PROGRAMME

SEMINAR ON NFPA 130/NFPA 502

30 JANUARY 2002

0830 hrs	Registration
0900 hrs	NFPA 130 - Station
1015 hrs	Coffee Break
1030 hrs	LTA Fire Safety Standard - Station
1130 hrs	NFPA 130 - Trainway & Emergency Ventilation
1210 hrs	LTA Fire Safety Standard - Trainway & Emergency Ventilation
1230 hrs	Lunch break
1330 pm	NFPA 130 - Vehicles & Emergency procedure
1400 hrs	NFPA 130 (Year 2003 Revision)
1415 hrs	NFPA 502 (Road Tunnels)
1515 hrs	Coffee Break
1530 hrs	Case Study on Road Tunnel Fire
1545 hrs	Passive Fire Protection to Tunnel
1615 hrs	Questions and Answers
1700 hrs	End of Seminar

NFPA 130 - 2000 Edition

Standard for Fixed Guideway Transit and Passenger Rail Systems



Christian Dubay

Fire Protection Engineer

NFPA 130 - 2000 Edition

Standard for Fixed Guideway Transit and Passenger Rail Systems



Christian Dubay
Fire Protection Engineer

1

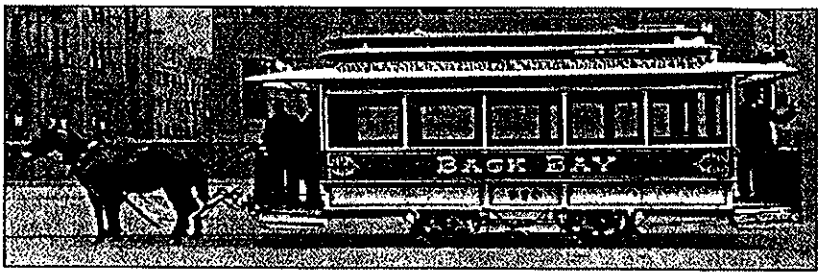
NFPA Codes and Standards

- Consensus development process.
- Technical support for all adoption and use.
- Complete coverage of all projects and topics from A-Z.
- Expert staff assigned to each technical committee.



2

History



1820's

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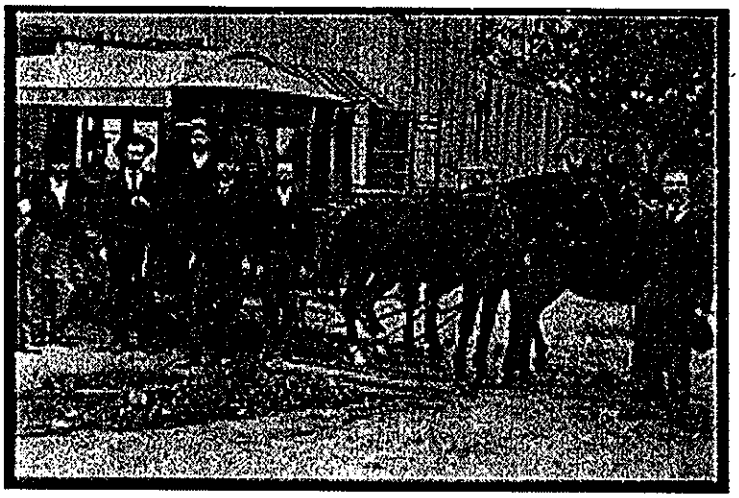

1850's w/ Rail

4



Late 1800's - Cable

5



1880's - Electrification

6

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1890's Elevated Start

7

NFPA 130 - Contents

Chapter 1 - General
Chapter 2 - Stations
Chapter 3 - Trainways
Chapter 4 - Emergency Ventilation System
Chapter 5 - Vehicles
Chapter 6 - Vehicle Storage and Maintenance Areas
Chapter 7 - Emergency Procedures
Chapter 8 - Communications
Chapter 9 - Referenced Publications

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NFPA 130 - Appendices

Appendix A - Explanatory Material
Appendix B - Ventilation
Appendix C - Emergency Egress
Appendix D - Test Procedure - Fire Hazard Assessment
Appendix E - Creepage Distance.
Appendix F - Referenced Publications



9

NFPA 130 - Scope

Passenger Rail
Fixed Guideway

- Underground, Surface, Elevated
- Stations
- Trainways
- Vehicles
- Vehicle Maintenance and Storage Areas

Life Safety



10

NFPA 130 - Scope

NFPA 130 Does not apply:

- Conventional Freight
- Buses or Trolley Coaches
- Circus Trains
- Tourist, Scenic, Historic, Excursion Operations

11

NFPA 130 - Purpose

Establish the minimum requirements that will provide a reasonable degree of safety from fire and its related hazards.

12

NFPA 130
Characteristics of Fire Safety

Fire safety for the whole systems shall be achieved by integrating the required levels for each subsystem

- Facility Design
- Operating Equipment
- Hardware
- Procedures
- Software Subsystems

13

NFPA 130 - Application

New Fixed Guideway/Passenger Rail Systems

Extensions to Existing Systems

Emergency Procedures (New & Existing)

New Rolling Stock

Retrofitting Existing Equipment

Retrofitting Existing Facilities

14

NFPA 130 - Chapter 1
General

- Scope
- Purpose
- Characteristics of Fire Safety
- Application
- Definitions



15

General Definitions

- **Authority.** The agency legally established and authorized to operate a fixed guideway transit and/or passenger rail system.

- **Authority Having Jurisdiction.** The organization, office, or individual responsible for approving equipment, materials, an installation, or a procedure.



16

NFPA 130 - Chapter 2
Stations

- Construction
- Ventilation
- Wiring
- Means of Egress
- Emergency Lighting
- Fire Protection



17

Station Definitions

- **Station.** A place designated for the purpose of loading and unloading passengers, including patron service areas and ancillary spaces associated with the same structure.
- **Station Platform.** The area of a station used primarily for loading and unloading transit vehicle passengers.



18

Station Definitions

- **Station, Enclosed.** A station or portion thereof that does not meet the definition of an open station.
- **Station, Open.** A station that is constructed in such a manner that it is open to the atmosphere, and smoke and heat are allowed to disperse directly into the atmosphere.

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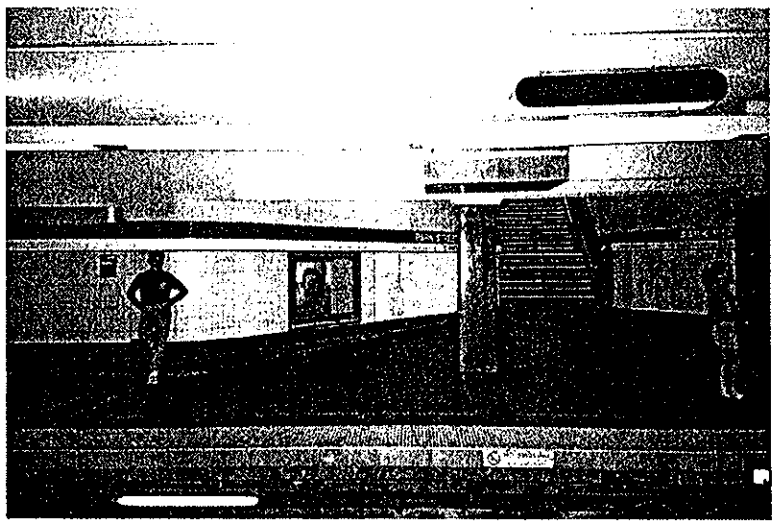

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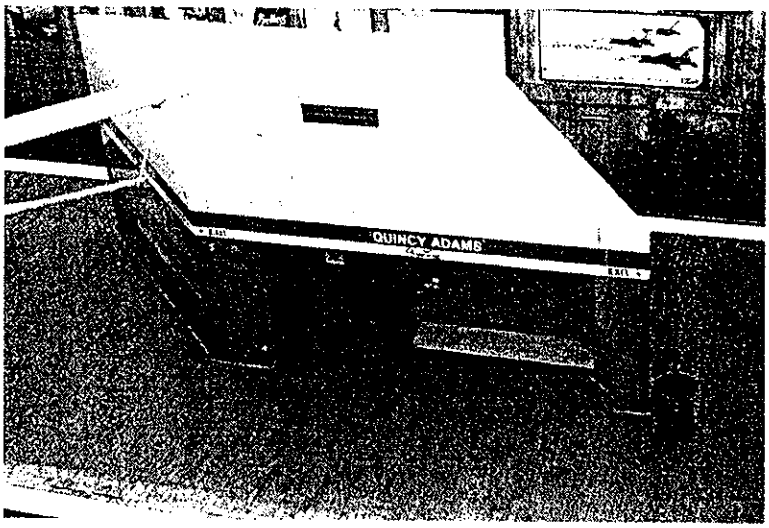

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Occupancy

- Contiguous Commercial Occupancies
- Common with Station
- Station Integrated with Occupancy

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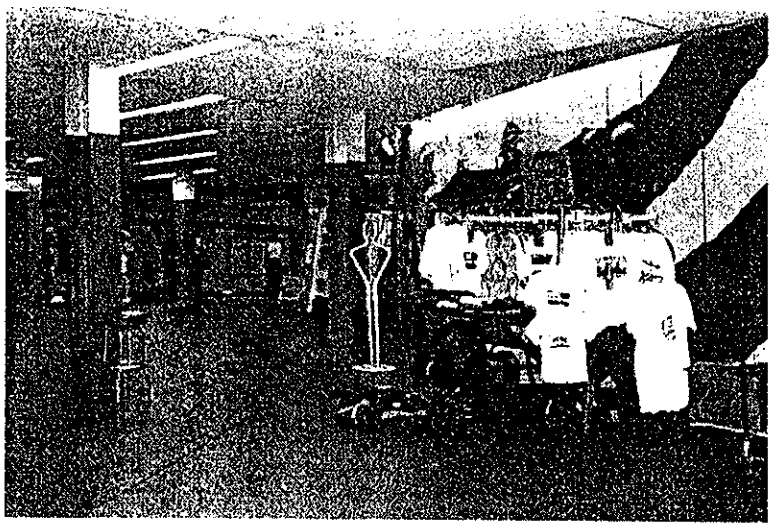

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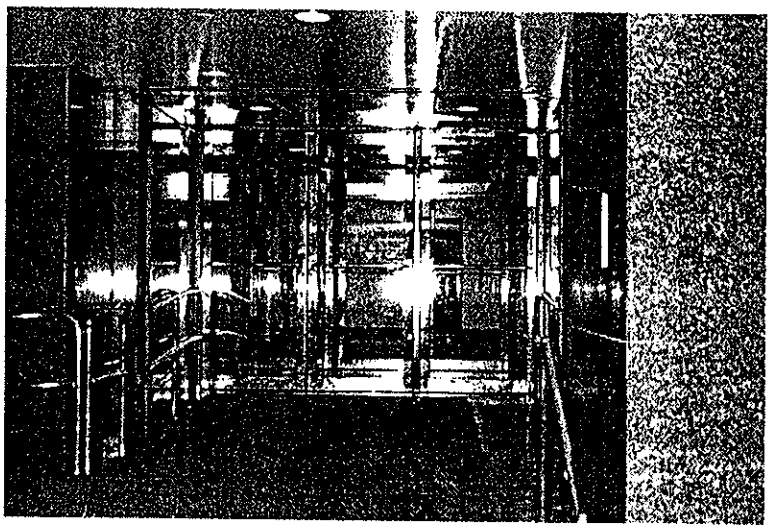

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31

Station Construction

- **Ancillary Spaces.** Separated by 2-3 hour fire barriers depending on use.
- **Doors.** Ancillary space doors rated 1½ or 3 hour rating depending on use of space. <NFPA 80>
- **Fire Separation.** Transit to non-transit – minimum of 3 hours.

32

Station Emergency Ventilation

- Chapter 4 of NFPA 130 applies to all enclosed stations.

33

Station Wiring

- NFPA 70
- Conduits, raceways, ducts, etc – 500°C for 1 hour or encased in concrete.
- IEEE 383 – Standard for Type Tests of Class 1E Electrical Cables, Field Splices, and Connections for Nuclear Power Generating Stations

34

Station Wiring

- Not surface mounted or exposed in air plenums with elevated temperatures.
- Emergency conductors must be protected from damage exposure.
- Emergency Ventilation Power Supply – Chapter 4 of NFPA 130

35

Egress – Stations - General

- NFPA 101®, Life Safety Code®
  - Means of Egress Chapter
  - New Assembly Occupancy Chapter
  - Except as modified by NFPA 130
- Evacuation to Point of Safety

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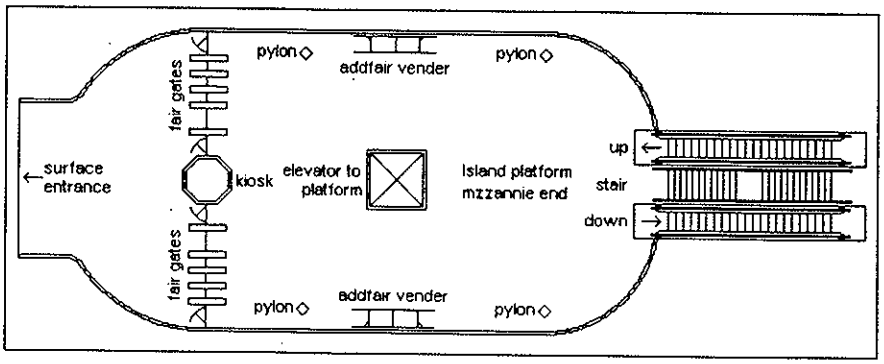
Mezzanine - End



NFPA

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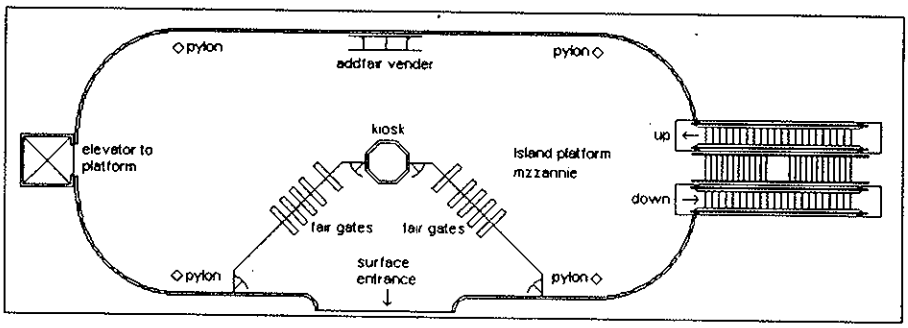
escalator = 1/2 capacity of normal stairs

Mezzanine - Side



NFPA

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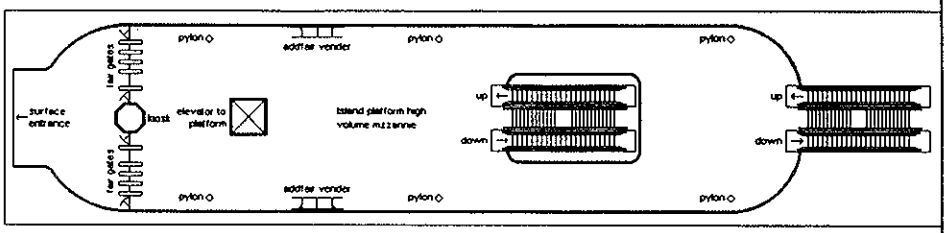
Mezzanine – End/Heavy Occupant



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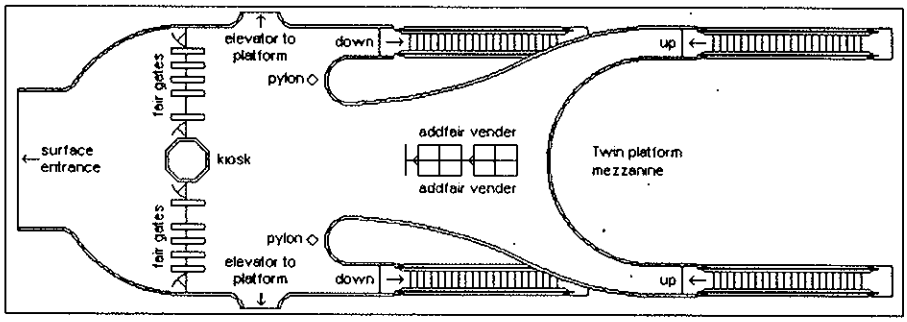
Twin Platform End



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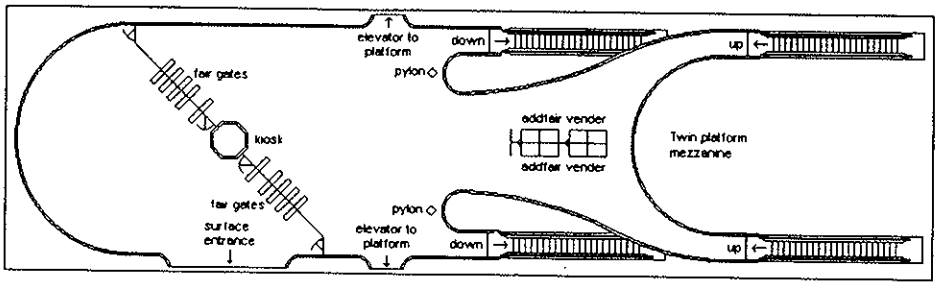
Twin Platform Side



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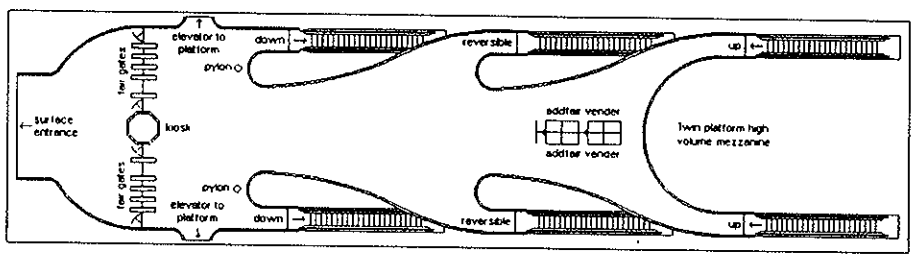
Twin Platform - Heavy Occupant



42

Deep station

6 mins to area of refuge

Twin escape via elevators.

EGRESS

43

Egress Definitions

- **Point of Safety.** An enclosed fire exit that leads to a public way or safe location outside the structure, or an at-grade point beyond any enclosing structure, or another area that affords adequate protection for passengers.

44

Station Occupant Load

- **Occupant Load.** Train load of all arriving trains plus the entraining load awaiting the train.
  - Peak 15 Minute Load
  - 1 Train Per Track and Platform

45

Station Occupant Load – Special

- **Special Events.** Civic Centers. Sports Complexes and Convention Centers.
- **Multiplatform Stations.** Each platform evaluated separately and occupant loads combined for exit analysis.
- **Other Uses.** NFPA 101®, Life Safety Code®

46

Platform Occupant Load

Peak entraining load plus Peak train load.

- OR -

Entraining Load x Surge Factor x 2

Plus

Train Load x Surge Factor x 2

(Must choose the greater value.)

47

Number and Capacity of Exits

- Evacuate platform load in 4 minutes or less.
- Maximum travel distance from platform 91m (300ft).
- Most remote point of platform to point of safety in 6 minutes or less.

48

Egress - Components

- Capacity – pim = persons per inch per minute

  Persons per Meter per Minute (pmm)
- Travel Speed – fpm = feet per minute

  Meter per Minute (mpm)
- Gates – ppm = people per minute

49

Doors and Gates

Minimum clear width is 915mm.

Capacity 89.4ppm

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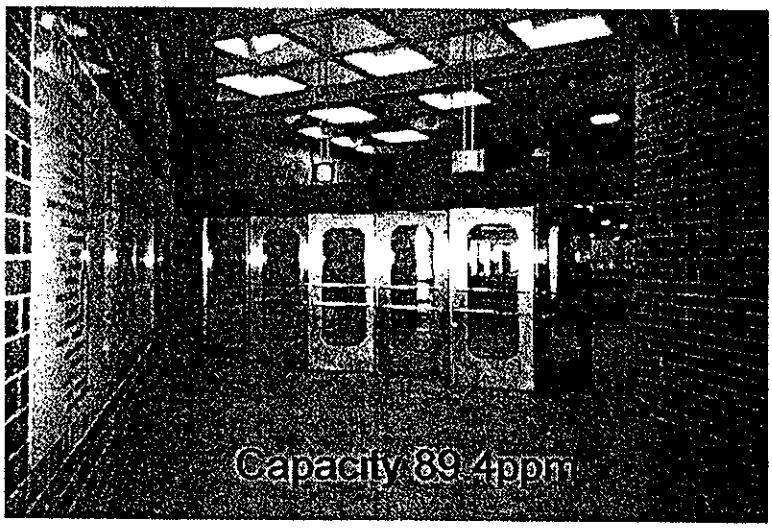

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Fair Collection Gates

- Gates – Minimum 508mm clear width and shall not exceed 1016mm in height.

  Capacity 50ppm per gate

- Turnstile-Type – Minimum 460mm clear width and shall not exceed 915mm in height.

