space	25L per $50m^2$ of floor space	500L total C1 and C2 per $50m^2$ of floor space	
Educational establishments (excluding laboratories) -For storage outdoors, or in sheds or attachments, the limits for the corresponding entry in residential buildings shall apply	5L per $50m^2$ of floor space	10L per $50m^2$ of floor space	500L total C1 and C2 per $50m^2$ of floor space	
Laboratories (see Notes 1, 2 and 5)	50L per $50m^2$ of floor space	100L per $50m^2$ of floor space	200L total C1 and C2	
Factories, workshops -Inside -And either- (a) in attached outhouses or sheds if separated by a partition having an FRL of	250L; or 1L per $2m^2$ space with no more than 250L in any $500m^2$ area 250L	500L; or 1L per $1m^2$ space with no more than 500L in any $500m^2$ area As immediately above	2000L; or 4L per $1m^2$ space with no more than 2000L in any $500m^2$ 2500L	In packages only – 2000L

60/60/60; or (b) outside, or in a detached shed or outhouse separated from the factory or workshop by at least 1m	As immediately above	1400L in tanks not over 700L each, or in packages	5000L	
Shops	As for factories and workshops (above) but no container for PG I or PG II liquid may exceed 20L capacity			Flammable products: 10000L, of which no more than 2000L are PG II, provided that storage is in closed packages, not to be opened except for tinting paint for immediate sale
Warehouses	As for factories and workshops (above) but no container for PG I or PG II liquid may exceed 60L capacity			
Service stations **Outdoors**	500L total in packages Any packages kept in a sales area shall be unopened packages not over 20L capacity	1250L total in tanks or packages An additional 1000L in packages can be kept outdoors	3000L total C1 and C2	As for factories, workshops
Open land -Outdoors above ground -Underground tank (s)	 5000L 5000L	 5000L 5000L	 10000L 10000L	 As for shops
Construction sites	2500L	5000L	10000L	As for shops

Technical Guidelines on Fire Safety Requirements for Petroleum Service Station and Proposed Technical Guidelines on Fire Safety Requirements for Hydrogen Fuel-Cell Vehicle Refueling Facilities and Hydrogen Fuel-Cell Vehicle Maintenance Workshop

By

Cpt. Aidil Arshad

Plans Audit Officer

Fire Safety & Consultation Branch

Fire Safety & Shelter Department

TECHNICAL GUIDELINES ON FIRE SAFETY REQUIREMENTS FOR PETROLEUM SERVICE STATION AND PROPOSED FIRE SAFETY GUIDELINES FOR HYDROGEN REFUELLING FACILITIES AND MAINTENANCE WORKSHOP

BACKGROUND AND OVERVIEW

There are Petroleum Service Stations located everywhere in Singapore, be it in residential estates, commercial areas and even in industrial areas. It is considered as an installation where fuel that is petrol or diesel for vehicles are stored and dispensed. A Technical Guidelines on Fire Safety Requirements for Petroleum Service Station have been developed and published to cater for the current and future petroleum service stations is Singapore. The circular was sent out on 10th July 2004.

2. Previously, before the technical guideline was published, FSSD has a set of guidelines touching on Petroleum Service Station and Storage of Petroleum in Underground Tanks. This was written in March 1989 by the Fire Hazardous Materials Branch, FSB. This guideline or known as a Technical Note was only referred to internally and was not circulated or incorporated into the Fire Code for external use. This technical note is referred to during consultation or checking of plans and the plans submitted are generally in compliance with all the requirements.

TECHNICAL GUIDELINES ON FIRE SAFETY REQUIREMENTS FOR PETROLEUM SERVICE STATION.

3 Siting of Petroleum Service Station

3.1 Any site chosen should be sufficiently spacious for it to be designed to minimise the risks of any unauthorized person to be at or near the filling stations. (i.e. it must be sited away from normal human traffics and isolated from other buildings' entrances and exits). Petroleum service stations shall be sited away from any places of public assembly where there is large number of people, such as town centres, neighbourhood centres, important buildings and key installations.

3.2 If the distances from the boundary line of the petroleum service stations to any residential buildings and places of public assembly are within the following dimensions,

a)	Residential buildings	-	50 meters
b)	Places of public assembly	-	90 meters

consultations must be made with FSSD of SCDF.

4 Storage and Tank Requirements

4.1 Tanks for all classes of petroleum in a Petroleum Service Station shall be installed underground. All underground tanks shall have a water capacity not more than 20kl each.

4.2 The vent discharge point shall be not less than 2.0m from any boundary and opening in a building e.g. Window, door, ventilator, air conditioner and forced air intake. The vent shall discharge into open air and vent discharge point shall be located not less than 4m above ground level.

4.3 The length of any hose required to connect a tank vehicle to the filling point shall not exceed 5m. The filling point shall be protected from accidental or physical damage. Guardrails or any necessary measures shall be installed to prevent damage by collision.

5 Fuel Dispensing System

5.1 Dispensing units at a service station shall be located in the open air where they will be adequately ventilated. These shall be located such that all parts of the vehicle being served will be on the premises of the service station and shall be sited not less than 6m away from any building, public roadway or boundary.

5.2 A clearly identified and easily accessible switch or circuit breaker (a centralized Emergency Shut-Off Device) shall be provided at a location remote from the dispensing devices, including remote pumping systems, to shut off the power to all dispensing devices in the event of an emergency and shall not be less than 6m or more than 15m from the dispenser. A sign incorporating the wordings "EMERGENCY CUT-OFF" shall be provided in the vicinity of the cut-off switch.

6 Attended Self Service Stations

6.1 All self-service stations shall have at least one attendant on duty while the station is open to the public. The attendant's primary function shall be to supervise, observe and control the dispensing of petroleum. Clear operating instructions shall be conspicuously posted at every dispenser. The dispensing area at all times is in clear view from the console area/cashier (area having control of the emergency shut-off devices for all and individual dispensing units including remote pumping systems).

6.2 The console/cashier operator shall at all times be able to communicate with persons at the dispensing area. This can be by means of a voice communication system. Sufficient numbers of close circuit cameras are to be installed at the petroleum service station to cover the forecourt, backcourt, dispensing areas and other critical areas of the petroleum service station. Provisions must be made for bollards and chains to be installed at the exit and the entrance of the petroleum service station during refilling by the tank vehicle to cater during high alert situations.

7 Electrical Equipment, Warning Signs and Fire Control

7.1 All electrical wiring and equipment shall be of a type suitable for the location, in accordance with NFPA 70 or SS 254. Warning signs shall be conspicuously posted at the individual dispensing area incorporating the following wordings: "WARNING - NO SMOKING, NO NAKED LIGHTS, STOP ENGINE". The lettering shall be at least 50mm high.

7.2 Approved types of fire extinguishers of rating not less than 70B (9kg) or 34B (2 x 4.5kg) shall be provided at the individual dispensing units and protected from the weather. Sufficient hose reels coverage shall be provided such that the service station usable area is within 6m of a nozzle attached to a 30m hose. Hose reels shall comply with the requirements of CP29.

INTRODUCTION OF HYDROGEN FUEL-CELL SYSTEM

8 Background

8.1 Fossil Fuels are depleting and industries are looking into other means of fuel for energy for chemical processing, petroleum industry, electronics, manufacturing and transportation. There is no impact on the environment, however hydrogen technology currently does not permit long distance travel due to lack of refueling network.

8.2 Locally this project is supported by the Economic Development Board of Singapore and National Environmental Agency under the SINERGY Program and the Technology Innovation and Development Scheme (TIDES). There is a plan of seeing mass implementation and commercialization of Hydrogen Fuel-Cell Vehicles which therefore requires Hydrogen Refuelling facilities and the maintenance workshop. Meetings and discussions were held between all the related agencies to discuss and develop standards for the Hydrogen Fuel-cell System and the maintenance workshop.

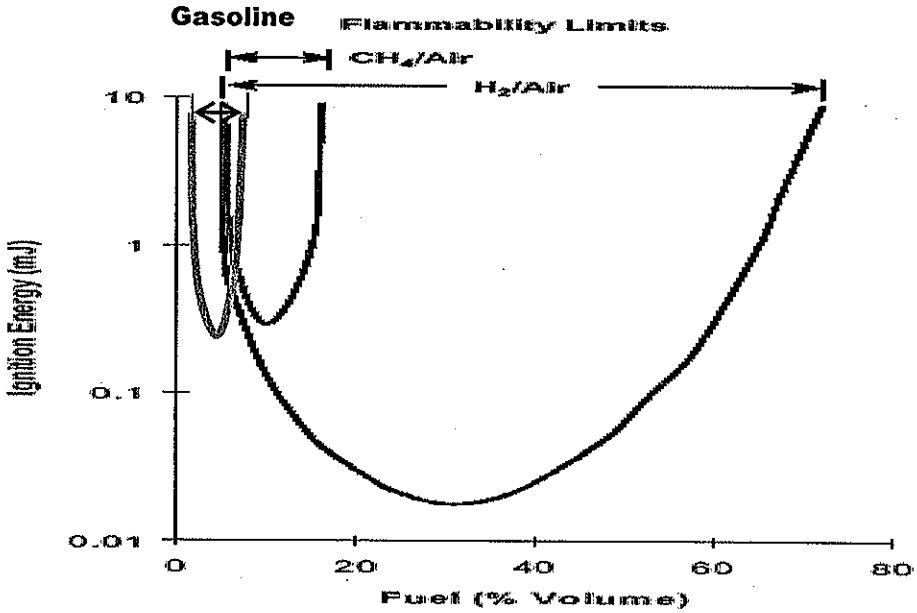
9 Codes and Standards

9.1 Codes and standards are being developed all over the world for hydrogen fuel systems. However, there are no matured standards available yet for the Hydrogen refuelling facilities or the maintenance workshop. Here are the status of the key codes and standards in U.S.

COMPONENT	CODES	STATUS
PRODUCTION	NFPA70/NEC/CEC ASME BOILER-PRESSURE VESSEL SEC.8	MATURE
TRANSPORTATION	DOT 49 CFR	MATURE
PIPELINE	NEC/CEC ANSI/ASME B31.1, B31.8	MATURE
STORAGE	NFPA50A: GASEOUS HYDROGEN NFPA50B: LIQUID HYDROGEN ASME BOILER-PRESSURE VESSEL SEC.8	MATURE 1994 MATURE
VEHICLE REFUELLING STATION	HV-3: HYDROGEN VEHICLE FUEL NFPA52: CNG VEHICLE FUEL HV-1: HYDROGEN VEHICLE CONNECTOR NGV1: NGV CONNECTORS	BEING DEVELOPED BASE FOR HV-3 BEING DEVELOPED BASE FOR HV-1
HYDROGEN VEHICLES	HV-3: HYDROGEN VEHICLE FUEL NFPA52: CNG VEHICLE FUEL HV-2: GASEOUS HYDROGEN TANKS NGV2: CNG STORAGE TANKS	BEING DEVELOPED BASE FOR HV-3 BEING DEVELOPED BASE FOR HV-2