  Capacity 25ppm per gate

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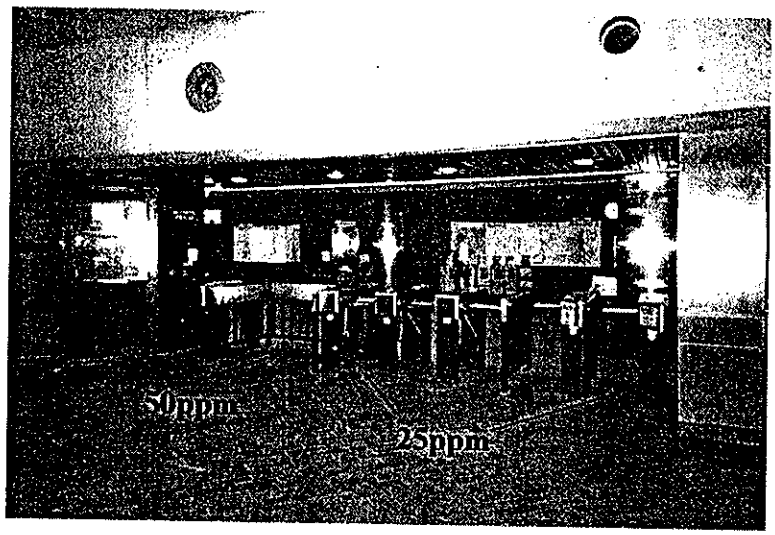

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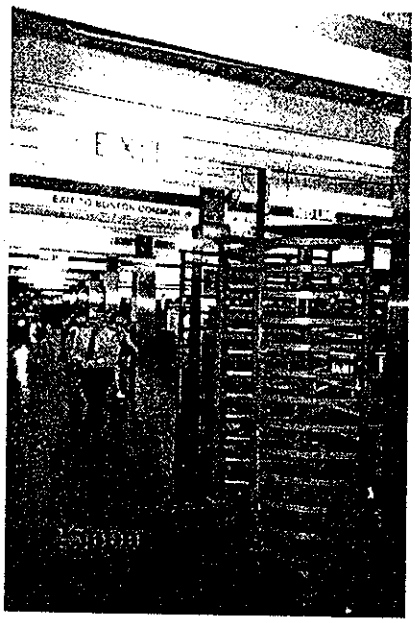

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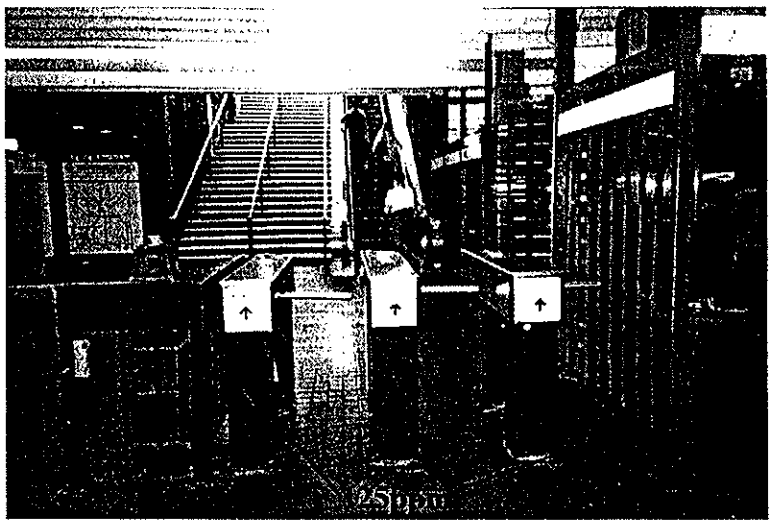

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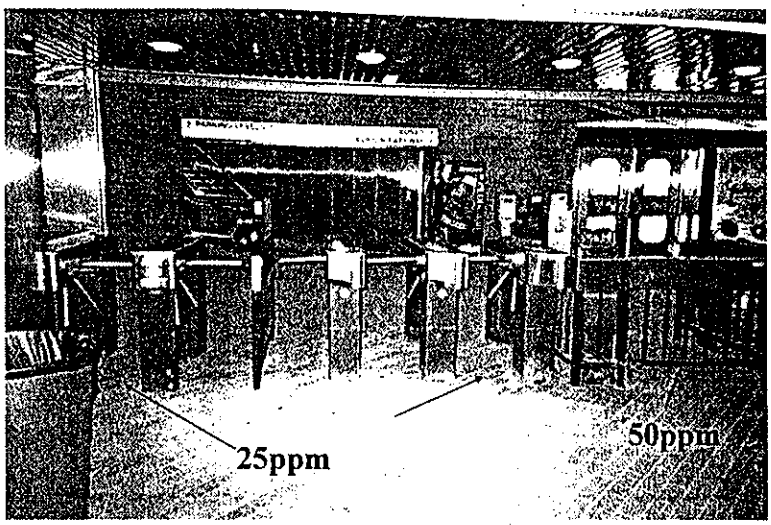

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Platforms, Corridors, and Ramps

- 4% Slope or less for ramps. Ramps greater with slopes greater than 4% are required to be treated as stairs. (minimum 1830mm clear for exit ramps)
- Minimum 1730mm clear width. Deduct 305mm from sides and 457mm from platform edge to determine availability.

Capacity 89.4pmm

Travel Speed 61m/min

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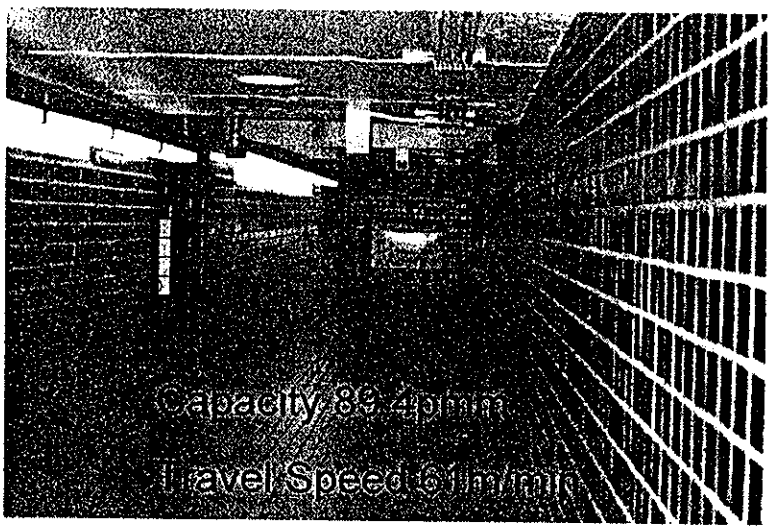

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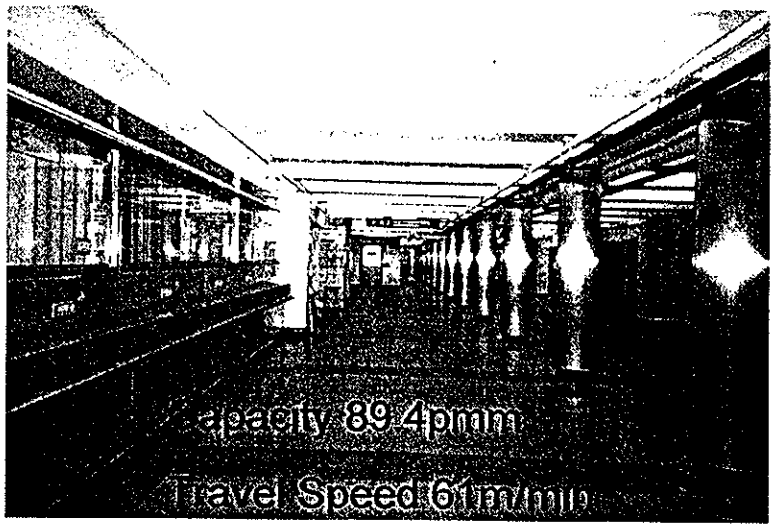

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Escalators

- Escalators shall be permitted.
- One must be considered out-of-service.
- Escalators shall not account for more than 50% of the exit capacity.
- Constructed of Non-Combustible Materials.

60

Escalators

- Minimum 1120mm clear width.
- Up Direction

  Capacity 62.6pmm

  Travel Speed 15.24m/min (vertical)
- Down Direction

  Capacity 71.1pmm

  Travel Speed 18.3m/min (vertical)

61

Capacity 62.6pmm

Travel Speed 15.24m



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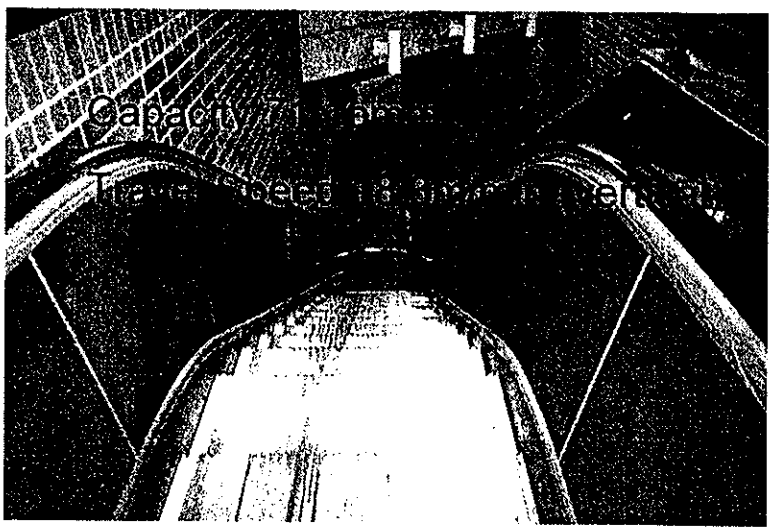

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64



65

Stairs

- Minimum 1120mm clear width.
- Up Direction

  Capacity 62.6pmm

  Travel Speed 15.24m/min (vertical)
- Down Direction

  Capacity 71.1pmm

  Travel Speed 18.3m/min (vertical)

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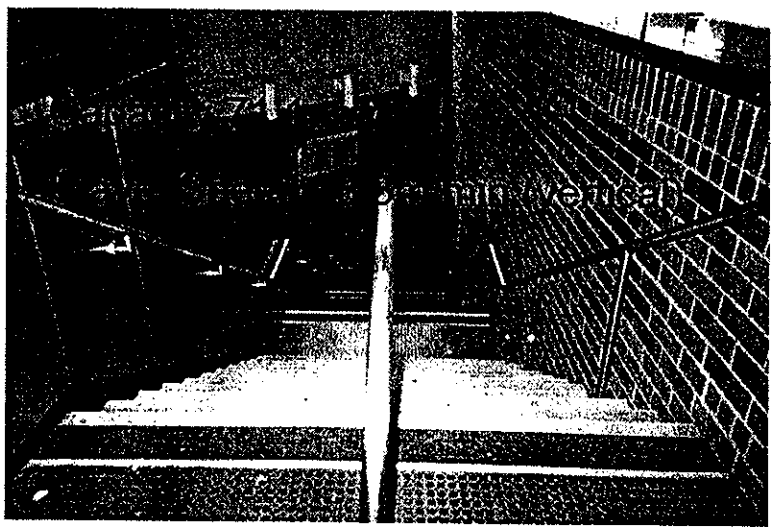

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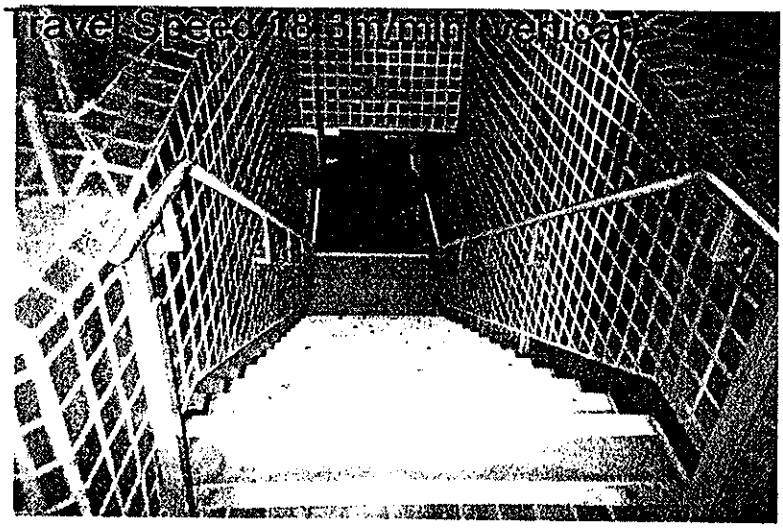
Capacity 71.1pmm



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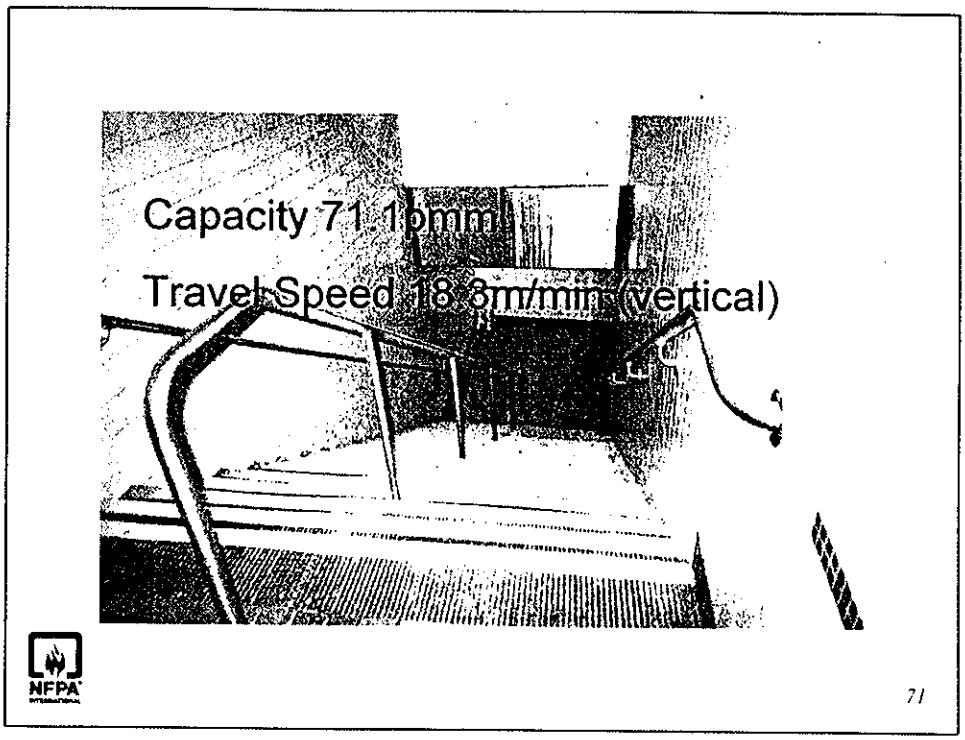
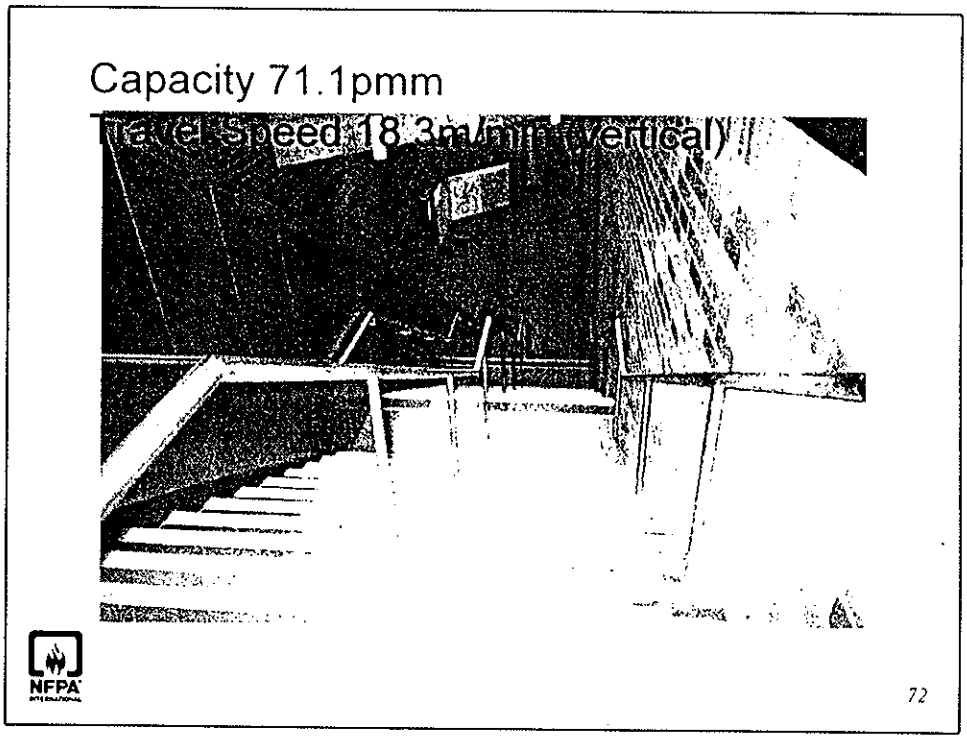

Capacity 71.1pmm
Travel Speed 18.3m/min (vertical)
71


Capacity 71.1pmm
Travel Speed 18.3m/min (vertical)
72

Capacity 62.6pmm

Travel Speed 15.24m



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Elevators

- Authority and Authority Having Jurisdiction – Coordination
- Disabled Occupants and Patrons
- Very Deep Stations
- In combination with horizontal exiting and areas of refuge.

74



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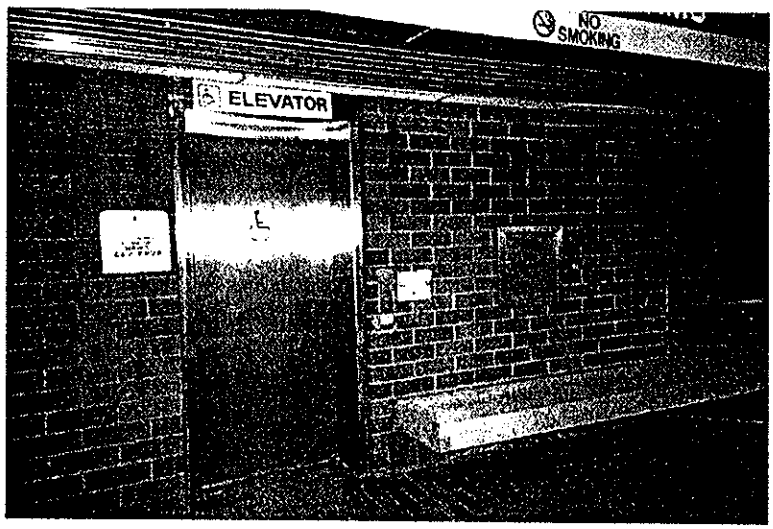

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Emergency Lighting

- NFPA 101®, Life Safety Code®
- Lighting for stairs and escalators shall highlight top and bottom steps and landings.
- Newell- and Comb-Lighting on escalators shall be on emergency power.

77

Fire Protection

- Protective Signaling Systems
- Emergency Communication
- Automatic Fire Sprinkler Systems
- Standpipe and Hose Systems
- Portable Fire Extinguishers

78

Protective Signaling System

- NFPA 72
- Proprietary System



79

NFPA 72

- Proprietary System
  - Contiguous and Noncontiguous Properties
  - One Ownership
  - Proprietary Supervising Station



80

Proprietary Supervising Station

- Central location for alarm and supervisory signal connection
- Staffed at all times
- Supervise Operations
- Investigate Signals

81

Proprietary System

- Proprietary Supervising Station
- Power Supplies
- Signal Initiating Devices
- Initiating Device Circuits
- Signal Notification Appliances
- Recording Equipment
- Emergency Building Control

82

Annunciator Panels

- Accessible to the Authority Having Jurisdiction.
- Audible Alarm
  - Heat Detector Activation
  - Smoke Detector Activation
- Visual Display
  - Location of activated device

83

Alarm Transmittal

- Fire Alarm
- Smoke Detection
- Valve Tamper Switches
- Water Flow Alarms

- Transmitted to Local Station and Central Supervising Station

84

Separate Zones

- Sprinkler System Water Flow
- Supervision of Main Control Valves



85

Ancillary Spaces

- Fixed Temperature and Rate-of-Rise Detectors
- Smoke Detectors
- When protected by automatic sprinklers additional detection shall not be required.



86

Emergency Communication

- Public Address System
- Fire alarm Pull Boxes
- Emergency Voice Alarm Reporting
  - Telephones
- NFPA 72



87

Voice Alarm Communication

- Central Supervising Station
- Passenger Stations



88

Alarm Reporting Devices

- Passenger Platforms
- Passenger Stations
- Spacing = 91.4m
- Distinctive Color
- Signage

89

Automatic Sprinkler Systems

- Transit Stations
  - Concessions
  - Storage Areas
  - Trash Rooms
  - Escalators in Single Entry Stations
  - Similar areas with combustible loading.

90

Automatic Sprinkler Systems

- NFPA 13
- Water Flow and Supervisory Alarms



91

Other Systems

- Other suppression systems are permitted with approval of Authority Having Jurisdiction.
  - NFPA 750 – Water Mist
  - NFPA 15 – Water Spray



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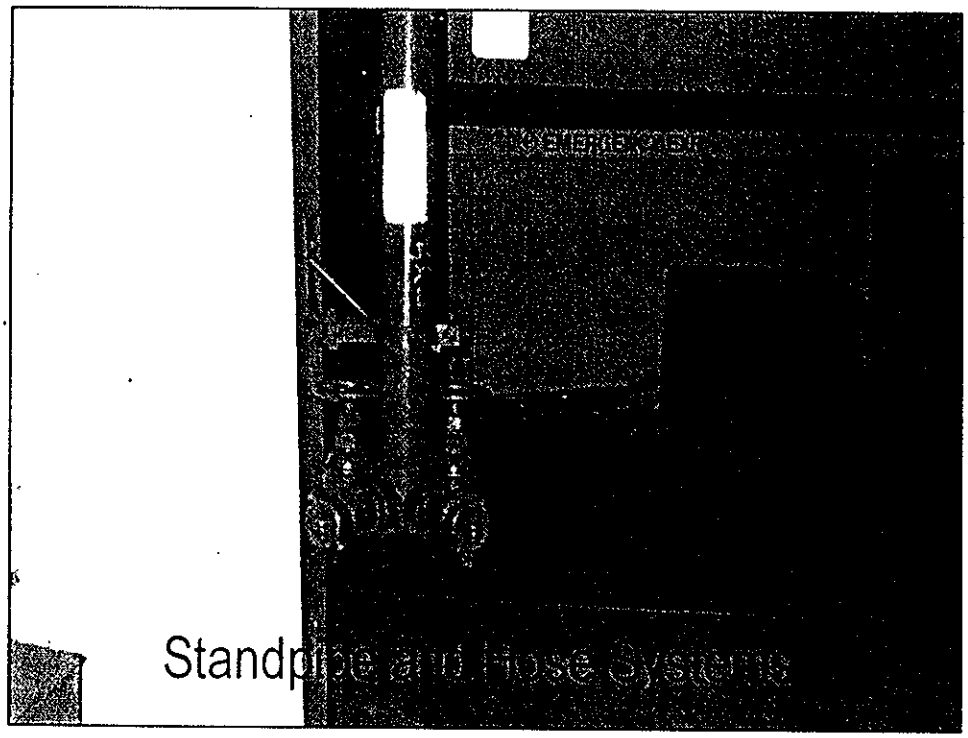

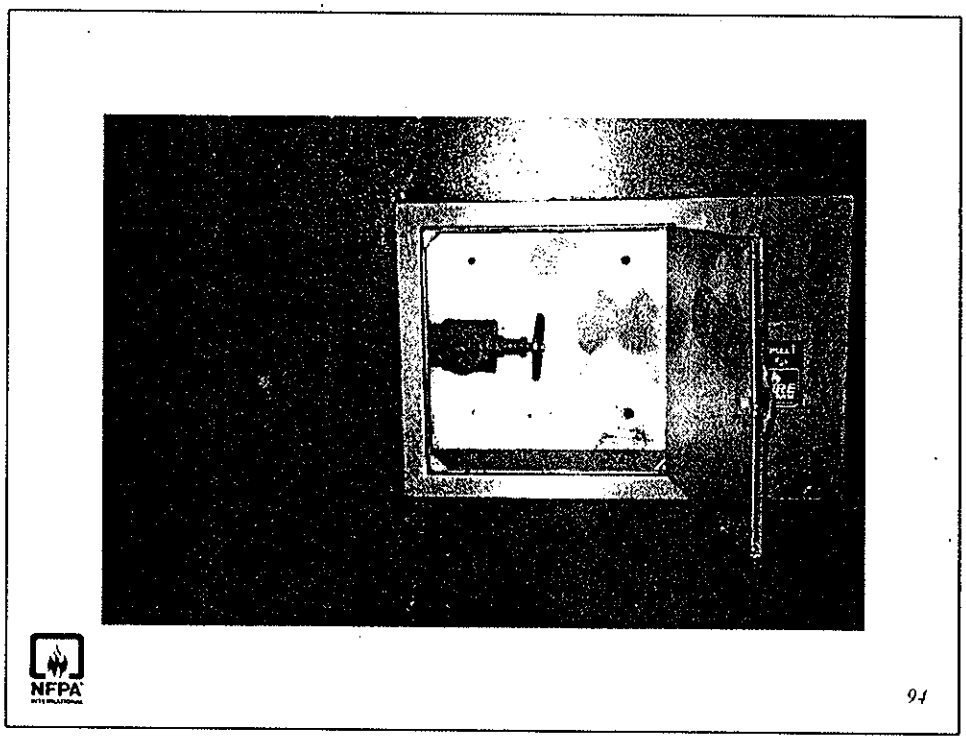

Standpipe and Hose Systems

- Class I or Class III
- Determined by AHJ
- NFPA 14

Location & Spacing

- No Requirements
- AHJ to Determine
  - Location
  - Spacing
  - Hose Type

Fire Department Connections

- Within 100 feet of vehicle access
- Signage

97

Multiple Platform Stations

- Cross Connection Pipe
- 4 inch minimum

98

Portable Fire Extinguishers

- NFPA 10
- AHJ to Determine
  - Number
  - Size
  - Type
  - Location



99

NFPA 130 - Chapter 3
Trainways

- General
- Underground
- Surface
- Elevated



100

Trainways - General

- Passengers will enter the trainway for evacuation only and under guidance.
- Warning signs at the trainway entrances.
- Emergency Telephones shall be provided along the trainway and at blue light stations.

101

Blue Light Stations

- Communication with Central Supervising Stations
- Traction Power Disconnect
- Signage.
  - Location of Blue Light Station
  - Distance to Exits in Each Direction.

102

Blue Light Stations - Locations

- Ends of Station Platforms
- Cross Passages
- Emergency Access Points
- Traction Power Substations
- Other Locations
  - As required by the Authority Having Jurisdiction.

103

Underground (Subways) Trainways

- Materials – Underground/Underwater
- Ventilation – NFPA 130 Chapter 4
- Wiring
- Power Supply for Emergency Ventilation

104

Underground (Subways) Trainways

- Emergency Exit Details
  - NFPA 101®, Life Safety Code®
  - Emergency Exit Stairways – 381m
  - Cross Passageways – 244m
  - Doors – Less than 222N (50lbf)
  - Exit Hatches – Less than 133N (30lbf)
  - Emergency Lighting – 2.69lx

105

Underground (Subways) Trainways

- Traction Power
  - Contact Rail Protection
  - Overhead Contact System Protection
- Passenger Egress
  - Uniform Walking Surface – Top of rail
  - Continuous
  - Raised – Handrail

106

Underground (Subways) Trainways

- Fire Detection – Traction Power Substations
- Standpipe and Hose Systems required where: $L_T > L_H - D_P$
- Standpipes required in tunnels under construction where the tunnel exceeds 61m beyond access.



107

Underground (Subways) Trainways

- Portable Fire Extinguishers
  - Numbers
  - Sizes
  - Types
  - Locations
- As determine by the Authority Having Jurisdiction.



108

Underground (Subways) Trainways

- Flammable and Combustible Liquid Intrusion.
  - Roadway Terminations
  - Median and Sidewalk Terminations
  - Above/Below Ground Storage Tanks
  - Service Stations
  - Storage Tanks In or Under Buildings

NFPA

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NFPA

110

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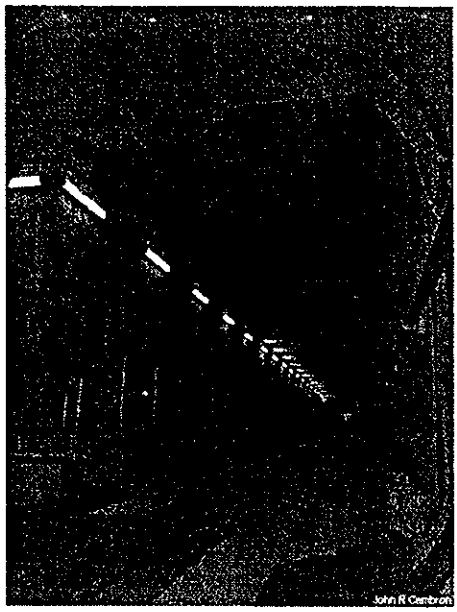

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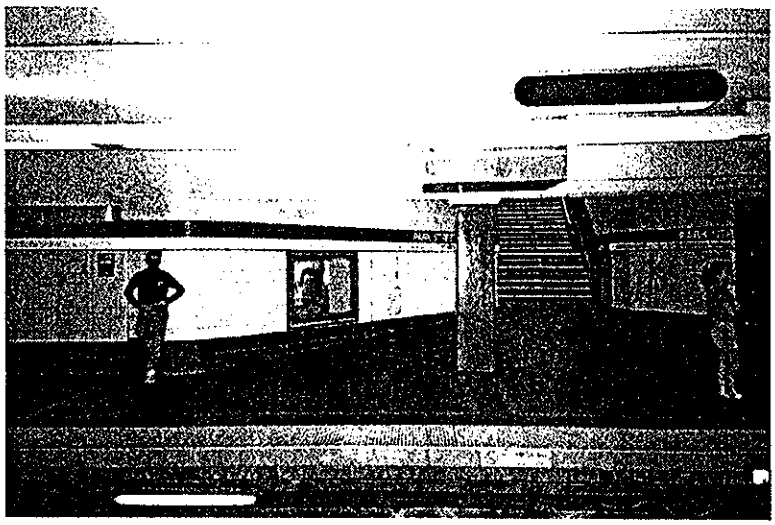

NFPA

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113

Surface Trainways

- Applies to at-grade or unroofed structure other than elevated.
- Construction Materials
- Traction Power
- Wiring
- Emergency Access
- Egress for Passengers

114



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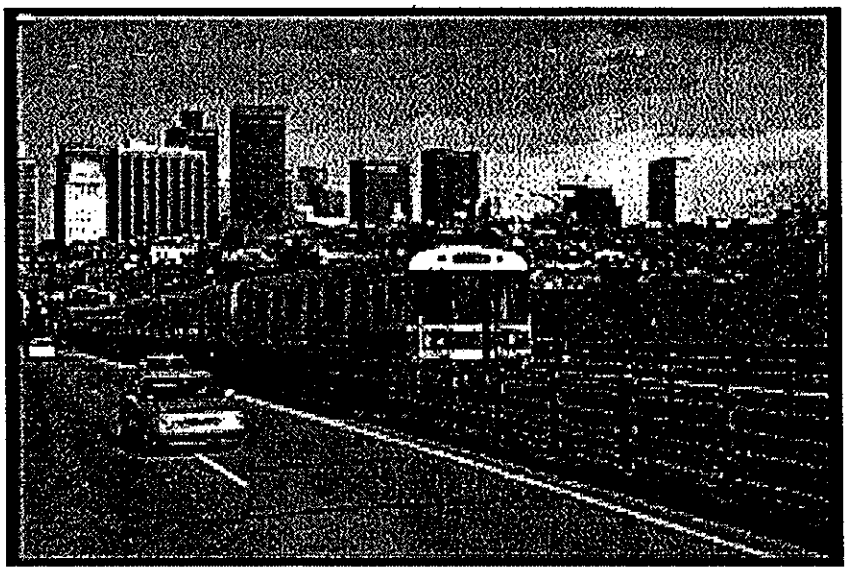

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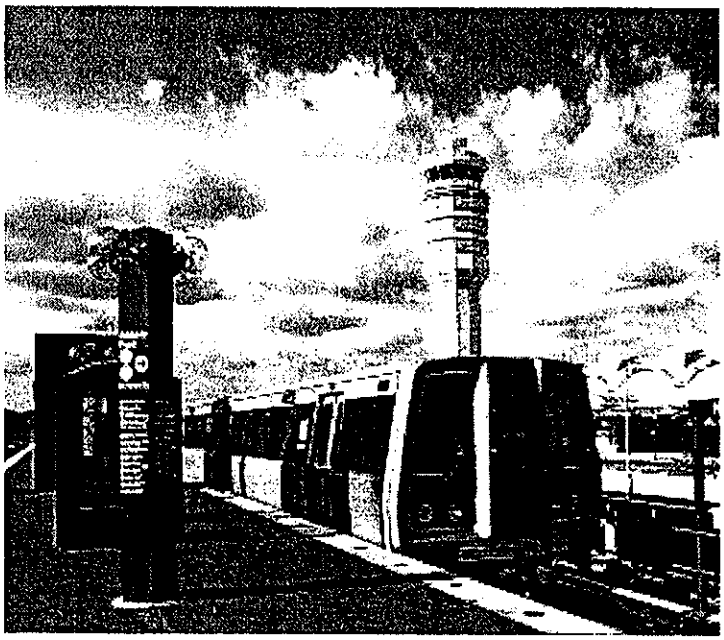

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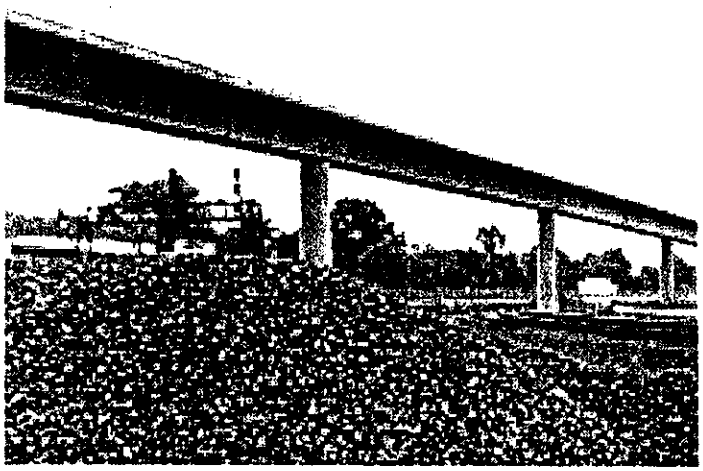
Elevated Trainways

- All structures not surface or underground structures.
- Construction Materials
- Traction Power
- Wiring
- Emergency Access – 762m
- Egress for Passengers

118



119



120



121

NFPA 130 - Chapter 4
Emergency Ventilation System

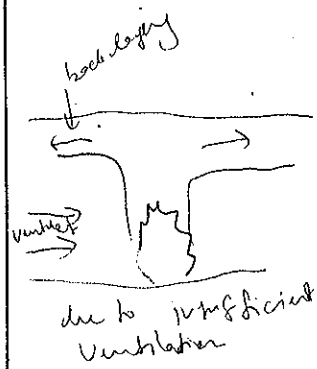
- General
- Design
- Emergency Ventilation Fans
- Devices
- Shafts
- Emergency Ventilation Systems Control/Operation
- Power and Wiring

122

Ventilation Definitions

- **Backlayering.** The reversal of movement of smoke and hot gases counter to the direction of the ventilation airflow.
- **Critical Velocity.** The minimum steady-state velocity of the ventilation airflow moving toward the fire within a tunnel or passageway that is required to prevent backlayering at the fire site.

123



Ventilation - General

- Required
  - Enclosed transit stations.
  - Underground or enclosed trainways greater than 305m.
- Not Required
  - Open transit stations.
  - Underground or enclosed trainwasy less than 61m.

124

Ventilation - General

- Underground or enclosed trainways between 61m and ~~100~~ 305m in length.
  - Engineering Analysis
  - Alternative – No Analysis required where emergency ventilation is provided.



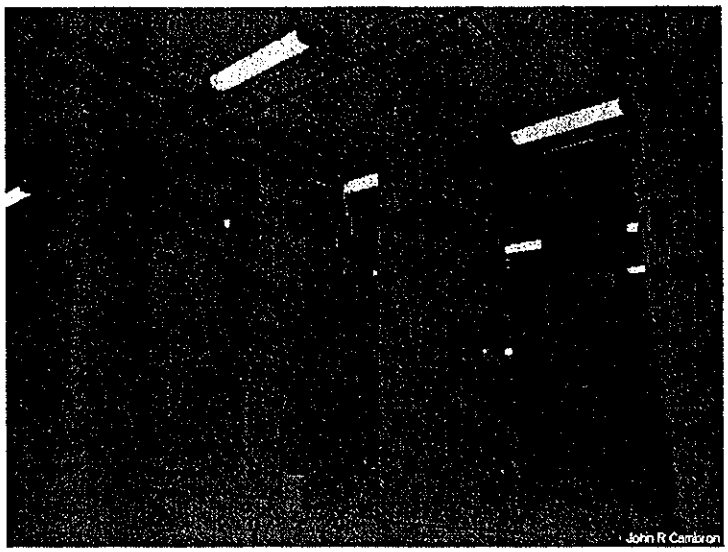
125

Ventilation - Design

- Provide tenable environment along the path of egress from the fire incident.
- Produce airflow rates sufficient to prevent backlayering of smoke in the path of egress.
- Be capable of reaching full operational mode within 120s.



126



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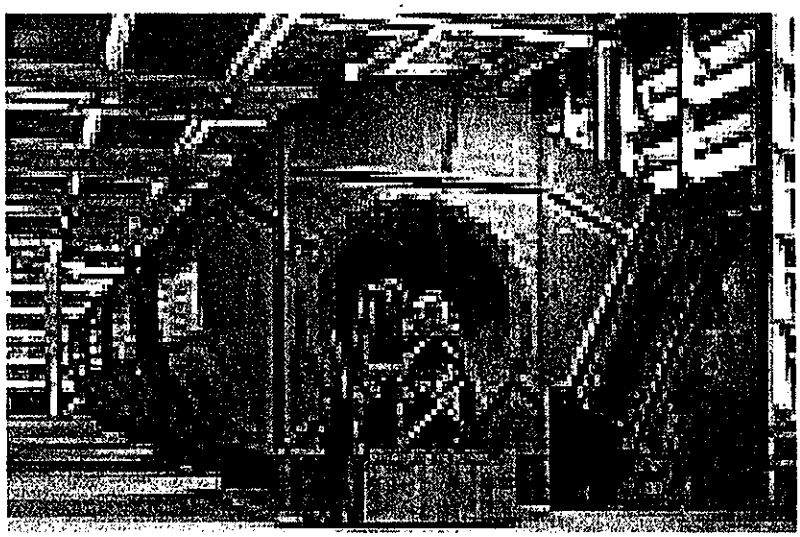

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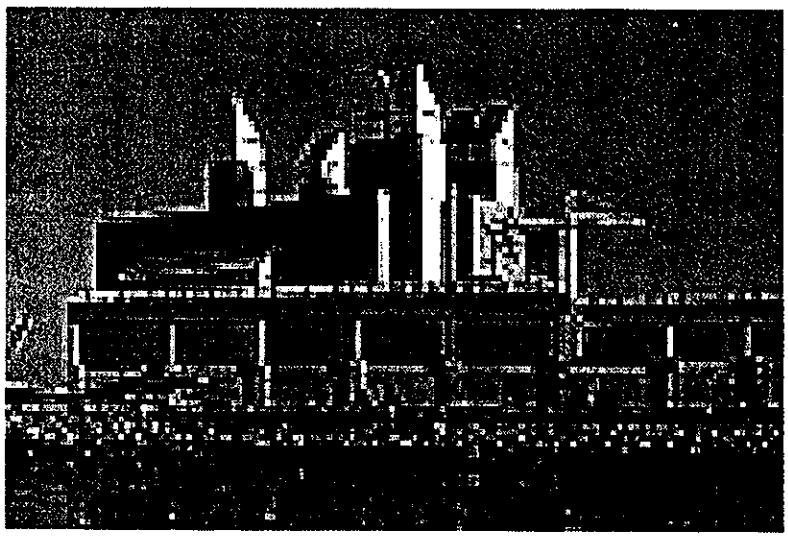


129

NFPA 130 - Chapter 5
Vehicles

- Applicability
- Construction
- Electrical Fire Safety Requirements
- Ventilation
- Emergency Egress Facilities
- Protection
- Vehicle Support and Guidance Systems

130

Vehicles

- Applicability
  - New vehicles for fixed guideway and passenger rail.
  - Retrofit of existing fixed guideway and passenger rail vehicles.



131

Vehicle - Construction

- Testing
- Structural Fire Resistance
- Interior Fire Propagation Resistance
- Electrical Insulation
- Equipment Arrangement



132

Vehicle – Electrical Fire Safety

- General Construction
- Gap and Creepage
- Propulsion Motors
- Motor Control
- Propulsion and Braking System Resistors

133

Vehicle – Electrical Fire Safety

- Wiring Methods
- Overload Protection
- Battery Installation

134

Vehicle - Ventilation

- Method to deactivate ventilation systems remotely or automatically.



135

Vehicle – Emergency Egress

- Exits at Sides and/or at Ends
  - Means to evacuate the passengers to a walking surface
- Emergency Lighting
  - NFPA 101®, Life Safety Code®



136

Vehicle - Protection

- Communications
- Portable Fire Extinguishers
- Lightning Protection
- Heater Protection
- Testing and Maintenance



137

Vehicle – Support and Guidance

- Capable of supporting vehicle in normal service.
- Capable of safe operation until defect is detected and taken out of service.
- Defects shall not result is unsafe condition for passengers.



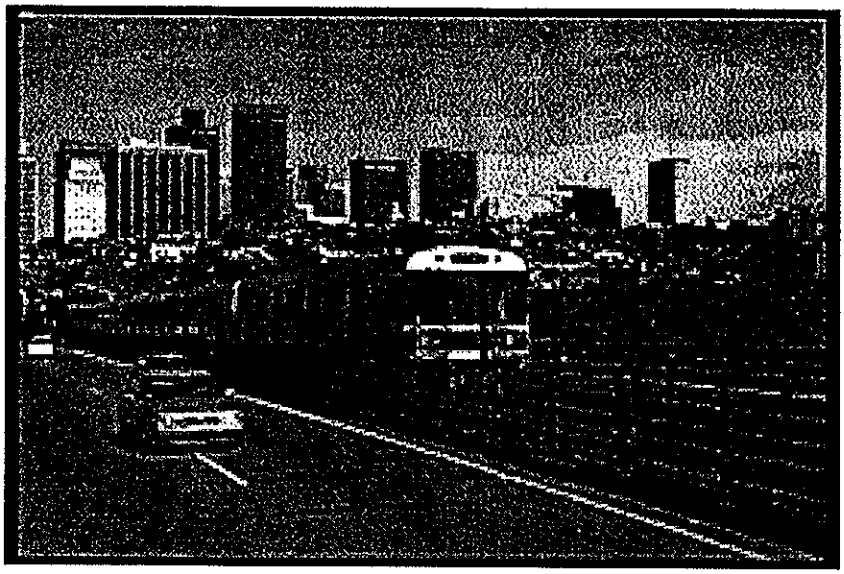
138

Vehicle Exterior

139



140



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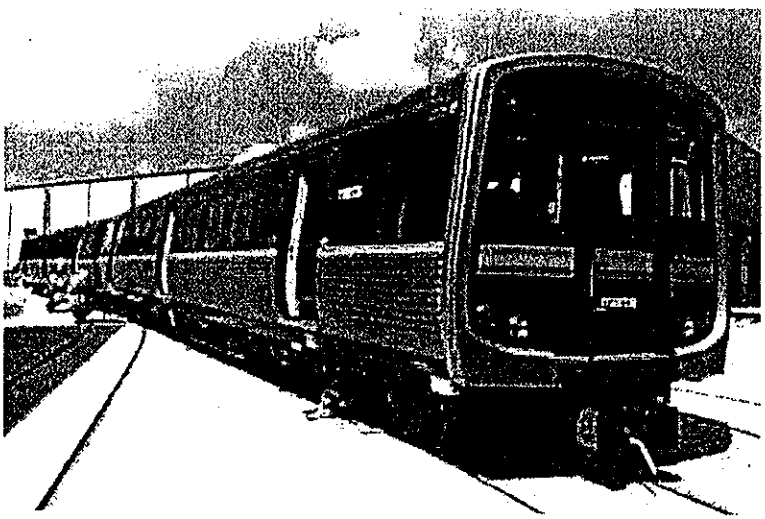

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Vehicle Interior

143



144



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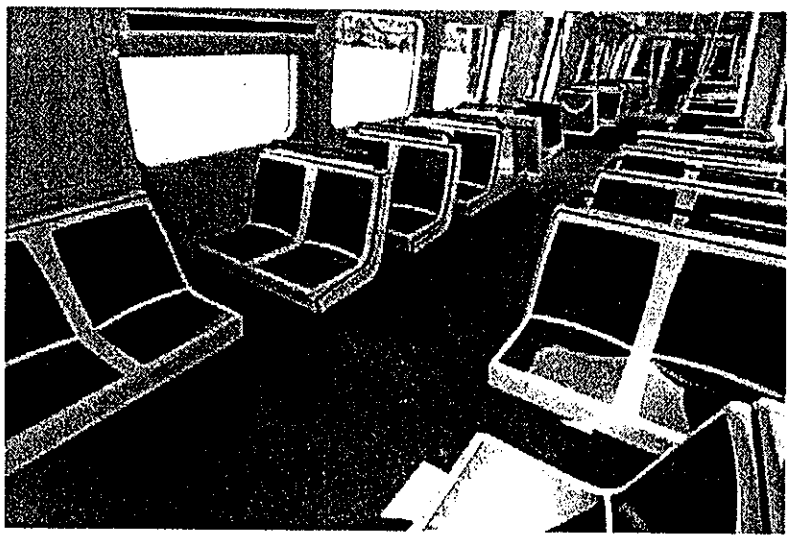