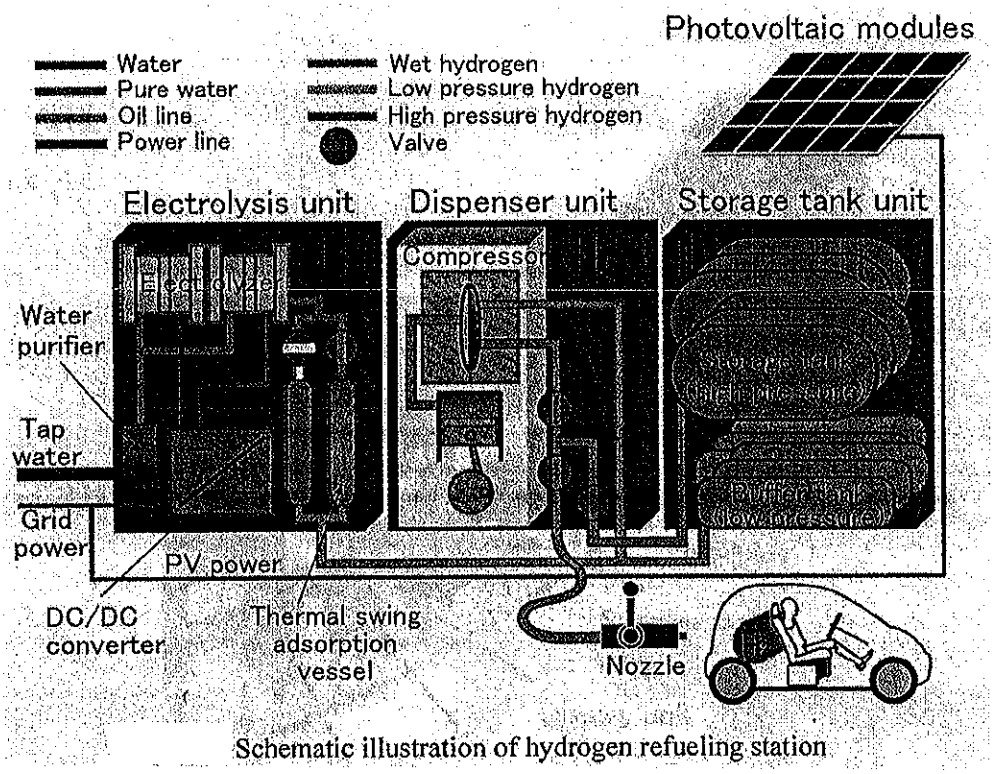
10 Properties and Characteristics of Hydrogen

10.1 Some properties of hydrogen make it less hazardous than other fuel or gases depending on the situation and how it is being handled or controlled. In a leakage involving fuel cell vehicle, hydrogen would escape much faster than natural and other gases due to its high sonic velocity and hydrogen has lesser mass energy and heat due to its low density thus less dangerous. In other words, hydrogen would disperse faster due to low density, viscosity and high diffusion coefficient. Hydrogen has the highest energy content per unit mass (141.9 MJ/KG) which is 3 times of gasoline. Its auto ignition temperature is 571 degree Celsius and has an expansion ratio of 1:848. Flammable limit of Natural Gas is 5.3% to 15%, Propane is 2.1% to 10% and Gasoline is 1% to 7.8% in volume. This range has little practical value. In many actual leak situations, the key parameter that determines if a leak would ignite is the lower flammability limit and hydrogen lower flammability limit is 4% which is 4 times higher than gasoline, 1.9 times higher than Propane and slightly lower than Natural Gas. It takes a larger quantity of hydrogen in a volume to ignite. Hydrogen has very low ignition energy and it is easily ignited by a small amount of sparks. But however, this ignition is a function of fuel and air ratio. Likelihood of ignition depends again on the exact fuel and air ratio, temperature, stability and geometry of the confined space. Hydrogen detonation in the open would likely to have no opportunity in open atmosphere. Considering the lower flammability limit of hydrogen (4%), explosion is possible only under most unusual scenarios. Hydrogen first has to accumulate and reach the right concentration in a close space without low energy ignition sources disturbing the process of accumulation. If there is a hydrogen explosion, it has the lowest explosive energy per unit stored energy in the fuel and this is 22 times lesser than gasoline. Hydrogen flame is almost invisible. However, due to its low emisivity, nearby material or people would less likely to be burnt or injured by the radiant heat transfer. Gasoline produces fumes and soot when it burns thus causes risk by inhalation. Hydrogen on the other hand produces water vapor, unless a secondary item burns.



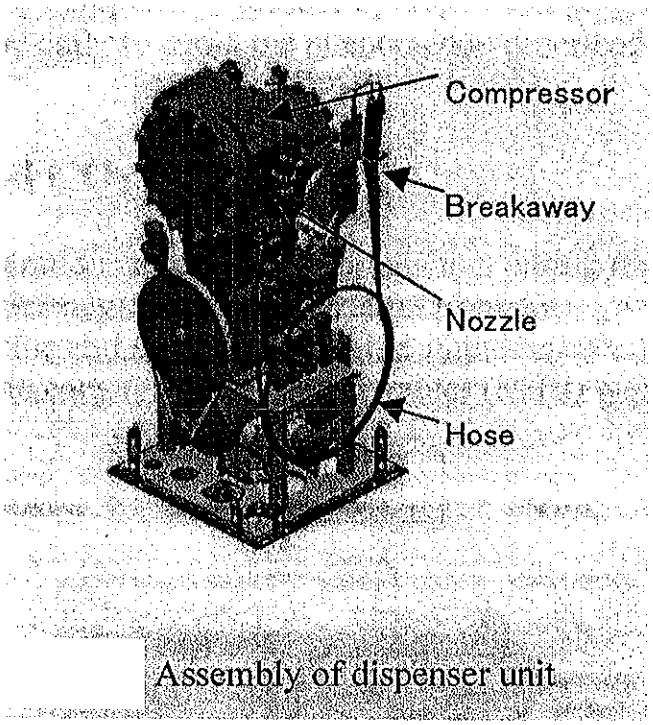
11 Overall Configuration of Hydrogen Fuel-Cell System

11.1 Large scale hydrogen production facilities include photovoltaic modules which uses sunlight energy to provide energy in producing hydrogen. However this is not currently looked into in this project. Basically the whole configuration for the installation consists of electrolysis unit, dispenser unit, storage or skid unit. The portion of the system that comes and go are the tube trailer delivering hydrogen to the refuelling facilities. Electrolysis unit consist of water purifier for processing water from reservoir into pure water. The electrolyzer generates hydrogen by electrolysis of pure water. A Hydrogen Gas-liquid separator is used to separate water mixed with hydrogen output from the electrolyzer.