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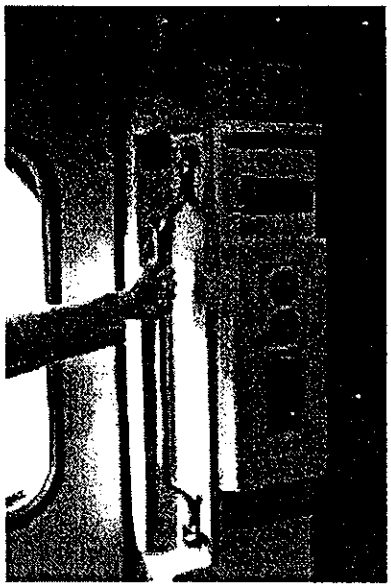


147

NFPA 130 - Chapter 6
Vehicle Storage and Maintenance Areas

- Open Areas
- Structures
- Fire Protection and Suppression Systems
- Operation and Maintenance

148

Vehicle Storage & Maintenance

- Open Areas
  - Water Supply – NFPA 24
  - Emergency Access
  - Fire Extinguishers
  - Communications



149

Vehicle Storage & Maintenance

- Structures
  - Noncombustible – NFPA 220
  - Drainage Systems, Floors and Roofs
  - Electrical Requirements
  - Traction Power
  - Maintenance Pit Areas
  - Ventilation



150

Vehicle Storage & Maintenance

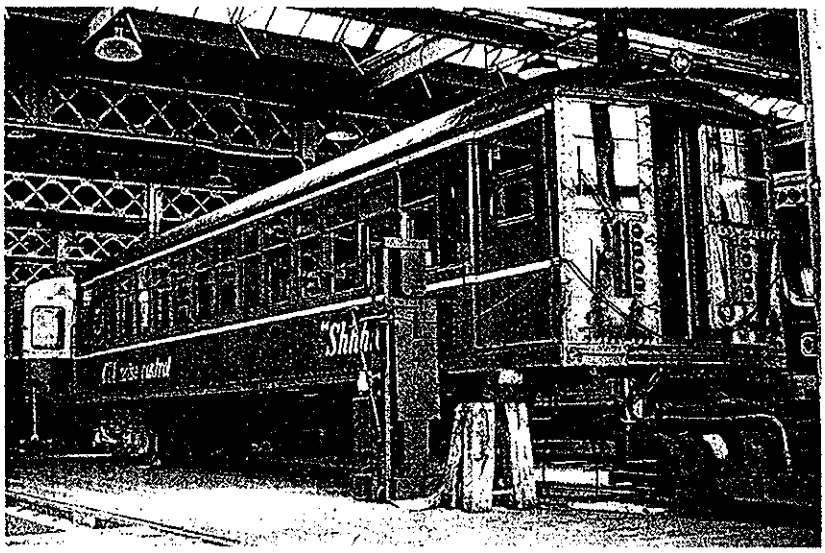
- Fire Protection Suppression Systems
  - Automatic – NFPA 13
  - Protective Signaling – NFPA 72
  - Standpipe – NFPA 14
  - Portable Extinguishers – NFPA 10

151

Vehicle Storage & Maintenance

- Operations and Maintenance
  - Vehicle Placement
  - Vehicle Maintenance
  - Painting/Cleaning/Paint Removal
  - Storage of Painting/Cleaning Liquids
  - Welding – NFPA 51B
  - Industrial Trucks – NFPA 505

152



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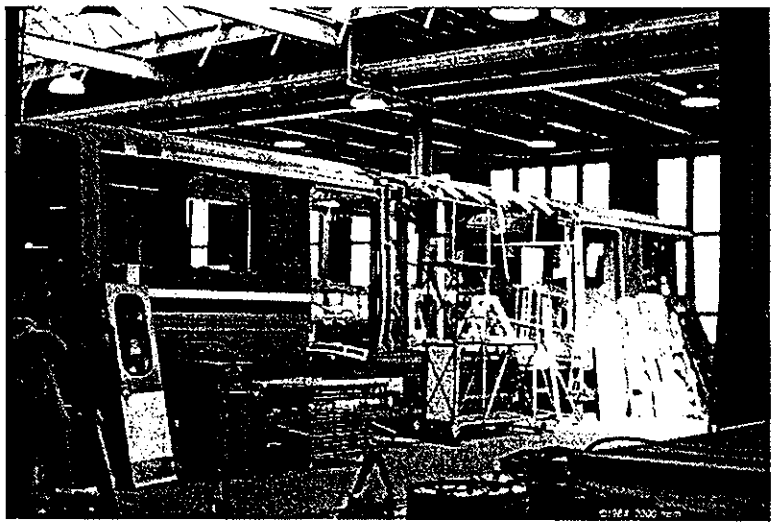

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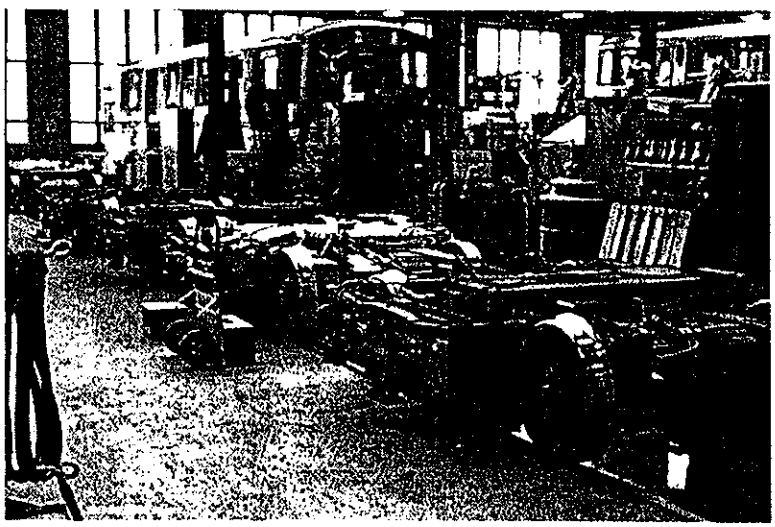

156

NFPA 130 - Chapter 7
Emergency Procedures

- Emergency Management
- Emergencies
- Emergency Procedures
- Participating Agencies
- Central Supervising Station (CSS)



157

NFPA 130 - Chapter 7
Emergency Procedures

- Liaison
- Command Post
- Auxiliary Command Post
- Training, Exercises, Drills, and Critiques
- Records
- Removal and Restoration of Traction Power



158

NFPA 130 - Chapter 8
Communications

- Central Supervising Station (CSS) and Command Post Relationship
- Radio Communication
- Telephone, Portable Telephones and Lines
- Messenger Service
- Public Address Systems

NFPA

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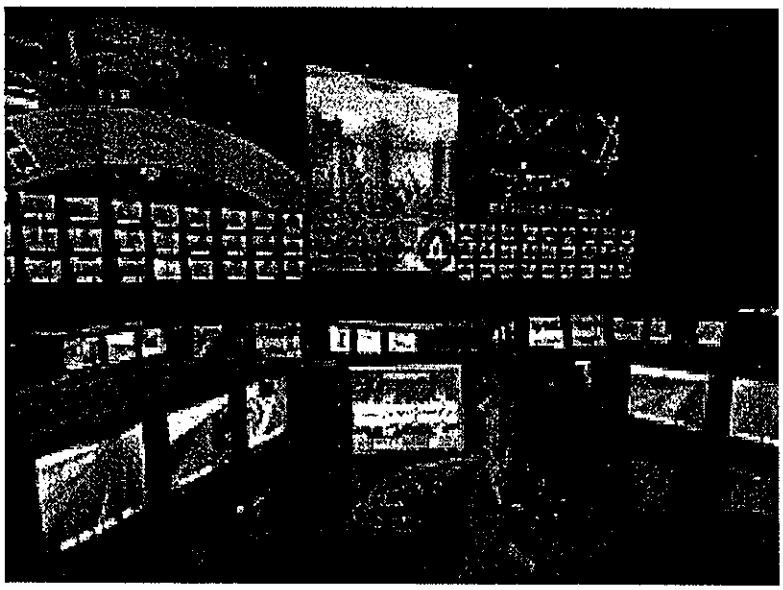

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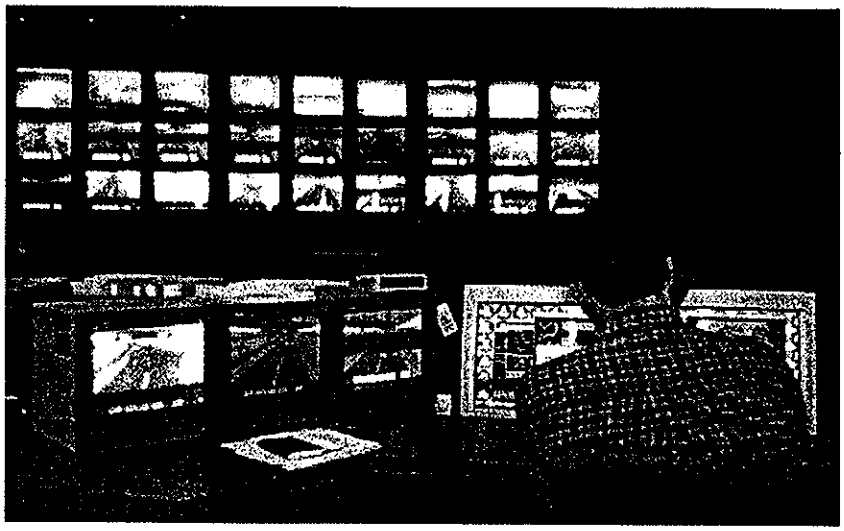

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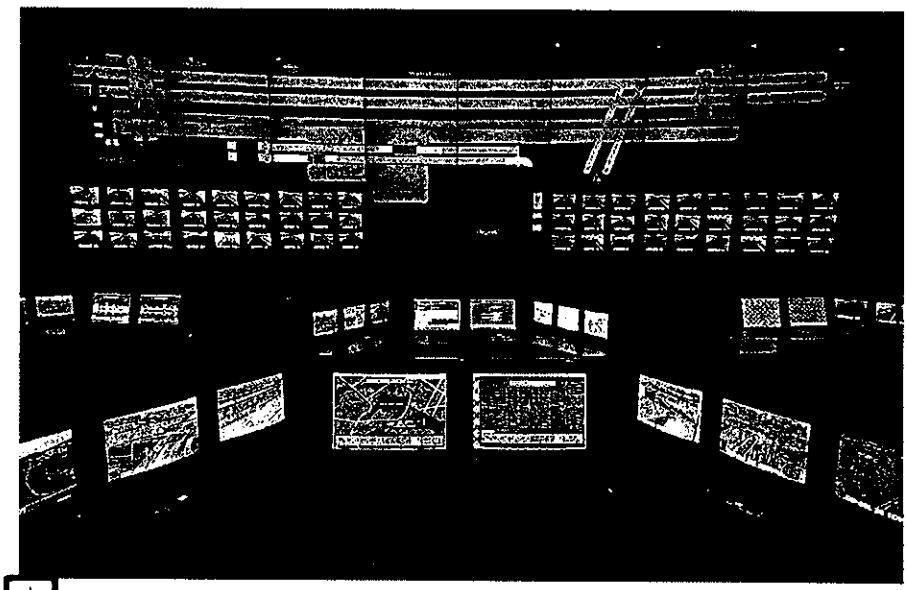

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NFPA 130 - Chapter 9
Referenced Publications

- NFPA 10 – Portable Extinguishers
- NFPA 13 – Automatic Sprinklers
- NFPA 14 – Standpipes
- NFPA 70 – National Electrical Code
- NFPA 72 – National Fire Alarm Code
- NFPA 101 – Life Safety Code
- NFPA 220 – Building Construction

NFPA

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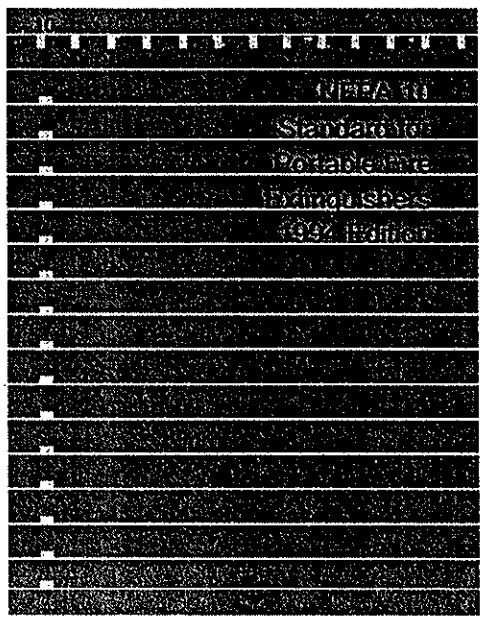
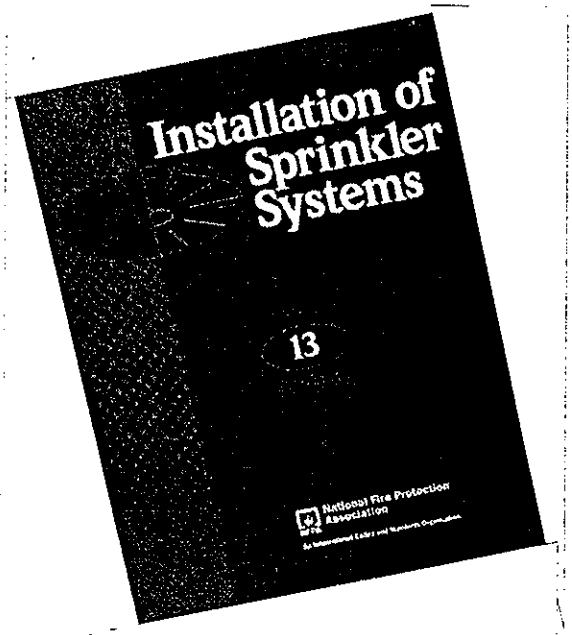


NFPA

164

NFPA 130 - 2000 Edition
Christian Dubay



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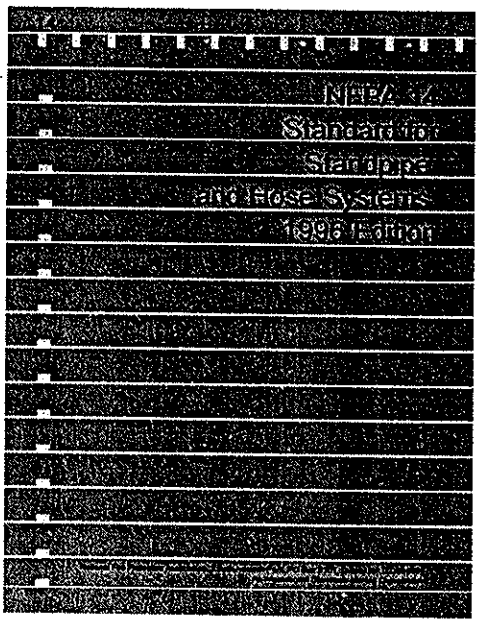

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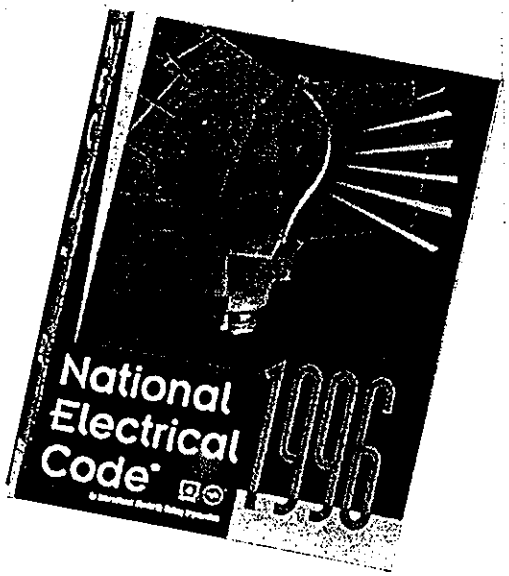
National
Electrical
Code
1996

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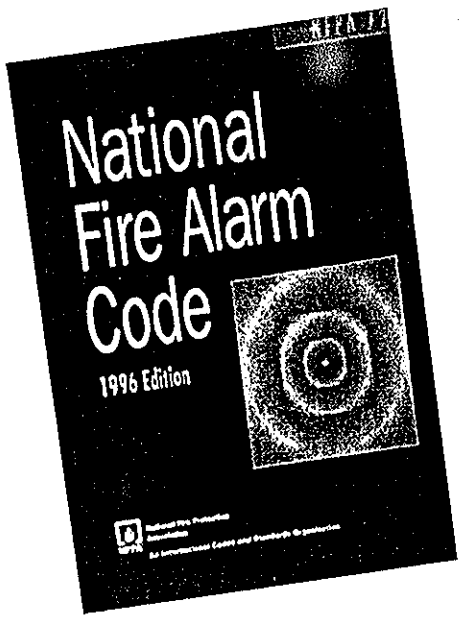
National
Fire Alarm
Code
1996 Edition

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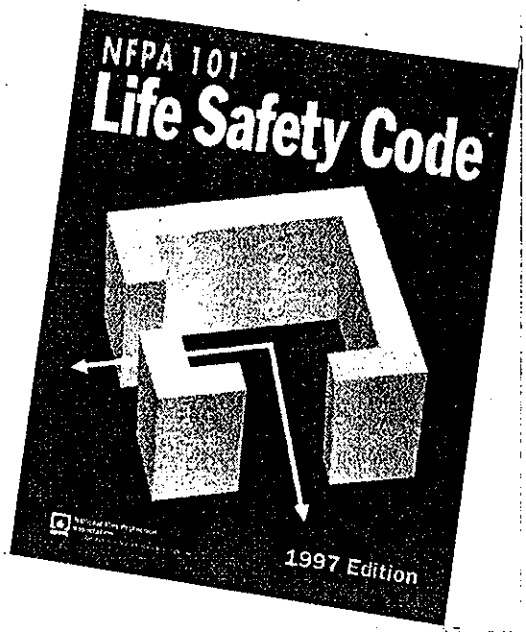
NFPA 130 - 2000 Edition
Christian Dubay



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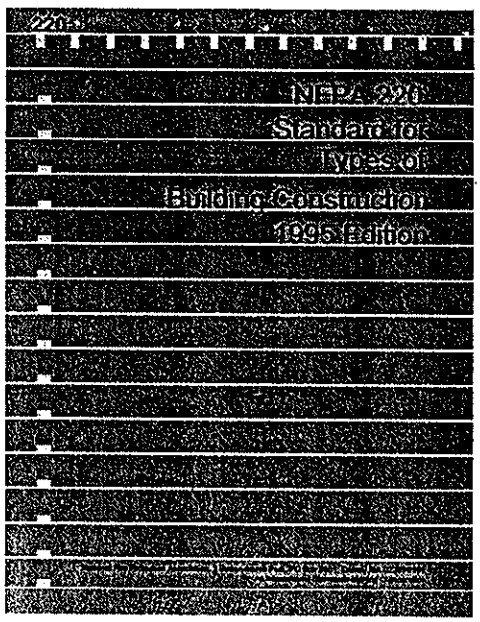

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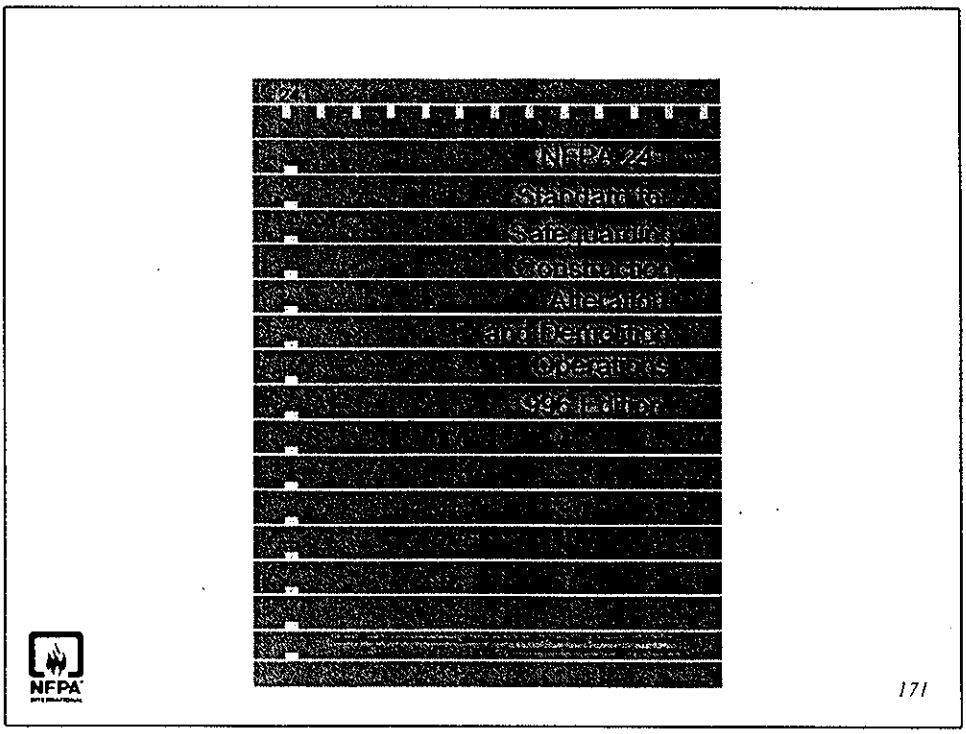
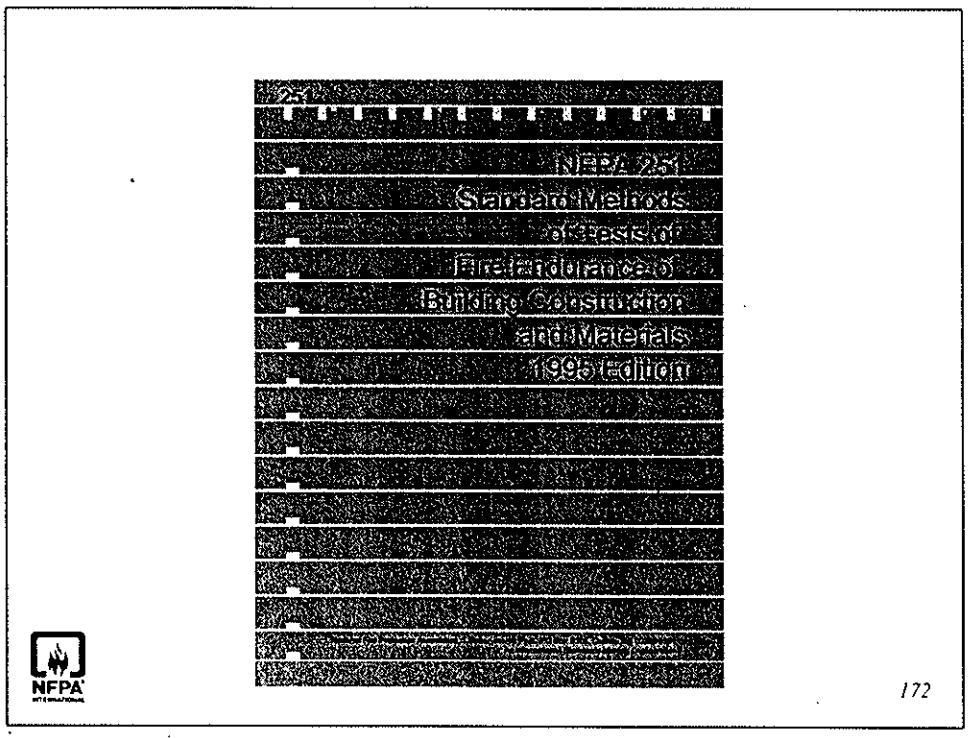
NFPA 130 - 2000 Edition
Christian Dubay





NFPA 130 - Appendixes

- A – Explanatory Information
- B – Ventilation
  - Tenable Environment
- C – Emergency Egress
- D – Fire Hazard Assessment
- E – Creepage Distance
- F – Non-Mandatory References

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NFPA 130 – 2003 Edition

- Transition from Standard to Code
- Tenable Environments
- Emergency Ventilation
- Performance Based Egress
- Vehicle Requirements
- Tunnels and Stations
- Emergency Response

174

NFPA Training - Technical Support

- Provide detailed training and technical support for NFPA 130 and related standards. Including Onsite, Seminars, Training Materials and Manuals.
- Support and training available for all NFPA Codes and Standards.
- Minimal costs - usually limited to travel costs for staff.



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Technical Questions and Training

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Reasons for producing a local Code for Fire Safety on Rapid Transit system (RTS)

1. NFPA130 was used for earlier phase of MRT Projects

2. For North-East line, both the requirements of Local Fire Code and NFPA 130 Standards were adopted to formulate design consideration and outline minimum fire safety provisions

3. Local Fire Code did not cover particularly exit capacity of Stations, emergency ventilation in tunnels, and etc. and requirements of NFPA 130 will govern

Reasons for producing a local Code for Fire Safety on Rapid Transit system (RTS)

4. Prevailing operational and technical requirements not clearly specified in the Fire Code or NFPA 130 also need special consideration.

5. The LTA Fire Safety Standard serves to unify the Fire and Life Safety provision in all future RTS.

6. The LTA Fire Safety Standard was prepared by Committee comprising Officers from LTA and SCDF and the Standard has been adopted by SCDF for RTS design.

STATION

1. **No commercial activities are allowed in the paid area.**

2. **Only one large shop (not exceeding 100 sq. m. and one small shop (not exceeding 15 sq.m.) and 2 ATMs are allowed in the free area.**

3. **Additional commercial spaces are to be located on a separate level.**

4. **Construction materials including finishes are to be non-combustible insofar as practical.**

5. **Cable used to be fire retardant or fire resistant and of low smoke and halogen-free; PSB approved type.**

STATION

6. **Method of calculating platform occupancy load similar to NFPA 130, 2000 Edition.**

7. **In line with NFPA130, open stairs and escalators within public areas need not be enclosed.**

8. **Each platform to be served by not less than 2 remotely located means of escape leading to the exterior of the station. This is the important change in the LTA Fire Safety Standard!**
   This implies that fare gates are to be located at 2 or more locations remote from each other and emergency stairs, if provided is to be designed to discharge at grade.

STATION

9. **No difference from NFPA130 to require evacuation from platform in less than 4 minutes.**

10. **Both NFPA and LTA Fire Safety Standards specify max. time of 6 minutes for evacuation from the most remote point on the station to a point of safety. Definition of point of safety is the same.**

11. **Exit capacity and travel speed are tabulated in a similar order in both Standards. The value adopted by LTA were more stringent due to rounding off.**

STATION

Comparison are shown below:

TYPE OF ESCAPE	Capacity		Travel speed	
	NFPA130	LTAFS	NFPA130	LTA FS
PLATFORM, CORRIDORS & RAMPS <4° IN SLOPE	2.27 pim or 80.3 ppm	80 ppm	200 fpm or 61 Mpm	60 Mpm
STAIRS, ESCALATORS & RAMPS >4° IN SLOPE	1.39 pim or 62.6 ppm	60 ppm	UP 50 fpm or 15.24 Mpm	UP 50 Mpm 15
	1.39 pim or 62.6 ppm	60 ppm	DOWN 60 fpm or 18.3 Mpm	DOWN 18.3 Mpm 18

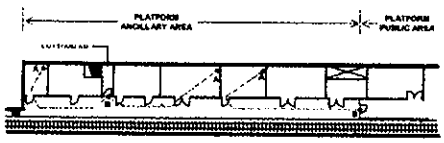
STATION

12. **Additional to exit requirement in public areas. LTA Fire Safety Standard provide different set of requirement for means of escape in commercial spaces and ancillary areas with similar provision as the Fire Code.**

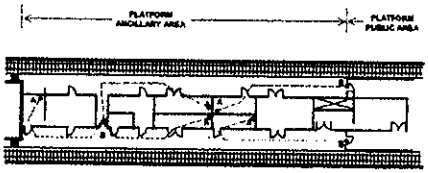
13. **Travel distance requirement for rooms located at the platform ancillary areas open to the stariways are defined quite uniquely. The max. distance is 90m and determination of travel distance including a door opening directly to the non-incident ~~stairway~~ train.**

STATION

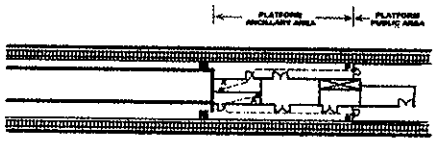
Diagram 2.2.4.4 - Means of escape for rooms located at platform level ancillary areas open to trainway



SIDE-PLATFORM



ISLAND-PLATFORM



ISLAND-PLATFORM

Travel distance from A to B < 90 m.

STATION

14. **Fire resistance of elements of structure for Station is not less than 2 hours except structure around underground trainway is 4 hours.**

15. **Transit and non transit occupants provided with a fire separation of at least 2 hours, NFPA requires 3 hours.**

16. **Public areas shall have a fire separation of at least 2 hours from non public areas, including fire doors. The compartmentation requirement for NFPA 130 is 2 hours walls/ floors with 1 ½ hour doors.**

17. **Shop and commercial spaces are also to be fire compartmented in 2 hour enclosure, except small shop provided with smoke barrier or above ground shops not located along station's means of escape.**

STATION

18. **Requirements for fire resistance period for special purpose rooms are different between NFPA 130 and LTA Fire Safety Standard.**
    - **The FRP is lower for substation, from 3 hours (NFPA) to 2 hours (LTA)**
    - **FRP is higher for generator and oil type transformer rooms, from 3 hours (NFPA) to 4 hours (LTA)**
    - **For other plant rooms, though FRP remains 2 hours, but the fire rating of doors was increased from 1 ½ hours (NFPA 130) to 2 hours (LTA Standards)**
19. **Notwithstanding the slight deviations in FRP, the basic concept of providing extensive fire compartmentation in Station is the same.**

STATION

20. **LTA Fire Safety Standard also includes other common requirements pertaining to**
    - **Smoke Stop lobbies**
    - **Compartmentation of protected shafts**
    - **Protection of concealed spaces**
    - **Fire stopping and etc**

    These are written in general accordance with the Fire Code

Calculation of Platform Occupancy Load

1. Size of station is determined by length of train employed in the transit system.
2. The platform area itself is not a real indicator for any expected no. of occupants on the platform.
3. The station occupant loads during emergency are a function of the passenger traffic volume and train carrying capacities rather than station platform areas.
4. Projected patronage figures, in AM and PM peak hours are used to derive platform occupancy load.
5. Entrancing load: No. of passengers awaiting for train.
6. Calculated train load: No. of passengers in the train, simultaneously entering the station on all tracks during peak hours.

Calculation of Platform Occupancy Load

7. System surge factor = 1.3

   and peak min. load = $\frac{\text{Peak hour load}}{60}$ X 1.30

8. Entrancing load (Peak direction) = Peak min. entrancing load x headway x 2 (Safety factor)

   Entrancing load (Non peak direction) = Peak min. entrancing load x headway

9. Calculated train load= (Peak direction) Peak min. link load x headway x 2 (safety factor) but not exceeding the train crush load

   Calculated train load= (Non peak direction) Peak min. link load x headway

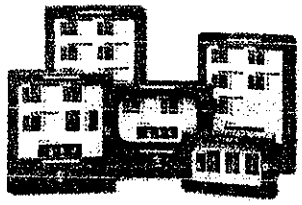
Calculation of Platform Occupancy Load

10. **Platform occupant load is the greater of the AM and PM peak period loads calculated.**

Automatic Fire Alarm system

APPLIANCE CODE: SS C.P. 10

1. Location of Main Alarm Panel (MAP)
   a. Underground Station with Fire Command Centre (FCC) – inside FCC
   b. Underground Station without FCC – in fireman's stair at ground level
   c. Surface/ elevated Station – near main entrance of Station
2. Location of Sub Alarm Panel (SAP)
   a. Fire fighting / smoke stop lobby
   b. Protected staircase
   c. Main entry into area covered by SAP



Automatic Fire Alarm system

APPLIANCE CODE: SS C.P. 10

3. Detectors not required for cross-ventilated public areas including entrances
4. Detectors not required for areas/ rooms protected by Automatic Fire Sprinkler system
5. Heat detectors in emergency fan room, tunnel ventilation fan room, UPV and etc.
6. Smoke detectors in electrical switch room, transformer room, GTM rooms, DB room, telecommunication room, signal equipment room, cable basement, etc

Tunnel Ticketing Machine

Automatic Fire Alarm system

APPLIANCE CODE: SS C.P. 10

7. Provide manual alarm call points and bells in Station's ancillary areas only, within coverage of 30m



8. No manual alarm call points and bells in the Station public areas. Emergency voice communication system is used to effect station evacuation

9. Alarm bells in commercial spaces and commercial floors to be activated only by flow switches, detectors or manual alarm call points serving the areas only



10. Noisy Plantrooms to be provided with Visual alarm (beacon lights) additional to alarm bells, e.g. ECS plantroom, TVF room, UPEF room, SPF room, CD generator room & CD cooling tower



Station Purging Fans

Automatic Fire Alarm system

APPLIANCE CODE: SS C.P. 10

11. Alarm signal will be sent to Repeater panel in SCR (PSC) and simultaneously to OCC. A hotline is provided between OCC and SCDF

← Station control Room

Passenger Service Centre

12. Fire alarm system is also linked to operations of lift homing, smoke purging/ smoke control system, releasing of AMS doors and etc

13. Detectors, bells and call points to be of listed type (UL/FM/LPC)

14. PSB labels for MAP, SAP and fire rated cables

Automatic Fire Sprinkler system

APPLIANCE CODE: SS C.P. 52

1. Every station requires protection by an Automatic Fire Sprinkler (AFS) system



2. Hazard Group for sprinkler design
   a. OH I for ancillary areas
   b. OH3 for commercial spaces

Automatic Fire Sprinkler system

APPLIANCE CODE: SS C.P. 52

3. AFS not required throughout the Station, but only to the following areas
   a. All ancillary areas, except compartmented electrical/ communication rooms, cable basement protected by smoke detectors, fan rooms & UPV protected by heat detectors
   b. Commercial floors
   c. Stores
   d. All CD rooms
   e. Offices and maintenance rooms
   f. Fire fighting/ smoke stop lobbies
   g. Escalator pits except escalators at entrance of multi-entry station



Standard Response

Automatic Fire Sprinkler system

APPLIANCE CODE: SS C.P. 52

h. Travellator pits/ trusses
i. Lift shafts
j. Hydraulic lift motor room

4. Public areas need not be protected by AFS

5. Sprinkler pipes passing through public areas need not be enclosed with fire rated material

6. Connection of flow switches to fire alarm system

7. Sprinkler control valve and ancillary valves to be electronically supervised

Automatic Fire Sprinkler system

APPLIANCE CODE: SS C.P. 52

8. Equipped with Sprinkler water tank and duty/ standby sprinkler pump with 2 sources of power supply
   no genset.
9. Components of sprinkler system including flow switches and fire sprinklers to be of listed type (UL/FM/LPC)

10. No protection (by detector or sprinkler) for corridor between platform ancillary areas and trainways

11. PSB labels for sprinkler pumps and fire rating protection to pipes



Smoke Purging system

APPLIANCE CODE: SS C.P. 13

1. **To be provided throughout the Public area including concourse and platform levels**
   a. **Station public area**
   b. **Corridors of ancillary areas in Basement**
   c. **Public areas outside underground commercial floors, if applicable**
2. **Purging rate set at min. 9 air changes per hour.**
3. **The smoke purging system in public area may be automatically activated by detectors. Recent amendment**
4. **Exhaust fans capable to operate at 250°C for 2 hours.**

Smoke Purging system

APPLIANCE CODE: SS C.P. 13

5. **Replacement air required.**
6. **1.2mm thick (18g) ductwork required.**
7. **Min. 2 sets of smoke purging fans required.**
8. **Smoke purging system need not be a dedicated system. Recent amendment**
9. **Interlocking of supply and exhaust fans. Recent insertion.**

Engineered Smoke Control system

APPLIANCE CODE: SS C.P. 13,

1. **To be provided in basement commercial spaces on commercial floors**

2. **Smoke control system is not required for small shops**

Hosereel

APPLIANCE CODE: SS C.P. 29

1. Hosereel to be provided throughout the Station including underground link but except train platforms, ground floor entrances with no shops and cable basement, etc
2. Locations of hosereel
   a. Adjacent to exits and protected lobbies
   b. Along exit routes
   c. Large rooms (TVF Rm)



SIDE MOUNTED HOSE REEL CABINET



HOSE REEL CABINET

Hosereel

APPLIANCE CODE: SS C.P. 29

3. 30m coverage (measured from most remote point of protected space)
4. Water supply can be taken from the sprinkler tank
5. PSB label



Portable Fire Extinguisher (PFE)

APPLIANCE CODE: SS C.P. 52, SS 232

1. PFE to be provided throughout the Station including cable basements / UPVs, commercial spaces & plantroom at ground level entrance, but except underground / above ground links

2. Coverage and rating to comply with SS C.P. 55

3. Dry powder PFE mostly used

4. PSB label





Voice Communication System

APPLIANCE CODE: SS C.P. 25

1. Voice Communication (VC) system includes
   a. PA System (1-way VC system)
   b. Emergency Fire Phones (2-way VC system to the public)
   c. Fireman Intercom between BIs and holding areas to tunnels (2-way VC system for SCDF)
2. 1-way VC system to be provided throughout the station. If fire alarm is not acknowledged by Staff, VC will activate station evacuation message after 8 mins.

Voice Communication System

APPLIANCE CODE: SS C.P. 25

3. Emergency Fire Phones to be provided in lieu of manual call points in station public areas. Passenger to travel not more than 90m to reach an emergency fire phone to speak with Station Staff.

Lift Installation

APPLIANCE CODE: SS C.P. 2

1. Fire Lift required only for underground stations exceeding 3 Basement with the following compliance:
   a. Fire Lift to be contained within a separate protected shaft

   b. Fire Lift to have access to every accessible floor, open to a fire fighting lobby at every level be adjacent to an exit stair connecting all level to ground

   c. Fireman lift operation

Lift Installation

APPLIANCE CODE: SS C.P. 2

2. All lifts shall *home* to designated floor (ground level) upon fire alarm

3. Homing of lifts upon power failure is not required under the recent amendments, provided a dual feeder power supply is provided and power supply can automatically switch over to the feeder upon failure of normal supply

4. PSB labelled emergency battery operated box to be provided in lift car

5. PSB label for lift car landing door

Station Dry Riser (DR)

APPLIANCE CODE: SS C.P. 29

1. 2 stacks of DR with Breeching Inlet (BI) located at each end of the station
2. 4-way BI with 150mm DR pipe, BI t be housed in box (as per SS C.P. 29) and be appropriately labelled.
3. Landing valves (LVs) to be provided on each basement level.



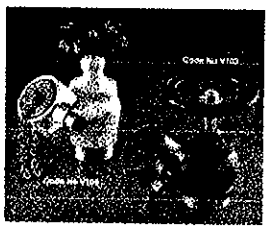
4-way breeching inlet



Station Dry Riser (DR)

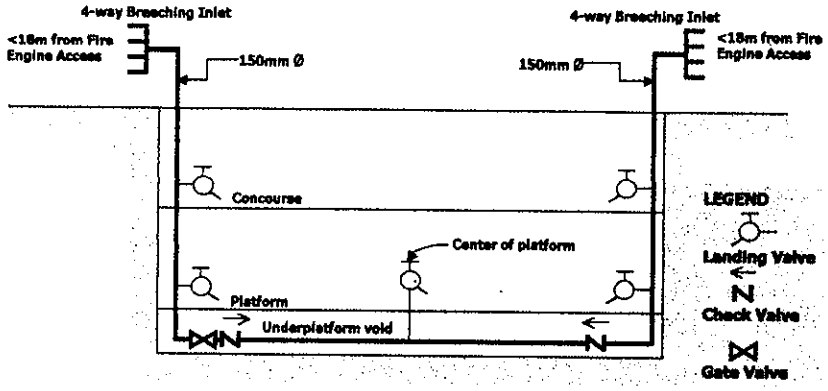
APPLIANCE CODE: SS C.P. 29

4. Position of LVs
   a. Fire fighting/ smoke free lobby
   b. Corridors in ancillary areas
   c. Train platform, within 38m



5. Station DR pipes need no fire rating, but cannot route through exhaust shafts, shops and high hazard areas.

Station Dry Riser (DR)



Dry Riser System in MRT Station

Station Dry Riser (DR)

6. Separate DR mains for basement commercial floors
   a. LVs to be within 38m
   b. DR pipe within Basement commercial floors to be 2 hour fire rated
   c. LV to be positioned in smoke stop lobby, exit staircase or outside entrances of basement commercial spaces



Station Dry Riser (DR)

7. Standby Fire Hose to be provided within 2m from each LVs
   a. Standard 63.5mm diameter and 30m length hose, kept stored in a Dutch Rolled position and housed in a glass tinted cabinet

   b. 2 length of spare fire hose to be kept within the Station

8. PSB labels for BI, LV and Standby Fire Hose

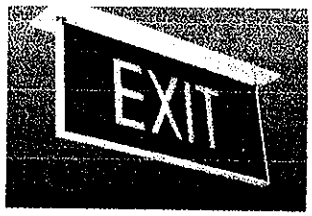




Emergency Lighting and Exit Signs

APPLIANCE CODE: SS C.P. 19

1. **Location of exit signs and exit directional signs**
   a. **Entrance to every exit and**
   b. **Additional exit directional sign in long corridor.**
2. **Provision of exit signs and exit directional signs**
   a. **All exits and**
   b. **All corridors/ lobbies leading to exits.**

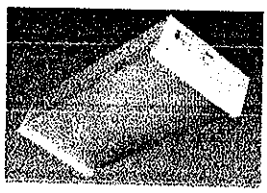


Emergency Lighting and Exit Signs

APPLIANCE CODE: SS C.P. 19

3. **Provision of Emergency Lighting**
   a. **All corridors and lobbies and along paths leading to these areas,**
   b. **In special purpose rooms, such as FCC, pump rooms, and etc,**
   c. **Near MAP, SAP and other fire fighting equipment,**
   d. **Paths leading to corridors/ lobbies/ fire exits.**
4. **Secondary Power Supply to be provided.**
5. **PSB Label for exit signs and emergency lighting (self contained battery type)**





Tunnel Safety Standards

Christian Dubay, P.E.
Fire Protection Engineer
NFPA International
Quincy, MA USA

NFPA 130

Standard for Fixed Guideway Transit and Passenger Rail Systems 2000 Edition

In the United States

- Atlanta (MARTA)
- Chicago (CTA)
- Cleveland
- Dallas (DART)
- Detroit
- NY & NJ Port Authority
- Philadelphia (SEPTA)
- Washington, DC (WMATA)

An International Standard

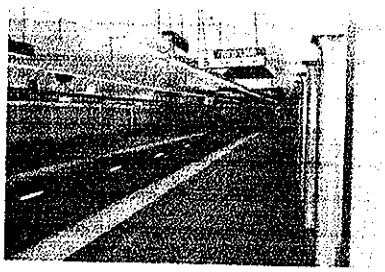
- Singapore
- Hong Kong, China
- Madrid, Spain
- Izmir, Turkey
- London, England
- Caracas, Venezuala
- Taipei, Taiwan
- Singapore

NFPA 130 – Scope



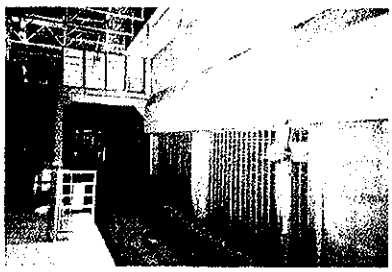
Stations

- Construction
- Ventilation
- Wiring
- Means of Egress
- Emergency Lighting
- Fire Protection



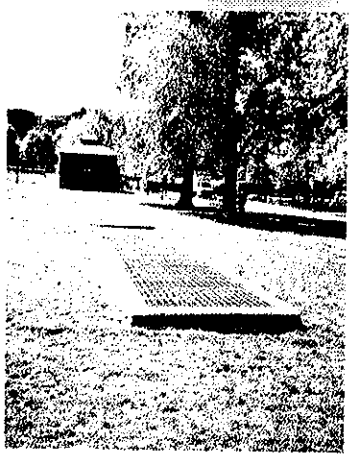
Trainways (Tunnels)

- Construction
- Ventilation
- Wiring
- Emergency Exiting
- Traction Power
- Egress for Passengers
- Fire Protection