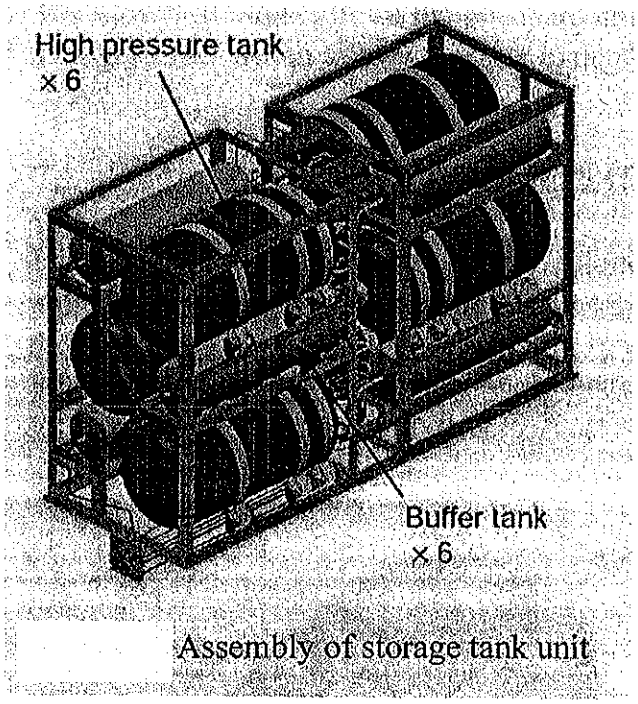


Schematic illustration of hydrogen refueling station

11.2 The dispenser unit is equipped with a diaphragm (air) type compressor that discharges hydrogen at a pressure of 35 MPA, a hose, a nozzle and a breakaway fitting. The breakaway fitting is designed to detach from the hose when pulled forcibly and shuts off the flow of hydrogen through an internal valve. This prevents the hose from breaking and leaking hydrogen gas if the vehicles just drive away with the nozzle still attached to it. It also has all the necessary safety provision according to manufacturer. Currently, dispensers are employing fast fill mode which makes use of pressure difference. Slow fill mode makes use of generated hydrogen. The skid unit (tank unit), generally consist of six high pressure tanks that stores high pressure hydrogen (450bar, 14kg, 167 cubic meter) and six buffer tanks that temporarily stores low pressure uncompressed hydrogen. As shown, high pressure tanks are installed sideways with buffer tanks inserted between to achieve a compact, space saving installation.



Assembly of dispenser unit



Assembly of storage tank unit

PROPOSED TECHNICAL GUIDELINES ON FIRE SAFETY REQUIREMENTS FOR HYDROGEN FUEL-CELL VEHICLE REFUELLING FACILITIES AND MAINTENANCE WORKSHOP

12 **Proposed Technical Guidelines on Fire Safety Requirements for Hydrogen Fuel-Cell Vehicle Refuelling Facilities.**

12.1 This guidelines covers the requirements for the installation of gaseous hydrogen systems at refueling facilities where the hydrogen supply to the premises originates outside the consumer premises and is delivered by mobile equipment. These guidelines also apply to Hydrogen Systems integrated with petroleum service stations. Hydrogen systems are allowed only outdoors or in a separate building (stand-alone).

13. **Proposed Technical Guidelines on Fire Safety Requirements for Hydrogen Fuel- Cell Vehicle Maintenance Workshop.**

13.1 This guidelines states the requirements for the premises dealing with servicing, maintenance and replacement of components. No hot work would be done within the workshop. The hydrogen fuel cell maintenance workshop may in some cases be incorporated into existing vehicle workshop which is already provided with a certain level of fire safety measures like ventilation or alarm systems. The requirements specified for hydrogen fuel cell vehicle maintenance workshop may already be partially complied with, and they would likely only have to be met by adaptation of, upgrading or additions to the existing systems.

14. Problems

14.1 With the introduction of hydrogen for commercial use, there are problems or queries that could be anticipated. Issues that could be raised from this are fire safety concerns for hydrogen fuel-cell vehicles being parked at underground parking space or operating in enclosed environment like road tunnels. There could be possible structural effects, fire rating, additional compartmentalization, additional ventilation and other necessary fire safety works. The public and building owners would be concern about the safety level of the building and the risk that they would be involved with. From these issues raised, there are implications, for example, addition of hydrogen sensors in current buildings that have underground car parks. Additional works on the ventilation system may be required to cater for any hydrogen leakage. With the present of hydrogen fuel-cell vehicles and the possible additional fire safety works involved, this will create a cost impact on the building owners.

15. Conceptual Studies

15.1 According to Daimler Chrysler, Japan and Germany where these vehicles are being used have no restriction on the usage of these cars in underground car parks or tunnels. In support of this, a final conceptual design report has been produced by the California Fuel Cell Partnership. This report covers simulation of 4 case studies and they are Commercial Multi-Storey above Ground Parking, Commercial Multi-Storey below Ground Parking, Residential 2 Vehicle Garage and Commercial Maintenance / Repair / Service Station. This study aims to safely accommodate hydrogen fuel cell vehicles parked in buildings. One of the approaches is to use Computational Fluid Dynamics Analysis. The shape behavior and the cloud or plume of hydrogen is estimated with respect to time and other parameters like, building dimension, leak source, air movement, air speed and direction and also the hydrogen properties. Actual practical test readings have also been taken by measuring gas dispersion in test garages. Helium is used to simulate hydrogen as it is non-flammable and has the nearest properties to hydrogen. Model predictions for helium will be compared with the actual results for calibration of models.

16 Recommendations

16.1 Based on the prescriptive provisions stated in the Fire Code, mechanical ventilation system required for basement car parks with total area exceeding 1900 square meters, a smoke purging system which is independent of any other system shall be provided with a rate of not less than 9 air-change. Since a control for smoke purging is already in place for basement car parks, the same provision can be used for ventilating basement car parks with hydrogen vehicles. The same requirements can be used for supply air and natural ventilation requirements with respect to the 2% openings. Perhaps the smoke extraction system could also be used to extract any hydrogen leakage with the proper spark proof protection and the right extraction rate.

16.2 A performance based approach can also be adopted with regards to designing the best extraction system for hydrogen leak taking into consideration into the volume space, geometry, air speed and direction and other related parameters.