Ventilation

- Design
- Fans
- Devices
- Control and Operation
- Power and Wiring



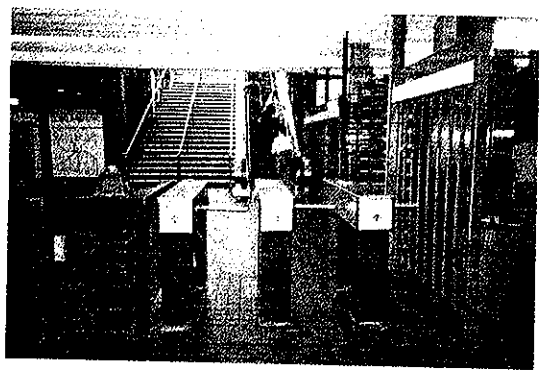
Emergency Procedures

- Emergency Management
- Types of Emergencies
- Emergency Operations
- Participating Agencies
- CSS
- Command Post
- Training



Changes to the 2003 Edition

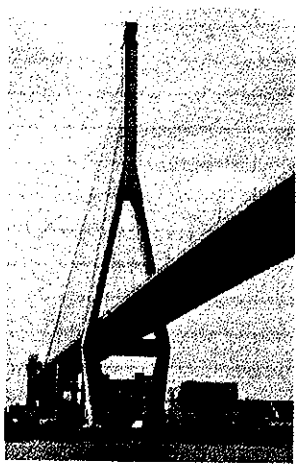
- Means of Egress
- Tenability

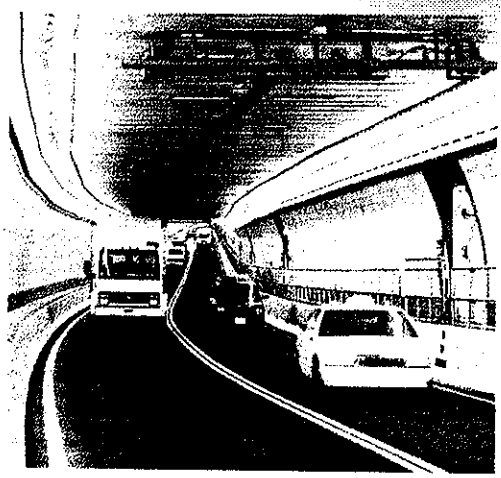


NFPA 502

Standard for Road Tunnels, Bridges and Other Limited Access Highways 2001 Edition

NFPA 502 - Scope





Road Tunnels

- Length
- Detection / Communication / Traffic
- Fire Protection
- Ventilation
- Control of Hazardous Materials
- Emergency Response Plan
- Emergency Egress Requirements

Tunnel Length

- <90m – Standard does not apply
- 90m-240m – Standpipe & Traffic Controls
- Entire Standard Applies
  - >240m & >120m to Area of Safety
  - >300m – Entire standard applies

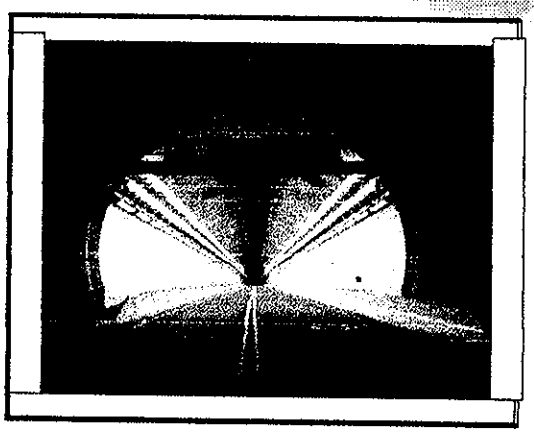
Detection

- Manual Fire Alarm Boxes
- CCTV
- Automatic Detection
- Fire Alarm Control Panel



Traffic Control

- >90m
- >240m



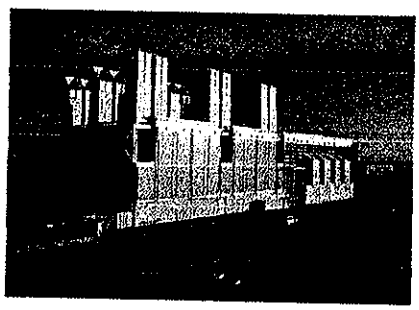
Fire Protection

- Fire Apparatus
- Standpipe and Water Supply
- Portable Fire Extinguishers

- Automatic Sprinklers

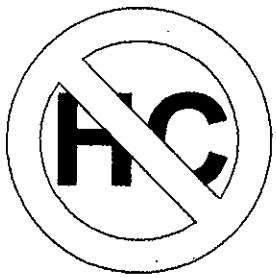
Tunnel Ventilation

- Normal Ventilation
- Smoke Control
- Design Objectives
- Design Criteria
- Fans
- Dampers
- Controls



Control of Hazardous Materials

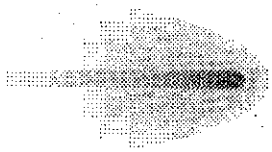
- Alternative Routes
- Traffic Volumes
- Vehicles Inspections
- Escort Services



Emergency Egress

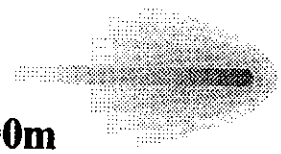
- Identification
- Walking Surfaces
- Tenable Environment
- Doors
- Emergency Exits
- Cross Passageways
- Accessibility at Portals

Tenable Environment



- Air Temperature
- Air Carbon Monoxide Content
- Carbon Monoxide Generated
- Smoke Obscuration
- Radiation
- Air Velocities
- Noise Levels

Exits

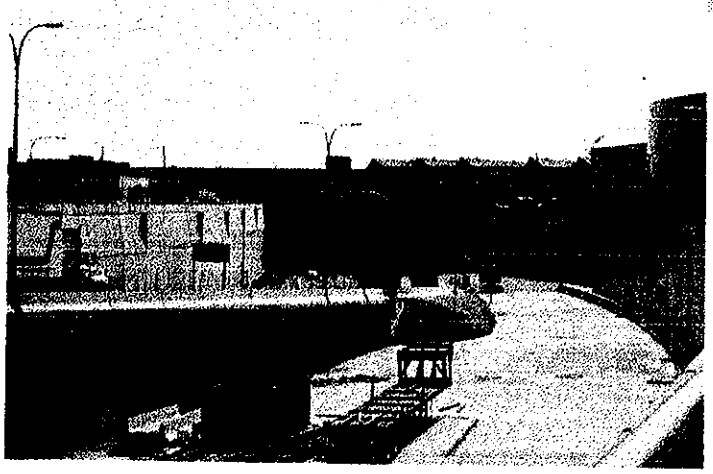


- Travel Distance to Exit - 300m
- Design - NFPA 101, *Life Safety Code*

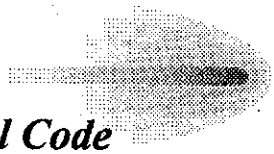
Cross Passageways

- Tunnel Separation – 2 hour
- Travel Distance – 200m
- Doors – 1 hour fire resistance rating
- Walkways
  - Width – 1m
  - Continuous
  - Protected

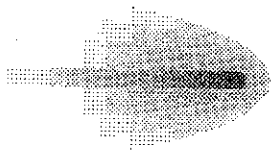
Accessibility at Portals



Emergency Lighting



- NFPA 70, *National Electrical Code*
- NFPA 110, *Emergency & Standby Power*
- Interruption
- Lighting Levels
- Special Emergency Features



Thank You

9-34 — FIXED GUIDEWAY TRANSIT SYSTEMS

Revised by Lawrence M. Engleman

Lawrence M. Engleman is technical director, system safety and security, Parsons Transportation Group, Washington, DC

The environment of a rapid transit system lends itself to some peculiar and difficult fire safety problems. Large numbers of people who move through these subterranean enclosures and elevated structures compound the life safety dangers. Fires within subways have attracted national attention over the years due to the danger facing passengers who must evacuate trains through smoke-filled trackways and other emergency exitways.

Among the causes of fire in a mass transit system are mechanical failure of undercar components, high-energy electrical short circuits, accumulation of combustible debris along the trackways and within vent shafts, accumulation of road film and oils on the transit vehicle underside, combustible materials in car components, combustible construction of trainways including crossties, and hazards associated with the human factor, such as carelessness, arson, and pranks.

This chapter covers areas in a rapid transit system requiring special attention, including subways, underground stations, and surface-level and elevated transit systems.

SYSTEM CHARACTERISTICS

Although subways and underground stations pose the most serious threat to transit users from fire, certain basic considerations must be recognized throughout the transit system.

Traction Power

Traction power, or the electrical energy needed to run trains, may be carried throughout the system by means of a third rail or overhead wiring and is typically a nominal 600 to 750 V dc. For modern transit systems with traction power provided by a third rail, a coverboard of electrical insulating material installed throughout the system prevents people from inadvertently coming in contact with the energized rail. The coverboard should be strong enough to hold a 250-lb (113-kg) weight applied at any point without deflection and should be supported so that a fire department ladder can rest against it safely. Warning signs should be affixed, as required, to the top of the coverboard in any area accessible to the public.

Disconnect switches should be located strategically throughout the system so traction power can be cut as quickly as possible under emergency conditions. Otherwise, alternate prompt and reliable means for disconnecting power should be provided.

Access/Egress to Stations

When determining required egress capacity, future occupancy needs must be considered. After a station has been constructed, it becomes very difficult, if not impossible, to place additional stairs or escalators where they best serve the public. Complying with required egress width may present major difficulty to designers. NFPA *101*®, *Life Safety Code*®, as modified by NFPA 130, *Standard for Fixed Guideway Transit Systems,* is a good source of guidance.

To establish required egress widths for any structure, it is first necessary to determine occupancy classification. For example, the State of California, other jurisdictions, and NFPA *101* determined that places where people await transportation should be classified as assembly occupancies. Effective June 1983, however, NFPA 130 established requirements for life and fire safety in transit stations, trainways, vehicles, and outdoor vehicle maintenance areas.

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The dynamic exiting concept in NFPA 130 determines occupancy based on estimated transit patronage waiting in stations and alighting from trains. NFPA 130 considers only those transit stations accommodating passengers and employees of the fixed guideway system and incidental occupancies. Where large numbers of people other than transit patrons are involved, such as where transit stations are incorporated into shopping malls, sports facilities, or other occupancies, NFPA *101* establishes egress requirements.

Because rapid transit systems are designed to move people rapidly, most new systems have installed escalators as the primary means to enter and exit stations. Escalators that are designed to be fully reversible, depending upon commute conditions, are acceptable as emergency exits. However, escalators should not account for more than half of the egress capacity from any one level.

When escalators are designed and accepted as required egress components, their usability in evacuating a station under emergency conditions must be seriously studied. For example, provisions must be made to stop all platform-bound escalators so that they can be used as stairs. Consideration also must be given to methods of stopping escalators so as to prevent injury to patrons. One possibility is to notify patrons, using a recorded public address announcement, which the fire alarm system may activate, stating that the escalator will stop within a specified period. This allows patrons to grasp the handrail and obtain a firm footing or may even alert patrons not to board escalators until they stop.

In many instances, escalators penetrate two or more floor levels to access the intended platform. This can pose special design problems because many designers prefer to maintain an open environment throughout a station complex. Vertical penetration of more than one floor without enclosures has been permitted in some rapid transit systems by increasing other fire protection components

Exit Barriers

Rapid transit stations contain two basic areas to separate those individuals who have paid their fare from those who have not. These are commonly referred to as "paid areas" and "free areas." Patrons in the free area can move directly to the outside without encountering barriers. Patrons within the paid area must go through fare barriers to access the free area. During emergency evacuation, either all fare barriers should open automatically, allowing patrons to evacuate the station rapidly, or specially designed access gates should be installed for the same purpose. With increased emphasis being directed to handicapped patrons, access gates become more useful in basic station design.

Procedures and methods that allow operators to quickly control or limit the number of patrons allowed into a station in the event of a delay or a malfunction are most important. A public address system that notifies and advises patrons during an emergency or a malfunction also is considered essential

Grilles or steel doors completely close off many stations after normal revenue hours. Installing small doors in the grilles can provide easy access for fire department personnel, as well as serve as an acceptable means of egress for any employees who may be working in he station.

Emergency Procedures

Due to the variety of hazards involved in a rapid transit system, local fire authorities must establish a direct line of communication with the system's top management. Good inspection techniques must be developed, and coordinated emergency response procedures planned. Access points to all parts of the system must be pinpointed, and engine and truck company response patterns tailored to meet special access problems. Information regarding the system, such as floor plans, electrification, vehicle design, structures, fire protection systems, and communications, is needed to plan emergency procedures properly. Specially developed map books, known as "Fire Maps," for fire department use may prove valuable. A wise course for a fire department is to assign one command officer the responsibility of coordinating all emergency activities required to protect against fires on rapid transit trains, on the right-of-way, and adjacent to the right-of-way.

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Communication also must extend in the other direction. Fires and other emergencies in adjacent properties may require modified transit operation. In downtown areas, fire suppression activities in nearby buildings can cause water drainage into subways, or flammable liquid spills can endanger below grade stations. Elevated structures may block fire department access to adjacent buildings.

The Transit Vehicle

The construction and use of the transit vehicle has become a fire and life safety problem. With a reasonable degree of attention, other elements of the transit system—guideway, stations, wayside equipment, and maintenanc facilities—can be designed with an acceptable level of fire protection. Construction materials and methods can provide a noncombustible, if not fire-resistive, profile. These elements are static, and many solutions for achieving a degree of fire resistance are already in use in related structures, such as buildings and bridges, and in support subsystems, such as elevators, escalators, and electrical and mechanical systems

Because of economic and comfort considerations, the modern vehicle has made extensive use of manufctured materials. The vehicle includes many attractive and serviceable plastics, such as foams, fibers, and other synthetic materials. These are often quite combustible and may emit toxic combustion products while burning. These problems are not unique to the fixed guideway transit vehicle. Combustible plastics are used in passenger compartments of other modes of transportation, including aircraft, buses, railroad trains, and the family car. However, the transit vehicles can accommodate several thousand people—far more than even a jumbo jet—and it therefore presents the potential for great loss of life.

Much attention must be focused on the materials and finishes of every item that goes into each transit vehicle including insulation for propulsion motors and other electrical wiring. The subway transit vehicle is the principal source of toxic smoke generated by, and fuel contributed to, a fire

Therefore, the transit vehicle is a primary concern in a fire and life safety program for a transit system Unfortunately, many existing fire test methods used to measure performance of materials in fire test conditions may be inadequate to predict actual fire performance. A guideline developed by the Federal Transit Administration (formerly Urban Mass Transit Administration) deals with the vehicle fire problem and recommends specific test methods and tests be used. It has been incorporated into NFPA 130 as Table 4-2-4. In addition, some transit systems have been able to use a so-called "Spartan" vehicle that has fewer combustible or toxic materials.

Considering all this, a complete fire risk assessment for new or renovated transit vehicles should be made and include fire propagation resistance, smoke emission, ease of ignition, and heat and smoke release rate. Vehicles' total combustible loading should be limited to as low a value as possible. For example, NFPA 130 advises that the combustible loading of the vehicle above the floor should not exceed 45,000 Btu/sq ft (511 mJ/m^2). Values as low as 30,000 Btu/sq ft (341 mJ/m^2) can be achieved. (See Appendix B-2.4.3. of NFPA 130.)

Newer individual test methods and appropriate use of test results are part of an overall fire safety effort. One test detailed in NFPA 253, *Standard Method of Test for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source,* provides a realistic test to evaluate flame spread on floor covering systems. Existing tests, such as those in NFPA 255, *Standard Method of Test of Surface Burning Characteristics of Building Materials;* NFPA 251, *Standard Method of Tests of Fire Endurance of Building Construction and Materials; NFPA 258, Standard Research Test Method for Determining Smoke Generation of Solid Materials;* ASTM E-162; ASTM E-84; and others also can be used if results are interpreted in relation to the transit environment. More appropriate tests are being developed to better predict the performance of materials when subjected to elevated temperatures especially with respect to the release of toxic products.

The difficulties of removing a person from the fire environment, particularly insubways, demands extreme care in evaluating materials for toxic hazard and their use in composite assemblies. To date, the use of test results related to smoke development and generalized statements on avoidance of "recognized" materials generating toxic products or

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combustion, have been the way to address this problem. The development and use of toxicity tests of material during fire exposure remains an unanswered need for transit safety

SUBWAYS

Fires within the confines of a subway system, especially those in trainways, are among the most difficult tc extinguish because fire fighters have limited room in which to operate. Access points for fire personnel, emergenc exit locations for passengers, availability of water supply, and ventilation capabilities are among the fundamental that must be considered in providing adequate safeguards for passengers and facilities for fire fighters coping witl emergencies.

A direct liaison between rapid transit authorities and fire officials is essential to keep emergency forces apprised o current conditions in underground installations. Floor plans of stations andsubways must be reviewed continually. Fire protection included in the original system design may have changed, thus requiring fire-fighting plans to bc updated.

Ventilation

Ventilation of underground subways is of primary importance. The removal of smoke under fire conditions must bc seriously studied. Several computer programs are available to model various smoke removal scenarios. Exitin schemes that allow passengers to exit rapidly into fresh air must also be developed. Some rapid transit systems hav installed fully reversible fans within vent shafts. They move large quantities of air by intake or exhaust and thu purge smoke from the subway in a predetermined direction so passengers can evacuate to the nearest station. Ventilation shafts and fans have been placed at each end of an underground station and, in some instances, betwee stations. When vertical shafts are included in the ventilation criteria, the possibility of flammable liquid spills entering the shaft at street level must be considered. Shafts should terminate in roadways only when absolutely n other alternative exists. Adequate sumps equipped with flammable vapor detectors must be developed to rtain such spills. Electrical equipment installed within shafts and fan rooms should meet local authorities' requirements fo expected fire exposure.

Access/Egress

Walkways: Primary consideration must be given to evacuation of large numbers of passengers to safety if a train i stopped between stations. "Safety" could be a station platform or direct access to the open air through vertica exitways. Many older, existing systems evacuate passengers by having them climb from the train to the trackway and then walk between the rails on crossties until they reach a vertical exit or station platform. In modern transi systems passengers evacuate the train to a walkway constructed alongside the trackway opposite the third-rail powe source. (See Figure 9-34A.) This lets passengers step directly from the train to the walkway, keeping them off th trackway and allowing specially equipped vehicles to respond to tain problems.

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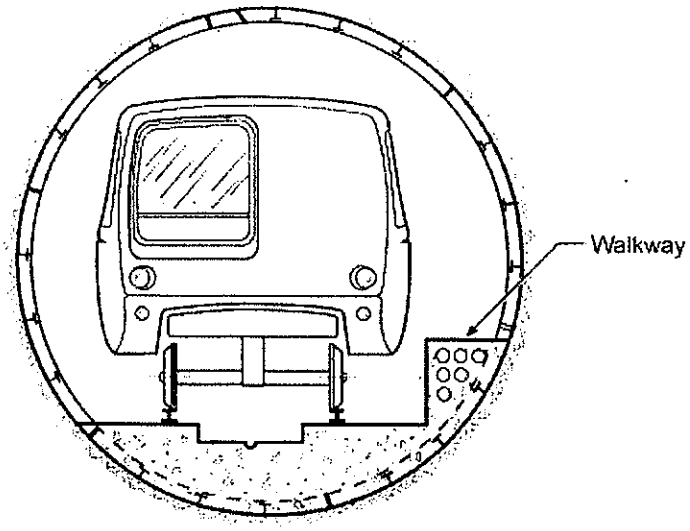

FIG. 9-34A. Sectional view of a single-tube subway tunnel, showing the location of the emergency passenger walkway to the floor of the car.

For trackways separated by concrete walls and fire doors, the walkway system also provides easy access to a train on the opposite trackway and an acceptable horizontal egress path that remains relatively free of smoke and heat (See Figure 9-34B.). Obviously, adequate emergency lighting must be provided to allow safe evacuation.

Tunnel or bore: Many rapid transit systems currently operate underground on trackways completely separated from each other by concrete walls and fire doors. (See Figure 9-34B.) As previously mentioned, this concept provides a refuge for passengers, as long as adequate train control and planning is practiced. Separation walls should have no less than a 2-hr fire-resistance rating, and openings in them should be protected by $1^1/_2$-hr fire doors. Cross-passageways between tunnels can be utilized in lieu of emergency exit stairways to the surface. Whenused, cross-passageways should not be more than 800 ft (244 m) apart. Hardware normally used in the installation of fire doors and frames has been found inadequate for the pressures generated by a train moving through the tunnel and for the damp environment found in tunnels. Special study and consideration must be given to the type of door, frame hinges, locking device, and method of securing the frame to the opening. Sliding fire doors with counterweight require special attention.

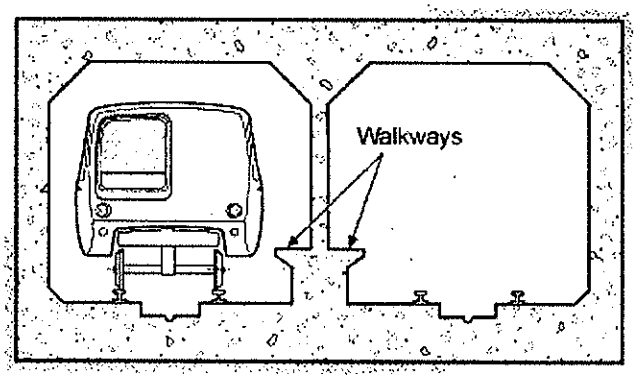

FIG. 9-34B. Sectional view of a subway tunnel having trackways separated from each other by a concrete wall. Openings through the wall, protected by fire doors, can provide an acceptable horizontal exit path from the trackway on which an accident has occurred to the other trackway, which remains relatively free of smoke and heat.

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Emergency egress: A number of factors must be considered to determine egress requirements from an underground subway system:

1. Train length.
2. Depth of trackway below grade.
3. Accessibility to exit at grade.
4. Accessibility to exit at trackway.
5. Time and distance needed for people to move to surfaces.
6. Available ventilation and controls.
7. Access to trackway for fire service.

Due to modern transit systems' ability to control smoke using sophisticated ventilation systems, and since unlimited numbers of vertical shafts are impractical, NFPA 130 allows emergency exit shafts to be placed so that maximum travel distance does not exceed 1,250 ft (381 m) in tunnels. The intent and basics of NFPA 101, as modified by NFPA 130, should be followed as closely as possible in designing exit stairs. Hatches can be used at the surface, if provisions prevent obstructions that would keep them from opening in an emergency

Many transit systems have created emergency exits by constructing conventional stairways in ventilation shafts. Unless the stairway is completely separated from the vent shaft by 2-hr fire-resistant construction and adequate control of air currents within the bore is maintained, this is extremely risky because smoke and heat may contaminate the vertical exitway.