Building Structural Design Under Fire Conditions

By

Assoc. Prof. Tan Kang Hai

Nanyang Technological University

Building Structural Design Under Fire Conditions

A/P Tan Kang Hai (PhD, PEng)
Nanyang Technological University

1

Outline of talk

- Myths about concrete structures
- Summary of collapse study
- Design of steel structures for fire
  - Section Factor
  - Limiting Temperature Method
- Design of composite slabs

2

Survey of Multi-Story Building Collapses Due to Fire, Fire-Resistance Capabilities of Test Laboratories, and Research Needs

- Project sponsored by NIST
- Report NIST GCR02-843, Dec 2002
- Presented to Third International Workshop Structures in Fire
- NRCC, Ottawa, Ontario
- May 10, 2004

Authors: Nestor Iwankiw & Jesse J. Beitel

3

Myths about concrete structures

Building Collapse Study Limited To:

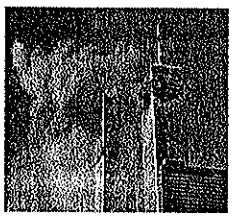
- Multi-story buildings – 4 storeys or more
- Fire-Induced Collapse
- Full or Partial Collapse
- Other Data As Available

Myths about concrete structures

4

Summary Of Incidents

- 22 incidents since 1970, thru Dec., 2002
- 5 of 22 were due to 9/11 events





Myths about concrete structures

5

Collapse Distribution By Location

• USA	15 (5 - 9/11)
• Canada	2
• UK	1
• Russia	1
• Egypt	1
• Brazil	1
• Greece	1

Myths about concrete structures

6

Collapse Distribution By Building Material

- Concrete 7 (1 – 9/11)
- Steel 6 (4 – 9/11)
- Brick/Masonry 5
- Wood 2
- Unknown 2

Collapse Distribution By Building Height

- 4 – 8 storeys 13 (2 – 9/11)
- 9 – 20 storeys 3
- 21 or more storeys 6 (3 – 9/11)

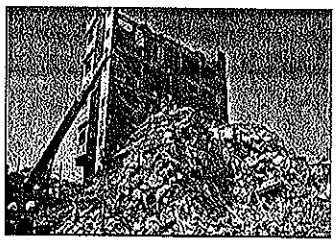
Collapse Distribution By Occupancy

- Office 9 (5 – 9/11)
- Residential 8
- Commercial 3
- Comm/Resid. 2

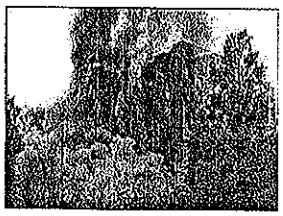
Collapse Distribution By Nature Of Collapse

- **Full Collapse** **8 (3 – 9/11)**
- **Partial Collapse** **14 (2 – 9/11)**

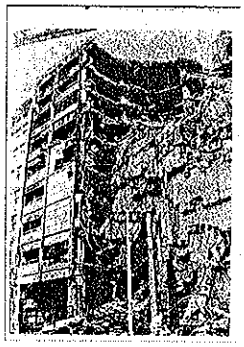
Textile Factory Collapse
July 21, 2000
Alexandria, Egypt
27 casualties



Apartment Block
June 3, 2002
St, Petersburg, Russia



Katrantzos Department Store
Dec. 19, 1980
Athens, Greece

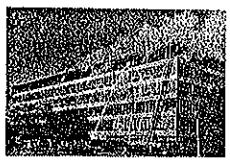


- Fire began 3AM, arson?
- 8-story, reinforced concrete
- 2-3 hr. fire duration reached 1000° C
- Most of floors 5-8 collapsed
- Plus additional failures
- Ref: Papaloannou paper, *Fire and Materials*, Vol. 10, 1986, pgs. 171-177

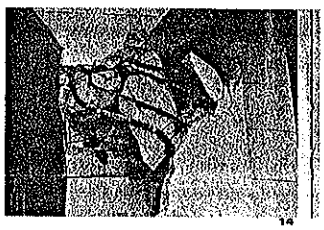
13

Myths about concrete structures

Military Personnel Record Center
July 12, 1973
Overland, MO



Brittle column failures due to large thermal expansion, similar to earthquake damage

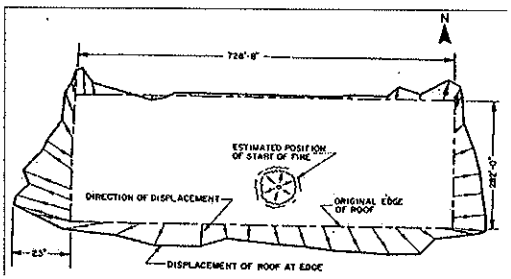


Ref: Sharry, et al, *NFPA Fire Journal, May, 1974*

14

Myths about concrete structures

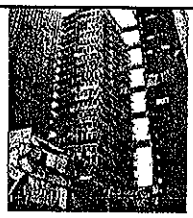
Residual Expansion of Roof Perimeter



15

Myths about concrete structures

CESP-2 Building
May 21, 1987
Sao Paulo, Brazil



Building Features:
- 21-story office
- Reinforced concrete
- No sprinklers
- Residual floor wood forms
- Wood partitions & ceilings



Fire effects:
- Berto & Tomina paper
- Core collapse after 2 hour fire
- About 9:30PM
- No casualties

Myths about concrete structures

NEW—RECENT

Jan. 26, 2004
Cairo, Egypt

- 12-story, concrete building collapsed after 3-hour fire
- 10 dead, over 30 injured
- BBC and Associated Press News Sources



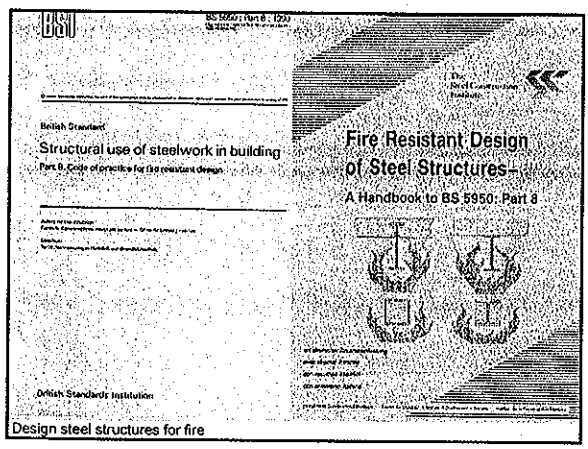
Myths about concrete structures

Summary Of Collapse Study

- **22 incidents identified between 1970-2002**
- **Except for 9/11 – low fatalities**
- **Occurs in all types of building construction**
- **Structural analysis and design for fire conditions must be improved - appears that structural systems do not always perform as expected**
- **Need to better understand structural & fire interactions**

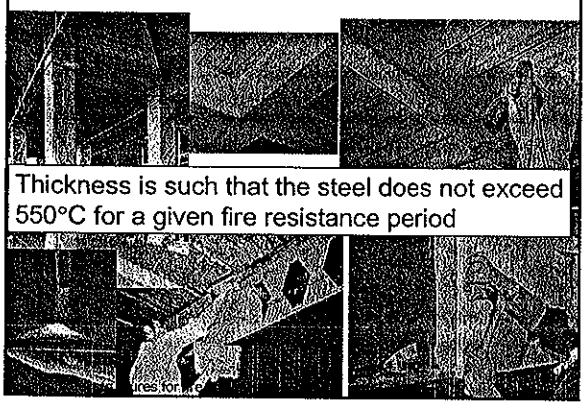
16

Summary of collapse study



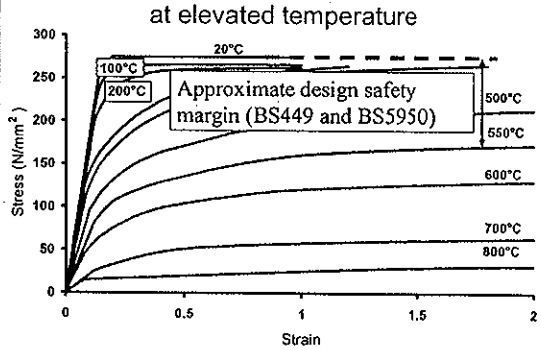
Design steel structures for fire

Traditional Fire Protection Methods



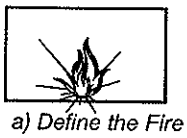
Thickness is such that the steel does not exceed 550°C for a given fire resistance period

Steel stress – strain properties at elevated temperature



Design steel structures for fire

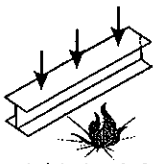
Design for fire



a) Define the Fire



b) Temperature Distribution



c) Structural response

Design steel structures for fire

22

Design of Steel Structure

- **Global Analysis**
- **Sub-frame Analysis**
- **Member Analysis**
  - **Strength Domain**
  - **Temp. Domain**

Design steel structures for fire

23

Structural Fire Design

BS5950 Part 8:1990. *Covers steel and some composite members.*

ENV 1993-1-2: 1995 (with UK NAD document) *Covers steel members*

ENV 1994-1-2:1994 (with UK NAD document) *Covers composite members*

Design steel structures for fire

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Basic Design Methods in BS5950-8

Covers the design of:

- Unprotected 'I' and 'H' beams, columns and tension members
- Composite floor slabs
- Concrete filled columns
- Protected sections
- Shelf angle beams

Basic Design Methods in BS5950-8

for steel members

a) Section Factors

(protected & unprotected)

b) Limiting Temperature Method

(protected & unprotected)

A fire limit state should be treated as an **Accidental Limit State** with its own associated partial factors

Load Factors (γ_f) - Table 2 BS5950-8

Dead Loads	1.0
Imposed Loads (permanent)	1.0
Imposed Loads (non-permanent)	0.8
Wind Loads	0.33

Material Strength factors (γ_m)

Steel	1.0
Concrete	1.3
Reinforcement	1.0

Definition of Section Factor

Section Factor = H_p/A

H_p = expose perimeter of the member;
A = cross-sectional area of the member.

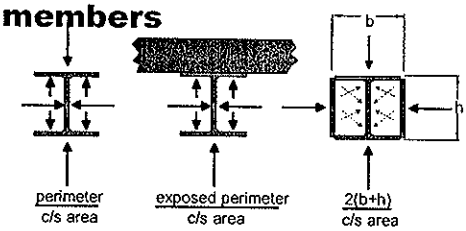


High H_p
Low A
Fast
Heating.



Low H_p
High A
Slow Heating

Section factor H_p/A - unprotected steel members



Section factor H_p/A - inherently protected systems



exposed perimeter / Total c/s area

exposed plate / Total c/s area

exposed flange / Total c/s area

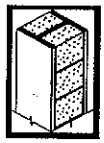


- **Section factor describes**
  - **the size and shape of member**
  - **the form of fire protection**
  - **the influence of mass**
  - **the rate of heat transfer**
  - **BS5950-Part 8 uses H_p/A**

- **Heated perimeter H_p - size of steel section & profile of protection system**
- **Area A relates to the amount of energy for unit temperature rise.**
- **A higher value of H_p/A implies a higher rate of heating up**

Minimum Section Factors for 30 mins. Fire Resistance (Table 4 BS5950-8)

Members in bending supporting slab	$90m^{-1}$	Min Section = 610x305x179UB
Columns	$50m^{-1}$	Min Section = 356x406x393UC
Columns with infill blockwork	$69m^{-1}$	



Based on LR not exceeding 0.6!

Design steel structures for fire – Section Factor

BS5950-8 Limiting Temperature Method

The Limiting Temperature Method provides a quick way in which temperature gradients (for beams) and instability effects (for columns) are taken into account.

Philosophy:
As a member heats up in a fire it will support the applied load until the temperature of the critical element exceeds the Limiting Temperature.

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Design steel structures for fire – Limiting Temperature Method

Temperature of critical element = Design Temperature

(Based on member type and fire resistance)

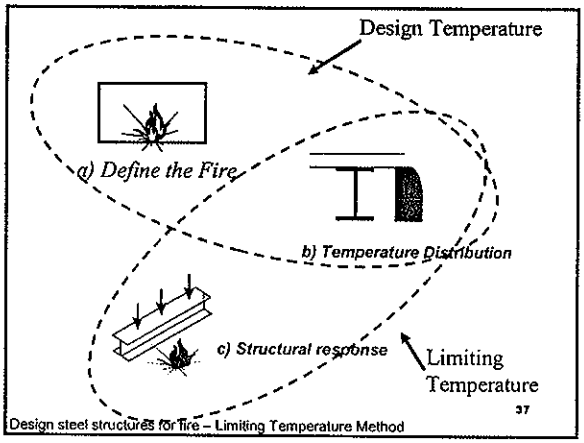
Limiting Temperature = Failure Temperature