Under no circumstances should required exitways contain straight, vertical ladders.

Internally illuminated exit signs with two power supply sources should be installed at the trackway level to direct passengers, and emergency lighting should be provided within the exit enclosure

Communication

Probably one of the most serious problems encountered during underground emergencies involves communications. Emergency telephones normally are identified throughout thesubway system by a distinctive light: in most systems blue lights designate emergency phone locations. Communication from the trackway directly to a central control room is accomplished merely by picking up the phone. Some systems use the Centrex principle for calls.

Blue light stations identifying the location of emergency tdephones also can serve multiple purposes. For example, on the Bay Area Rapid Transit (BART) System headquartered in Oakland, CA, stations include a third-rail or power-disconnect button, a maintenance jack, a 110-V outlet, and a 20-lb (9-kg) multipurposedry chemical portable extinguisher. Stations are spotted throughout the underground system at 1,000-ft (30-m) intervals or in line of sight, whichever is shorter.

Communication through a subway system is sometimes very difficult, particularly radio communcation. Many newer subway systems have installed equipment that lets fire department radios be used in subsurface stations and tunnels. Where this capability does not exist, fire authorities should make every effort to test their communications system under actual conditions throughout the subway system. Consideration should be given to using hard-wired communication systems that may already exist. Portable radios or emergency phones with a direct line to the transit system's central headquarters or to train radios are both useful. Every system should have a radio network providing two-way communication connecting personnel on trains and other vehicles anywhere in the system.

During emergencies, radio frequencies and telephone lines quickly become overwhelned. Portable hardwire telephones, dedicated to fire department use, should be available for point-to-point communications.

Fire Protection in Underground Trainways

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A principal fire protection device in fixed guideway transit systems is the standpipe hose system.NFPA 14, *Standard for the Installation of Standpipe and Hose Systems*, provides good guidance for installations, and Class I or Class III service should be specified.

Standpipes: Standpipes should be located in stations and throughout the underground trainway system. Standpipe in tunnels should be at least 4 in. (101.6 mm) in diameter or sized by hydraulic calculations and may be of the dry type. Generally speaking, local fire authorities determine locations of standpipe outlets, with consideration given t fire department access at tunnel level, available vertical access shafts for emergency forces, available street access to the fire department, and Siamese connections at grade level.

Some rapid transit systems require that dry standpipe outlets be no more than 200 ft (61 m) apart throughout th underground. Others have determined that maximum separation distances of 300, 400, and 500 ft (91, 122, and 152 m) are acceptable.

Some rapid transit systems place bins or boxes containing $2^1/_2$-in. (64-mm) hose near dry standpipe outlets anc leave inspection and testing of such hose to rapid transit system personnel. Fire authorities operating under this principle should seriously consider assigning personnel to witness hose inspections and required waterflow testing Other transit systems and fire departments have agreed to only place hose and appliances in lockers at the base of access shafts. In areas where local fire authorities wish to use only their own hose, provisions must be made t transport hose and other equipment to a fire site or to store necessary equipment in tunnels and stations.

Special apparatus: In lieu of supplying the fire hose required at standpipe stations, some systems have taker innovative measures to ensure that hose is available when needed. BART, for example, with approval of fir authorities, removed all fire hose from its subway system, except the $1^1/_2$-in. (38-mm) hose located within stations. In turn, BART agreed to furnish five fully-equipped, specially-designed fire engines capable of traveling by street o rail to previously designated rendezvous points. The responding fire department then boards he apparatus and goes to the fire or emergency location within the underground. Each piece of apparatus includes, as part of its inventory 1,200 ft (366 m) of $2^1/_2$-in. (64-mm) hose and 400 ft (122 m) of $1^1/_2$-in. (38-mm) hose, as well as nozzles, a portable emergency generator, a power saw, a cutting torch, extension cords, flood lights, demand breathing apparatus, life lines, miscellaneous tools, a high-expansion foam unit and nozzle, a 300-gal (1136-L) water tank, an a small pressure pump.

A more practical solution is manual pushcarts designed to run on rails and stored in stations. These carts range from small commercially available maintenance carts to specially designed folding multilevel carts constructed using ligh weight alloys.

Fire department operational plans: Fire departments that respond to emergencies in underground systems must b extremely familiar with the layout, access, exit, communications, ventilation, and other special factors that must b part of an operational plan for both the fire department and the transit system. Such plans must be reviewed anc practiced regularly, and all fire department members and system employees must be trained to respond appropriatel to underground incidents.

Every fire fighter entering an underground system to fight a fire must have self-contained breathing apparatus (SCBA) to meet the requirements of NFPA 1500, *Standard on Fire Department Occupational Safety and Health Program*. One challenge facing the fire department is how to maintain an adequate supply of replacement air cylinders for members working below grade level. This may require long-duration breathing apparatus and trucks t refill or deliver quantities of SCBA air cylinders.

Fire extinguishers: Fire extinguishers should be placed on board each vehicle. In addition, fire extinguishers should be placed near fixed equipment throughout the underground system where ignition sources and/or combustible exist. Locations should include electrical equipment, sumps, ventilation equipment, and so on. If th blue light or the

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Jurisdiction.

Deluge systems: Train fires may start in under-car equipment, and train operators are instructed to take trains with fires onboard to stations for passenger evacuation. When possible, many newer systems have opted for under-car deluge systems. These systems consist of fixed piping connected to a water supply, with open sprinklers located between rails. They are activated manually from the station attendant's booth or at the ends of the platform

Over-car deluge systems are designed to create a water curtain between a burning train and the platform. They can be activated automatically by heat detectors in the trainway or manually as described above. Examples of both types of deluge installations are found in the Baltimore Metro System

Emergency communications: Subway stations typically do not have traditional fire alarm systems with pull stations and bells. Instead, the public address system alerts and directs passengers in the event of an emergency. Passengers can report emergencies through emergency voice alarm reporting devices located on the platform and throughout the station. Emergency communication systems should conform toNFPA 72B, *National Fire Alarm Code.*

Fire detection systems: All nonpublic areas commonly classified as support or ancillary areas, if not protected by an automatic fire suppression system, should be fully protected by a fire detection system conforming toNFPA 72. Listed smoke detectors are preferable, although rate-of-rise heat detectors may be used if authorized by the fire authority.

It is good practice to provide supervision for all fire detection and automatic fire suppression systems. Supervisory signals should be received at the system's command center and annunciated by zone at the station agent's booth or kiosk.

Wet standpipes: Where separate standpipe and automatic sprinkler systems are provided, wet standpipes usually are supplied by a piping system that is separate and distinct from that used for automatic sprinkler systems. Fire department Siamese connections, properly labeled and installed at grade level, let the fire department supply additional water to either system.

Fire hose cabinets may contain $1^1/_2$-in. (38-mm) and $2^1/_2$-in. (64-mm) control valves, as recommended inNFPA 14, *Standard for the Installation of Standpipe and Hose Systems.* A maximum of 100 ft (30 m) of attached $1^1/_2$-in. (38-mm) hose with nozzle and/or $2^1/_2$-in. (64-mm) hose and a spanner wrench may be stored in cabinets for use by the fire department at the discretion of the local Authority Having Jurisdiction. A suitable portable fire extinguisher may also be placed in the cabinet. To reduce pilferage of fire equipment, cabinets should be locked and a breakaway glass panel installed to allow ready access under emergency conditions. Some rapid transit systems have installed intrusion alarms, which send a signal to the station agent if a fire hose cabinet has been opened.

SURFACE OR ABOVEGROUND GUIDEWAYS AND STATIONS

Generally, combatting fires in transit systems at or above grade is no more difficult than fighting any other type of fire at grade. Primary consideration always must be given to the traction power. Even when assured that the power has been shut off, fire department personnel should operate under the assumption that the third rail or overhead wire is still energized.

For fires in trains on surface track or aerial guideways design must address certain basic consderations, such as means of escape from elevated trainways. As in all other rapid transit configurations, communication is paramount in any emergency operation. The ability to direct emergency forces to the scene of an incident and to place the system in a safe condition for access is necessary for patrons and emergency personnel

Access to a trainway also may require special provisions. Locating trainways in a joint corridor with a railroad or

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emergency station is suitably located, one or the other would be a preferred place for extinguishers. The size and type of exposure expected dictates the extinguisher's size and type

Drainage: Adequate drainage of water accumulated during a fire requires careful consideration. Fire authorities should be made aware of the underground system's drainage capabilities and recognize that large amounts of water could seriously impair other required rescue operations. When fighting structural fires at street level near station entrances or street ventilation grills, fire officers should alert rapid transit officials that water intrusion into their system may be expected and take steps to prevent water intrusion using tarps.

Stations

Underground rapid transit stations should be constructed of minimum approved noncombustible materials—that is Type I, Type II, or combinations thereof—as outlined in NFPA 220, *Standard on Types of Building Construction.* Many modern rapid transit systems use reinforced concrete construction for the station's outer shell and protected steel beams, girders, and columns within the shell. This results in a structure with a substantial fire-resistive capability.

A rare fire of major proportion within a subway station was the King's Cross Station fire, which occurred in London England, on November 18, 1987. Thirty patrons and one fire fighter were killed in that fire. Station fire hazards include poor housekeeping and electrical fires in escalator machine rooms. The primary fire hazards in underground stations are concessions and trains. Small concessions that sell newspapers and magazines normally have a low-hazard classification, while major concessions, such as restaurants or theaters, have a high hazard classification for smoke and heat development.

Newspaper and magazine concessions should be limited in size and must not block required egress routes. Automatic sprinkler protection should be installed to protect the entire concession area. Possible future expansion of the area should be considered in designing the fire protection system

Station public areas should be separated from nontransit areas with a fire barrier having at least a 3-hr fire rating Major concessions or openings from public areas of the station into existing commercial structures should be protected by fire door assemblies having a 3-hr fire protection rating. Even if the rapid transit system owns the commercial activity and the station, good separation between the two areas is needed. Fire barriers can be established by installing fire doors or automatic fire extinguishing systems to prevent fire and smoke spread from the commercial occupancy into the station or from the station into the commercial occupancy. Before making any opening into a rapid transit system, existing conditions on both sides of the proposed opening must be reviewed carefully so an effective fire protection plan can be developed.

Protection for Underground Stations

An underground rapid transit station may be compared to a multiple-basement structure, except that a rapid transit station generally has a low fire-loading factor when compared to a commercial basement. Strict application of building or fire code requirements may cause exceptionally high and not necessarily justified construction costs. If minimal combustible storage or concession areas are involved, large, open public areas may be left with little or no risk of fire involvement. If such is the case, limiting automatic fire protection systems to those areas containing combustibles and designing the systems for possible expansion may have some merit, although the limitations of partial protection must be clearly understood.

Automatic sprinkler systems: All areas in transit stations that are used for concessions, storage, and fare collection, including other similar areas with combustible loadings, as well as the steel truss area of all escalators in a single-entry station should be protected by automatic sprinklers equipped with flow alarms and supervision Trainways are excluded. NFPA 13, *Standard for the Installation of Sprinkler Systems*, should be used for guidance. Other approved fire extinguishing systems, such as cleanagent extinquishng systems in train control rooms, could also be used in lieu of the automatic sprinkler system, but only with the approval of the Authority Having

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freeway may limit access for long distances of the trainway. Tainways extending from population centers throug undeveloped areas sometimes extend where surface roads and water mains do not exist. Trainways in congeste areas, trainways elevated to unusual heights, and trainways in other sections not accessible to emergency vehicles or paramedic units, could create other problems. Trainway construction also may cause problems of fire exposure an access to adjacent structures. For example, an elevated trainway above existing city streets and adjacent to existin buildings may interfere with fire department operations at those buildings

Similar problems may exist at stations. However, permanent exits provide both patron evacuation and emergenc personnel access. Recent systems have incorporated stations in the lower eevations of high-rise buildings or withir mall complexes that have divergent occupancies. In these cases, detailed plans for coordination and compatibl design are necessary.

Stations that can be considered to be buildings would normally be reviewed through normal code procedures. If a transit system passes through more than one jurisdiction, particularly if different basic codes apply, development of a common set of requirements is desirable to achieve uniformity throughout the system

Most existing building codes do not usually address the subject of trainways. The exception isNFPA *101,* which does deal with such facilities. Items that should be considered during a plan review of a guideway include

1. Designated mileage markers to provide a response location for fire personnel.
2. Locations where overhead trainways may intersect with known street locations
3. Access gates allowing patrons to exit the system under fire department direction
4. Available wayside communications allowing the fire department to communicate directly with the system's command center.
5. Locations of substations, switching stations, gap breaker stations, or other major electrical installations o concern to local fire authorities.

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NFPA 13, *Standard for the Installation of Sprinkler Systems*
NFPA 14, *Standard for the Installation of Standpipe and Hose Systems*
NFPA 30, *Flammable and Combustible Liquids Code*
NFPA 72, *National Fire Alarm Code*
NFPA *101L, Life Safety CodeL*
NFPA 130, *Standard for Fixed Guideway Transit Systems*
NFPA 220, *Standard on Types of Building Construction*
NFPA 251, *Standard Method of Tests of Fire Endurance of Building Construction and Materials*
NFPA 253, *Standard Method of Test for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source*
NFPA 255, *Standard Method of Test of Surface Burning Characteristics of Building Materials*
NFPA 258, *Standard Research Test Method for Determining Smoke Generation of Solid Materials*
NFPA 259, *Standard Test Method for Potential Heat of Building Materials*
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ROAD TUNNEL FIRE SAFETY

Issues regarding fire prevention and mitigation systems are intensified when it comes to the unique subterranean spaces of tunnels.

Pam Weiger

Call it an awakening. When a passing motorist hit a truck loaded with 80 drums of carbon disulfide inside the New Jersey end of the Holland Tunnel 51 years ago, the ensuing fire ignited real concern among tunnel experts about the dangers lurking inside the nation's more than 100 underground vehicular tubes. Today, the number of tunnels worldwide has grown significantly. Yet only one other major incident—California's Caldecott Tunnel fire in 1982—has occurred in the United States.

its report *Prevention and Control of Highway Tunnel Fires*, the Federal Highway Administration (FHWA) defines a major tunnel fire as a hazardous materials fire inside a tunnel with an intensity of 100 MW or more, 341 million Btu/hour. The report, which was published in 1983, identified four major hazardous material fires in tunnels in the preceding 50 years, including the Holland Tunnel and Caldecott Tunnel fires. Since that time, several others have been reported, including the Mont Blanc Tunnel fire, which occurred on March 24, 1999 between France and Italy, and the May 29, 1999 Alpine tunnel fire in Austria. Thirty-nine lives were lost in the Mont Blanc Tunnel fire.

According to the FHWA report, the Caldecott Tunnel fire occurred in Oakland, California, on April 7, 1982 when an empty bus collided with a full gasoline truck, rupturing the gas tank and spilling the fuel, which ignited. Seven people died, including the bus driver, and two people were hospitalized for smoke inhalation. Six vehicles in the tunnel were destroyed, as were most of the tunnel support systems, including lighting, emergency phones, signs, alarms, and wiring. Repair costs were estimated at more than $3 million, according to a report the Oakland Fire Department submitted to the National Transportation Safety Board.

While that incident may have been the last major tunnel fire in the U.S., there have been many smaller tunnel emergencies over the years.

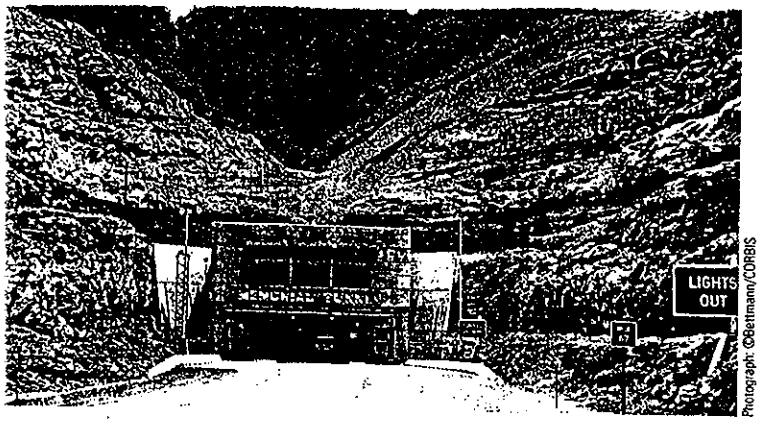
Fire prevention and mitigation systems

When it comes to the "systems" for preventing and mitigating fire in the unique, enclosed space of a tunnel, the differences between subterranean environments and other environments are so vast there's no straightforward comparison between them. Communication, egress, ventilation, drainage, water supply, and traffic control issues are all exacerbated when moved underground or under water.

The United States has been spared the type of major tunnel fires that have hit other parts of the world. For example, a truck carrying 14 tons of polyethylene caught fire in West Germany's Moorfleet Tunnel in 1969. And 7 people were killed and 173 vehicles were destroyed in a 1979 fire in Japan's Nihonzaka Tunnel Shizuoka Prefecture, near Yaizu City, Japan, when four large trucks and two automobiles collided three-fourths of the way into the tunnel.

American tunnels and their European counterparts

Tunnels in the United States aren't as long as their European counterparts. For example, the Mont Blanc Tunnel is 7 miles (11 kilometers) long. Nor are U.S. tunnels typically single-bore tunnels in which traffic moves in both directions. American tunnels generally don't have two companies operating independently of each other running one tunnel, either. While there are guidelines in Europe, there are no standards in place for tunnel construction.



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West Virginia Turnpike northern entrance to Memorial Tunnel.

The fire that burned for three days in March 1999 in the Mont Blanc Tunnel occurred in a single-bore, two-lane tunnel connecting France and Italy. The fire began in a refrigerated truck carrying a seemingly innocuous cargo of flour and margarine. The tunnel relied on a 30-year-old, full-transverse ventilation system that failed to protect those trapped inside, killing 39 people as the heat and smoke intensified. The ventilation was administered by separate systems on each end of the tunnel, one controlled by Italian operators and the other by French operators, neither of whom could control the actions of the other.

"We had to call the control room on the Italian side, wait for their ..n, and then call the control room on the French side," says Lt. Col. Jean-Guy Laurent of the French fire service, who took over command of French, Italian, and Swiss firefighters two hours into the fire. Before the incident, he says, fire officials looked at the ventilation system but were never allowed to test it or conduct simulated emergency exercises inside the tunnel.

Internal communication was a problem, as well. The fire was so intense that it burned the asphalt housing the cable designed to transmit portable radio signals among fire personnel inside the tunnel. Because the truck was halfway into the tunnel when it burst into flames, it burned for more than five minutes before firefighters could reach it. That, says Laurent, was the greatest lesson learned.

"You have to get to the fire within the first five minutes, or it'll be too hot by the time you reach it," he says. As a result, they're putting a fire station in the middle of the tunnel to cut future response times.

The Mont Blanc Tunnel has 8,202 feet (2,500 meters) of mountain above it. The fact that the Holland Tunnel didn't may have helped prevent fatalities in the 1949 fire. While 66 people were injured, no ...ed in the New York tunnel because of what a follow-up report called "an unusually fortunate set of circumstances."

Phil Egilsrud, a mechanical engineer specializing in tunnel design, saw the smoke from his office at the Port Authority of New York and New Jersey, which owned the Holland Tunnel.

"The fire was so intense that the ceiling above the truck collapsed, and the exhaust duct drew out the smoke at the point of the fire," he remembers. "That was my idea for subsequent tunnel design—to put dampers in the ceiling every 300 feet (91 meters) or so that could be opened when sensors detect a fire underneath them. But that idea never caught on."

As the project manager for the Mt. Baker Ridge and the Mercer Island Tunnels in Seattle and the I-10 tunnel in Phoenix, Egilsrud saw few changes in the industry before he retired in 1992 after completing design work on the Ted Williams Tunnel in Boston.

"There was more concern about fire and building wider tunnels," he says, "but basically things stayed the same as far as ventilation went."

Today, however, the technology is rapidly changing. Boston's Central Artery/Tunnel project, of which the Williams Tunnel is a part, is building 7½ (12 kilometers) miles of highway, about half of which will be underground. Scheduled for completion in December 2004, the underground highway will eventually carry an estimated 245,000 vehicles a day through 3½ miles (6 kilometers) of tunnel, the longest section of which will be about 2.7 miles (4.3 kilometers) long. Its deepest point will be 120 feet (36 meters) below street level.

Boston's new tunnels will have a state-of-the art ventilation system that includes seven ventilation buildings, making it the largest road tunnel ventilation system in the world. The project is one of the first to benefit from the results of the Memorial Tunnel Fire Ventilation Test Program, conducted by the FHWA in cooperation with the Massachusetts Highway Department and the West Virginia Department of Transportation in an abandoned road tunnel in West Virginia.

Memorial Tunnel fire ventilation test program

The tunnel near Standard, West Virginia, was an active, two-lane tunnel for 34 years before road realignment made it obsolete in 1987. In 1993, it was converted into a sophisticated fire ventilation laboratory with temperature sensors, video cameras, and velocity probes to study the behavior of smoke and heat under various ventilation systems.

Testing for the Memorial Tunnel program included six different types of ventilation systems: full transverse, which introduces air at the roadway level and extracts vitiated air at the ceiling throughout the tunnel; partial transverse and partial transverse with single-point extraction or oversized single-extraction ports, which place large ports over the fire area; longitudinal ventilation with jet fans, which are used in many European and Asian tunnels but aren't widespread in the United States; and natural ventilation, which uses natural airflow. Infernos as intense as 100 MW gasoline fires—equivalent to a flammable fuel spill of 200 gallons (757 liters)—were set to learn more about the movement of smoke and the speed at which it travels.

The tests showed that dilution, without some means of extraction, wasn't a very effective means of ventilation. One of the major findings from the tests also validated longitudinal ventilation systems, or jet fans, for use in the United States.

"We didn't know if the fans would be strong enough," says Anthony Caserta, a tunnel engineer with the FHWA who participated in the testing. "But even if we lost a fan right under the fire, we found that fans behind it would be able to prevent backlayering."

The new information was put to use in construction of the Bobby Hopper Tunnel in Arkansas. The Central Artery/Tunnel project was already underway before the test results were in, but the new knowledge allowed the installation of jet fans on exit ramps in the Boston tunnels.