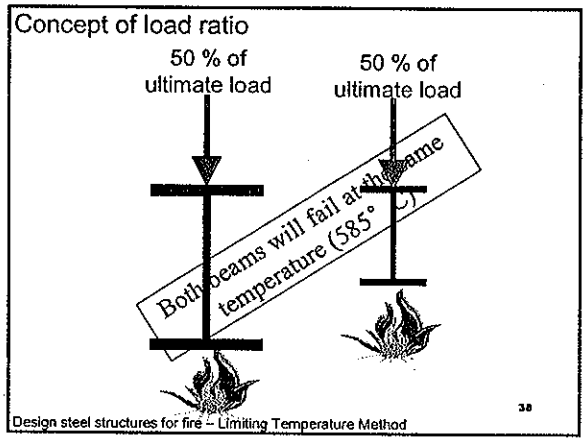
(Based on member type, thermal gradient and applied load)

Limiting Temperature > Design Temperature

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Design steel structures for fire – Limiting Temperature Method





Load Ratio

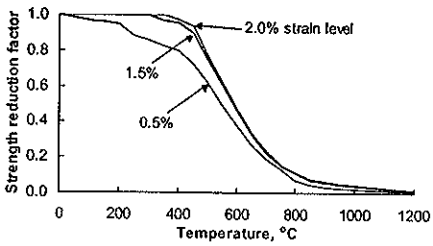
Provides an indication on the 'reserve' of strength in ambient temperature design that can be utilised in fire design

$$\text{Load Ratio} = \frac{\text{Load or moment at fire limit state}}{\text{Member resistance at } 20^\circ \text{ C}}$$

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Design steel structures for fire – Limiting Temperature Method

No mathematical formulations or tables for stress-strain curves at *T* except the strength reduction factors for grade 43 and 50 steel.



40

Design steel structures for fire – Limiting Temperature Method

Strength reduction factors in Table 1 BS5950-8

	Strength reduction factors		
Temp	0.5	1.5	2.0
550°C	0.492	0.612	0.627
600°C	0.378	0.460	0.474
650°C	0.269	0.326	0.337

41

Strain limits defined in BS5950-8

Non- composite beams

1.5%

Unprotected or protected beams with protection materials > 1.5% strain. Based on standard tested beams & deflection of span/30.

0.5%

If protection materials have not been tested, then the strain limit for protected beams is reduced to 0.5%.

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Design steel structures for fire – Limiting Temperature Method

Strain limits defined in BS5950-8

Beams:
Non-composite beams **1.5%**
(based on standard tested beams & deflection of span/30)

Composite beams **2.0%**
(for a given deflection strains in a composite beam are higher)
Note:
If protection materials have not been tested to higher strains then, for beams, the strain limit is reduced to 0.5%

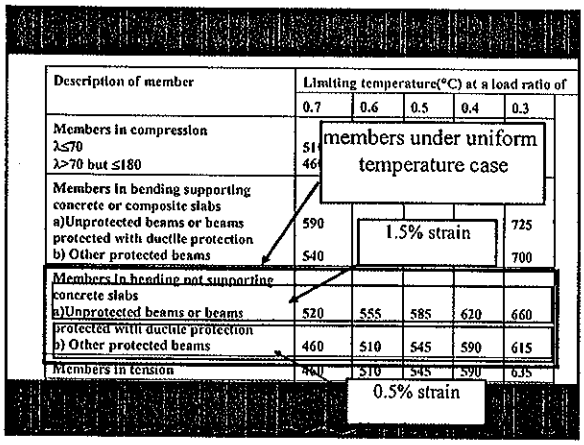
43

Strain limits defined in BS5950-8

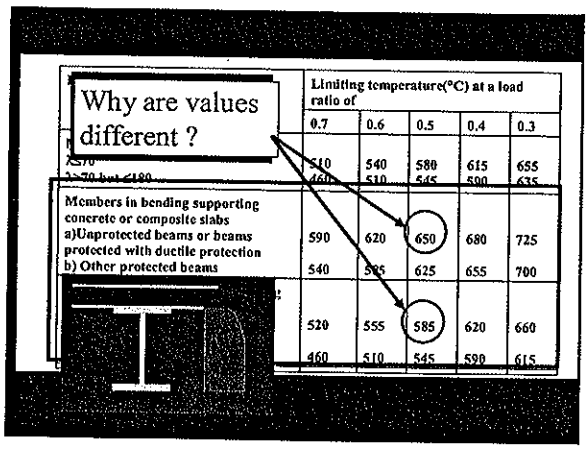
Columns **0.5%**
(columns have relatively low strains prior to failure)

Tension members **0.5%**
(imposed to limit excessive elongation)

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Description of member	Limiting temperature(°C) at a load ratio of				
	0.7	0.6	0.5	0.4	0.3
Members in compression					
λ≤70	51				
λ>70 but ≤180	46				
Members in bending supporting concrete or composite slabs					
a)Unprotected beams or beams protected with ductile protection	590				725
b) Other protected beams	540				700
Members in bending not supporting concrete slabs					
a)Unprotected beams or beams	520	555	585	620	660
protected with ductile protection					
b) Other protected beams	460	510	545	590	615
Members in tension	460	510	545	590	635



Description of member	Limiting temperature(°C) at a load ratio of				
	0.7	0.6	0.5	0.4	0.3
Members in compression λ≤70 λ>70 but ≤180	510 460	540 510	580 545	615 590	655 635
Members in bending supporting concrete or composite slabs a)Unprotected beams or beams protected with ductile protection b) Other protected beams	590 540	620 585	650 625	680 655	725 700
Members in bending not supporting concrete slabs a)Unprotected beams or beams protected with ductile protection b) Other protected beams	520 460	555 510	585 545	620 590	660 615

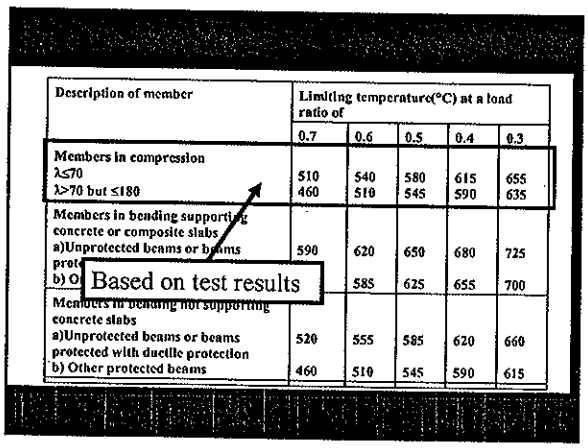


Table 5: BS5950-8

Description of member	Limiting temperature(°C) at a load ratio of				
	0.7	0.6	0.5	0.4	0.3
Members in compression λ≤70 λ>70 but ≤180	510 460	540 510	580 545	615 590	655 635
Members in bending supporting concrete or composite slabs a)Unprotected beams or protected with ductile pr b) Other protected beam				680 655	725 700
Members in bending not supporting concrete slabs a)Unprotected beams or beams protected with ductile protection b) Other protected beams	520 460	555 510	585 545	620 590	660 615

Based on 0.5% strain

Design steel structures for fire – Limiting Temperature Method

Table 6 Design temperatures for columns and tension members

Flange thickness (mm)	Fire resistance period (min)			
	30	60	90	120
≤ 8.8	841	945	1006	1049
9.4	801	911	950	1020
11.0	771	900	950	1020
12.5	747	891	950	1020
14.2	724	882	950	1020
15.4	650	877	950	1020
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
67.5	494	762	950	1020
77.0	479	774	950	1020

NOTE: The values given assume *heating from four sides.*

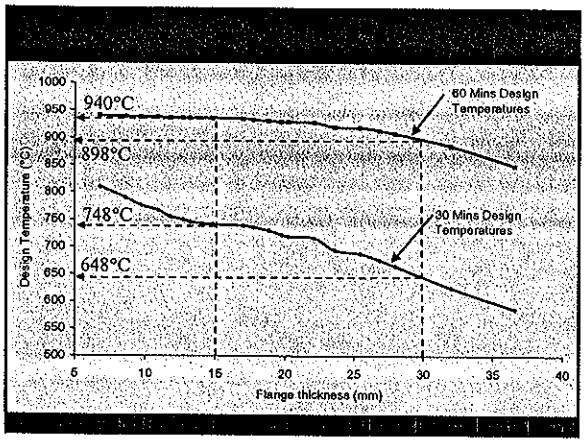
Table 7 Design temperatures for beams

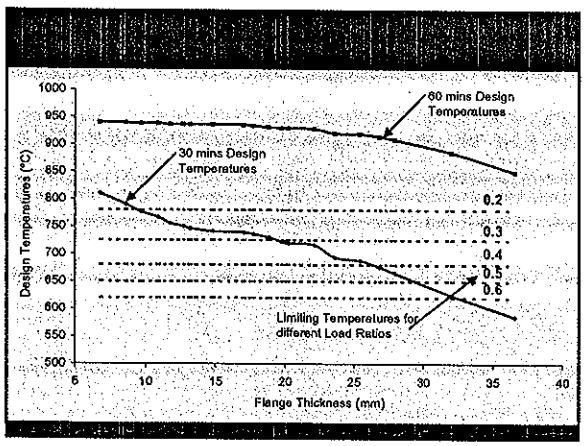
Flange thickness (mm)	Fire resistance period (min)			
	30	60	90	120
≤ 8.8	810	940	1000	1045
8.8	790	938	1000	1045
9.7	776	938	1000	1045
10.9	767	938	1000	1045
11.8	755	938	1000	1045
12.7	750	938	1000	1045
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
32.0	625	885	1000	1045
36.8	585	849	1000	1045

NOTE: The values given assume *heating from three sides.*

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Design steel structures for fire – Limiting Temperature Method





- **For beams having three or four sides exposed to fire, *R* is taken as the greater of:**

$$R = \frac{M_f}{M_c} \quad or \quad R = \frac{mM_f}{M_b}$$

- **For tension members exposed on 4 sides *R* is calculated**

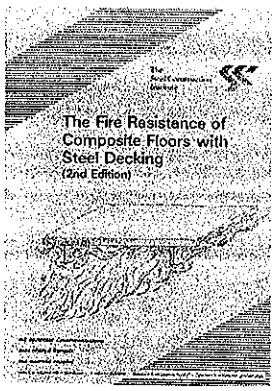
$$R = \frac{F_f}{A_g p_y} + \frac{M_{fx}}{M_{cx}} + \frac{M_{fy}}{M_{cy}}$$

Design of Composite slabs

BS5950-8 allows two design methods:

a) Simple Design Method
(based on test results)

b) Fire Engineering Method
(analytical method)



SCI Publication 056

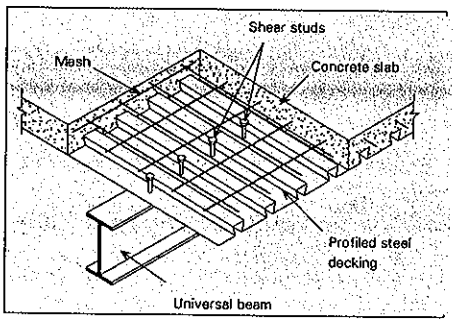
(Referenced in BS5950-8)

Guidance on:

Simple Design Method

Fire Engineering Method

Simplified Design Method



Limitations/restrictions on Simple Design Method

- Slab must be continuous over at least one support.
- Single layer of mesh must be placed with a top cover between 15 and 45mm
- Up to 2 hours fire resistance

Limitations/restrictions on Simple Design Method

- Applied load up to 6.7kN/m^2
- Spans of up to 3.6m
- No calculation is required and preferred method on most projects

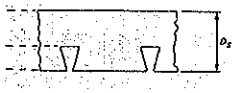


Table 7 *Simplified design for dovetail decks*

Maximum span (m)	Fire resistance (hours)	Minimum dimensions			Mesh size
		t (mm)	D_s (mm)		
			NW	LW	
2.5	1	0.8	100	100	A142
2.5	1½	0.8	110	105	A142
3.0	1	0.9	120	110	A142
3.0	1½	0.9	130	120	A142
3.0	2	0.9	140	130	A193
3.6	1	1.0	125	120	A193
3.6	1½	1.2	135	126	A193
3.6	2	1.2	145	130	A252

NW *Normal weight concrete*
LW *Lightweight concrete*

Design of composite slabs

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End

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