Phase Four of the Memorial Tunnel program involves a computerized computation fluid dynamics model, due out this summer. Using this model, tunnel engineers will be able to enter data about a certain tunnel and ventilation system, start a computerized fire in the tunnel, simulate the operation of the fans, and see how smoke and heat develop in a particular scenario, including the length of time it takes to reach a "safe" condition. The model will be applicable to existing tunnels, as well as those in the planning and design phase.

With construction on the Central Artery/Tunnel project about two-thirds complete, the latest advances in control and monitoring techniques are being implemented. Safety features will include 400 video cameras, 130 electronic message signs, 30 infrared height detectors, and 6 emergency response stations operating around the clock.

Egress issues

One of the primary concerns involving tunnels is evacuation. In the subterranean world, escape becomes a critical issue.

"Exits are the most significant factor," says Boston Fire Department Deputy Chief John Kenney, who oversees the department's special projects division, which includes technical rescue personnel dealing with tunnels, trench collapse, and confined space rescues. He's been his department's liaison with the Central Artery project for the past 3½ years and currently serves on the NFPA Technical Committee responsible for NFPA 502, *Limited Access Highways, Tunnels, Bridges, Elevated Roadways, and Air Right Structures*, which allowed adjacent tunnel tubes to serve as a temporary refuge during a fire.

The cross passages between tubes will work here, as long as they're properly marked and maintained, and the doors are kept shut," says Kenney.

He hopes to see the language in NFPA 502 strengthened "after we saw that refuges were a problem in Mont Blanc because the fire burned much longer than anticipated, and people died." The tubes in Boston are being separated by two-hour fire walls.

The proposal phase for NFPA 502 has just been completed, and the committee will send them out for public comment in August. The next edition of the standard is due out in the Fall of 2001.

Communication among fire personnel in tunnels is an issue in this country as it was in Mont Blanc. Radio signals are often unreliable underneath tons of earth. In Boston, "leaky cables" are run with repeaters through all tunnels so communication remains constant not only during emergencies, but also when fire units are driving through the tunnels in response to other calls for help.

Meanwhile, newer, longer tunnels are being proposed and built every day. The largest submerged tunnel in the world in terms of length is scheduled to open this year between Sweden and Denmark. The 11,483-foot (3,500-meter) Oresund Fixed Link consists of two lanes of rail traffic and two double-lane tubes of road traffic. And construction is currently underway in Norway on a 15-mile (24.5-kilometer) roadway linking the country's two main cities, Oslo and Bergen. The tunnel will be 50 percent longer than the St. Gotthard Tunnel in Switzerland, currently the longest road tunnel in operation, and the longest in the world through mountains.

One of the biggest fears among emergency personnel who must respond to tunnel fires still remains a problem after 50 years: illegal hazardous cargo, which was the cause of the Holland Tunnel fire. While dangerous materials are outlawed in many tunnels, including the Holland Tunnel, there's always the chance that an unmarked truck will violate the law. A spot-check of 6,000 trucks entering the Holland Tunnel a few days after the 1949 fire found more than 100 vehicles in violation of the existing safety regulations.[1] To combat this uncontrollable element, standards of construction and operation are constantly being updated and modified, so that when the unthinkable happens, top-notch systems and people will be in place to handle it.

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References:

1. "The Holland Tunnel Chemical Fire, New Jersey—New York, May 13, 1949," report by the National Board of Fire Underwriters, W.E. Mallalieu, General Manager, New York, 1949.

NFPA 502 – 2001 Edition

The Technical Committee for NFPA 502, *Limited Access Highways, Tunnels, Bridges, Elevated Roadways, and Air Right Structures*, is now processing a revision to the 1998 edition, which will be published in the Fall of 2001. The Technical Committee has completed the Report on Proposal stage of the revision, and the official committee report will be available on the NFPA web site later this summer. The Technical Committee is now in the process of addressing several technical issues, including:

- **Fire detection criteria**
- **Tunnel length criteria**
- **Emergency egress criteria**
- **Revision of Appendix D to address fire sprinklers in road tunnels**

Anyone interested in submitting comments to the proposed changes should visit the NFPA web site at www.nfpa.org to view the Technical Committee's Report on Proposals. Any technical questions relating to NFPA 502 can be submitted to NFPA 502 staff liaison Christian Dubay at cdubay@nfpa.org.



THE SINGAPORE FIRE CODE AND M & E CODE OF PRACTICE

1. The Fire Code and relevant PSB's Codes of Practice and Specifications.

1.1 While the Fire Safety Act and Regulations provide the overall legislative framework of control, the standard of fire protection and technical requirements for fire safety measures are indeed prescribed primarily in the Code of Practice for fire Precaution in Buildings, 1997 (commonly known as the Fire Code).

1.2 The current Fire Code categorises buildings into eight main purpose groups. They are:

Group 1: Small residential
Group 2: Other residential
Group 3: Institutional
Group 4: Office
Group 5: Shop
Group 6: Factory
Group 7: Places of public resort including hotels
Group 8: Storage

As the anticipated fire risk of each purpose group differs, so too the provisions for fire safety measures. For example, in the case of small residential where both the occupant load and fire risk are low, the fire safety measures required are minimal. On the higher end, the fire code calls for a whole host of fire safety facilities in the design of high-rise commercial or industrial buildings involving large occupancies, public access, and high fire risk due to activities or storage.

1.3 The first official fire code was published in 1974, after the 1972 Robinson fire. It was formulated by Building Control Division which was then the fire authority, with inputs from the Singapore Fire Brigade. The code put together the relevant sections from the Fire Brigade's appendices and some foreign codes such as the Greater London Council's guidelines, the Uniform Building Code of Canada and the National Fire Protection Association codes. It had served both practising professionals and the authorities fairly well by setting common standards and directions.

1.4 The 1974 fire code was subsequently reviewed to improve the provisions through experience gained in the course of implementing the code and the practical problems faced by the professional and fire fighters, resulting in the publication of the revised code in 1982. The Fire Safety Bureau was formed in 1985 and in 1987 initiated a complete review and updating of the 1982 code. In this review; chaired by FSB, alongside other government departments, professionals from various bodies participated actively to produce a more user-friendly code incorporating new feature to keep pace with building design trend and upgrading of fire technology. The fruit of their joint effort was the 1991 Fire Code, released in November 1991 and made enforceable on 1st May 1992. This Fire Code had been under continuous and constant reviews to take into consideration of new building design trend and upgrading of fire technology. On 26th September 1997, a new Fire Code 1997 was released. This new Fire Code had been enforced since 2nd January 1998. A series of Fire Code Handbook were also published to provide detail explanation and informative illustration to facilitate interpretation of the clauses.

1.5 In the Fire Code, appropriate fire safety measures are directed at reducing the risk of fire breaking out, restricting the spread of fire through fire compartmentation, protecting the building from external fire risk, providing early detection of fire and alarming the occupants, ensuring means of escape and site access, and suppressing the fire by means of automatic fire sprinkler system for tall or large non-residential buildings.

1.6 The Fire Code also makes general reference to overseas standard (for example, British Standard) for fire test requirements and the various PSB Codes of Practice particularly for the design of different M&E fire safety systems.

1.7 The relevant PSB Codes of Practice are compiled as follows:-

a. SS CP 2 - Code of Practice for installation, operational and maintenance of Electric passenger and goods lifts.
Among the fire precaution requirements contained in this code are special provisions requiring all lifts to be equipped with a Emergency Battery Operated Supply, passenger lifts in public buildings to automatically homed upon fire alarm or power failure. Operation of fire lift is also covered.

b. SS CP 10 - Code Of Practice for the installation and servicing of electrical fire alarm systems.
The code was first published in 1980 and was drastically revised in 1993. the new code, which carries new safety features and incorporates the use of addressable fire alarm system, has come into operation from 1st February 1994.

c. SS CP 13- Code of Practice for mechanical ventilation and air conditioning in buildings.
The code prescribes safeguards intended to restrict the spread of fire and smoke through air duct systems, maintain integrity of fire compartmentation affected by duct installations and for smoke control such as pressurization and smoke extraction system.

d. SS CP 19 - Code of Practice for the installation and maintenance of emergency evacuation lighting and power supply systems in buildings.
This code provides technical requirements for the provision of an electrical emergency lighting system for the safe and ready evacuation of occupants in a building experiencing power failure, including in a fire emergency situation.

e. SS CP 25 - Code of Practice for emergency voice communication system in buildings.
The code contains guidelines for a built-in system of internal communication (whether one-way or two-way) within buildings dedicated for use in a fire or other emergency.

f. SS CP 29 - Code of Practice of fire hydrant systems and hosereels.
The code encompassed the requirements for the design,installation, testing and maintenance of fire hydrants, dry and wet rising mains and hosereel systems in building for manual fire fighting by fire fighter or occupants (hosereel only).

g. SS CP 31 - Code of practice for installation, operation, maintenance, performance and constructional requirements of mains failure standby generator systems.
The code gives recommendations to ensure power supply is available to support continuous operations of life safety system and fire protection appliances.

h. SS CP 45 - Code of Practice for halon 1301 fire protection system.
This code establishes uniformity in halon 1301 engineering practice with emphasis on system reliability and fire safety. Its usage has been rescinded since 1994 due to the government ban on new halon 1301 system.

i. SS CP 52 - Code of practice for automatic fire sprinkler system.
The code provides comprehensive design standard for effective automatic suppression of fire by means of water discharges from sprinkler for various hazard groups.

j. SS CP 55 - Code of Practice for the use and maintenance of portable fire extinguishers. The code covers the selection, installation, inspection, testing and maintenance of portable fire extinguishers.

k. SS 332 - Specification for fire doors.
This specification covers configuration and testing standard for various fire doors.

l. SS 232 - Specification for fire extinguishers.
This specification provides details of construction of fire extinguishers using different extinguishing medium and their test methods.

m. SS 333 - Specification for fire dampers.
This specification dictates the material used in constructing fire damper and its various components, and the fire test standards.

1.8 The Fire Code 1997 also made reference to BR 186 and BR 258 for Atrium Smoke Control System and Engineered Smoke Control System.

a. BR 186 – Design Principles for Smoke Ventilation in Enclosed Shopping Centre.

b. BR 258 – Design Approaches for Smoke Control in Atrium Building.

1.9 Some overseas Standards have been accepted by the authority for design of specific systems. The examples are given as following;

a. NFPA 130 - Standard for Fixed Guideway Transit and Passenger Rail Systems.

b. NFPA 750 – Standard on Water Mist Fire Protectin Systems.

c. NFPA 2001 – Standard for Clean Agent Fire Extinguishing Systems.

d. NFPA 502 - Standard for Fire Safety of Road tunnels.

2. Technical Fire Safety Requirements

2.1 Element of Structure

a. Elements of structure include structural frame, loadbearing wall, floor, external wall, compartment wall, separation wall and structure enclosing a protected shaft.

b. Elements of structure shall have fire resistance ranging from ½ hour (for most single-storey building only) to 4 hour (for high-rise building with warehouse usage or for basement of shop, factory and warehouse).

c. For high-rise office or hotel building, the fire resistance period required is 1½ hour.

d. Notional fire resistance periods (FRP) for masonry structure are given in the Fire Code. For example, brick wall (load bearing or non load bearing) of 100mm thickness would have a FRP of 2 hours, a reinforcement concrete slab of 150mm thick with 25mm cover to reinforcement could achieve a FRP of 4 hours.

e. Steel structures has nil fire resistance periods and require passive fire protection such as concrete encasement, fire rated cladding or spray-on with vermiculite materials or approved intumescent paint.

2.2 Means of Escape

a. Generally each floor shall have at least 2 protected exits, remotely located. Stair shall be enclosed in protected shaft.

b. Spacing of the stair shall be such that the distance from the most remote point of floor to the exit door shall not exceed 15m (if there is only one escape direction) of 45m where there are 2 independent routes. In the case of sprinkler protected building, the distance are increased to 30m and 75m for one way and two way escape respectively for office and to 25m/ 60m for shop. For building with higher fire hazard or with sleeping usage, (such as hotel and hospital) the required distances are shorter.

Please refer to table 2.2A of the Fire Code for details.

c. Width of the stair is dependent on the number of occupation calculated basing on occupancy rate published in the fire code. The floor having the highest occupant load would determine the width of stair required.

d. Dead end corridor should be minimized in the design of floor layout, maximum distance shall not exceed 13m.

e. For building exceeding 4 storey escape to exit staircase shall not be direct but through ventilated smoke-stop lobby or external corridor.

f. For building with more than 4 basement storeys, escape to exist staircase shall also be through ventilated smoke stop lobby.

g. Door to exit staircase or smoke stop lobby shall have a minimum FRP of ½ hour or half rating of the element of structure, whichever is the higher.

h. Exit door shall be identified by illuminated exit sign. Escape routes essential rooms and large occupied areas shall have artificial lighting, equipped with emergency power supply from either battery pack, UPS or standby generator.

2.3 Fire compartmentation

a. For building below 24m, compartments shall not exceed 3 storeys with each compartment's size not larger than 3800m^2 in area or 14200m^3 in cubic content. For floor below pavement or on a level higher than 24m, compartment shall not comprise more than one storey subject to a maximum floor area of 1900m^2 or a maximum cubicle extent of 7100m^3. This fire compartmentation requirement may be waived if the building is sprinkler protected.

b. Special purpose rooms such as kitchen, air-conditioning plantroom, switch room transformer room, fire command center, generator room, fire pump room, lift motor room, large store and etc. where the rooms either contain higher fire hazard than ordinary occupancy or are used to house important fire fighting facility shall be fire compartmentalized. The FRPs varies from 1 hour to 4 hours depending on the associated hazard. Protected shafts containing staircase, lift, electrical services and pipe risers are also fire compartments.

c. Door openings in the compartments shall be protected by fire doors or fire shutters. For opening due to penetration of ventilation or air-conditioning duct, fire dampers shall be installed to maintain integrity of the compartments. However, in the case where the openings are penetrated by smoke extract ducts, kitchen exhaust ducts or ventilation ducts which are used for smoke extraction purpose, fire dampers are not permitted. Fire rated duct shall be provided in lieu. Other openings in the compartment wall and floor carried by cable and pipe penetrations shall also be effectively fire stopped.

d. In hotel development, each guest room shall be compartmented from adjoining rooms and corridor by 1 hour FRP. Door to each guest room shall be fire door.

2.4 Electrical Fire Alarm System – SS CP 10

a. Except residential buildings, almost all other developments need to provide some form of fire alarm to warn occupant of any fire alarm, pinpoint the area where fire is detected and perform functions such as transmitting fire signal to fire brigade, initiating system shut down, starting-up smoke extraction systems, bringing lifts to ground floor and others. Please see attached table extracted from the Fire Code1997 for the required fire alarm system for different type of buildings.

b. Broadly speaking, electrical fire alarm system can be classified under manual or automatic type. In a manual system fire alarm can only be activated manually by striking the alarm call point. Whereas, in automatic fire alarm system, detectors, flow switches and other devices are installed to automatically raise a fire alarm when there is a change in room temperature (heat detector), smoke in the space (smoke detector) or water flow in the sprinkler pipe (flow switch). Important signal such as running of electrical fans, fire pumps and etc. can also be wired and registered in the main alarm panel.

c. Where a building is required to be installed with an automatic fire alarm system, the fire alarm system shall be connected to a fire station through an approved alarm monitoring station (i.e. DECAM). Similarly, for buildings used as health care occupancy, hotel, oil refinery, oil depot, general warehouse, chemical plant, theatre, cinema, concert hall or high hazard factory/premises shall be connected to DECAM. The intent is to transmit the fire alarm signal from the building automatically to fire station so that fire engines could be dispatched to the building almost immediately without delay.

d. System wise, fire alarm system can be 'conventional' type involving laying of hard wires between the main alarm panel and all field devices, or the 'intelligent' micro-processor type using electrical pulse to scan the alarm circuit and reflect abnormal conditions. However, all fire alarm system is equipped with battery and charger so that the system can remain operational for a period of time even during a total power failure. Furthermore, each system is incorporated with features to supervise the line status against any open, or short circuit due to malfunction or removal of field device or cutting of alarm or bell wiring.

e. Fire Code 1997 stipulated that for a building of mixed commercial cum residential use, the upper storeys of the building shall be provided with manual fire alarm system. However, if the habitable height of the building does not exceed 24 metres, only alarm bell needs to be extended to the common area of each residential floor. In the case where the residential developments (irrespective of the height of the building) are located over car park, alarm bells shall be extended to the common area of each residential floor. The purpose is to alert residents should there be a fire in the lower floor with commercial usage or car park facilities which would pose a higher fire risk.

f. Fire Code 1997 also spells out the fire safety aspects of workers' dormitories. Unlike residential premises the occupancy rate in these dormitories are exceedingly high. There is tendency for workers to cook within the living area and this poses a great fire hazard especially when the workers are sleeping and the cooking left unattended. The Fire Code 1997 requires the provision of fire alarm system for the dormitories to ensure early evacuation of the occupants should there be a fire outbreak.

2.5 Lift System – SS CP 2

a. For building exceeding the height of 24m or the depth of the basement is more than 9 metres below ground level, at least one firemen's lift shall be required. The purpose of this lift is to facilitate firemen to fight fire internally. Fire lift shall be provided with an operational feature that would enable firemen to cancel first or earlier call which had been inadvertently made to the fire lift during an emergency. When operated (by switching to fire mode at ground level), the firemen's lift will come under the full control of the firemen, it will response to call only form the lift car.

It has the speed of traveling from ground floor to the top most floor in 1 minute. The fire lift must adjoin a staircase and land on every floor opening into an independent and protected lobby which is used as a holding area for fire fighting operations, minimum dimensions for firemen's lift and fire fighting lobby are specified in the fire code.

b. The firemen's lift can be used as an ordinary passenger lift normally. A special provision in the Fire Code and the Code of Practice require all lifts in public building to automatically home to the ground floor and render inoperational when a fire alarm is activated. This will prevent occupants from using the lift when a fire alarm occurs. In the event of power failure, emergency standby generator installed within the building will automatically start-up upon loss of normal power, to supply emergency power to bring all lifts sequentially to ground level. After which power is returned to the firemen's lift for its continuous operation under power failure.

c. Other than homing facilities, each lift is also provided with a special emergency battery supply to power one light, one fan and alarm bell in the lift car. This is the second line of defence to ensure that passengers even they may be trapped in the lift due to power failure or lift fault, they will not be left in total darkness or be suffocated in stuffy air, and they could wait in reasonable comfort for rescue after raising an alarm.

d. New requirements – homing to alternative floor.

2.6 Automatic Fire Sprinkler System – SS CP 52

a. In Singapore, all building (except residential building) exceeding the height of 24m shall be protected by automatic sprinkler system. All basement occupancy shall also have sprinkler protection, except that if the basement is cross-ventilated such as to avoid smoke logging conditions, the basement storey may be exempted from the requirement for provision of automatic sprinkler system, at the discretion of the fire authority.

b. A new clause in Fire Code 1997 had been introduced to address the trend of apartment/maisonette building having basement car park without sprinkler system. The sprinkler may be waived in basement car park provided that it consists only one level and with external openings and voids which provide effective cross-ventilation.

c. Sprinkler system shall be complete with full water supply kept in sprinkler water tanks (compartmented). Sprinkler pumps shall be duplicated (one duty, one standby). In building with emergency standby generator, the electrical sprinkler pumps may be provided. If not, one of the pumps shall be diesel engine driven type.

d. Sprinkler system shall be designed according to the hazard classification of the building. Activation of sprinkler will raise a general alarm via operation of flow switch in the sprinkler piping.

2.7 Rising Main and Hosereel System – SS CP 29

a. Fire hosereel consisting a 30m long 25mm diameter hose complete with nozzle and rotating drum is the primary fire fighting apparatus designed to be used by occupants. Depending on the available water pressure from the town main and location of the hosereel, water supply to hosereel can either be tapped directly from town main or taken from pumps and water tanks. Flow expected from hosereel is merely 0.4 l/s with a throw of 10m.

b. Reserved and installed for use by firemen are the dry riser or wet riser (stand pipe). Dry riser shall be provided in building with a height between 24m and 60m, where water can be charged from the fire pumper. For building exceeding 60m, the riser (stand pipe) shall be constantly charged with pressurised water and is termed wet riser. Wet riser system is complete with duplicate fire pumps, having the ability to deliver 38 l/s water via a single landing valve in the case of non-residential building and 27 l/s in residential building. Wet riser tanks have a water storage capacity for 90minutes operation.

c. In the old fire code, hardstanding is required to be provided to the engine to reach every residential unit. With the provision of dry rising main for residential building having a habitable height exceeding 10 metres but not exceeding 60 metres, the fire engine can access to the dry rising breeching inlet immediately to carry out internal fire fighting operation. As such, the provision of hardstanding is no more required in the Fire Code 1997.

d. The Fire Code 1997 also introduces requirement of standby fire hose (30 metres in length and 64mm nominal internal diameter). The hose shall be kept stowed (not to be connected) in a Dutch Rolled position and housed in a locked glass fronted cabinet adjacent to each landing valve at the riser location. The cabinet shall be located at a height of 900mm above floor level and conspicuously labelled.

e. As the occurrence of a fire cannot be ruled out during construction, the Fire Code 1997 stipulated that it is necessary to ensure that rising mains are properly installed in buildings that are under construction. The rising mains must be progressively installed as the building gain height.

f. The non-provision of the hosereel in residential building was reconsidered and found to be essential for high rise residential apartment blocks. This requirement is thus re-instated in the Fire Code 1997 for high rise apartment blocks with habitable height exceed 24 metres. Residents of high rise residential flats can thus make use of the hosereel to fight incipient fire inside an apartment or a maisonette unit a s a first line of defence.

2.8 Mechanical Ventilation and Smoke Control Systems

A. Basement Smoke Control System – SS CP 13

a. Where the total aggregate floor area of all basement storeys does not exceed 1900 sq. m, smoke vents shall be provided and adequately distributed along perimeter of basement. Smoke vents outlets shall be easily accessible during fire fighting and rescue operation.

b. Engineered smoke control system is required for basement level where the total aggregate floor area exceeds 1900 M2. This does not apply to basement or a portion of basement that is used as carparking and compartmented from the rest of the basement. In which case, only smoke purging system is required.

c. In the case of engineered smoke control system, the minimum clear height below smoke layer measuring from the floor level is required to be maintained at 2.5metres so as to facilitate occupants to escape for safety.

B. Basement Carpark Smoke Purging System – SS CP 13

a. Where the car parking areas in basements with total floor area exceeding 1900 sq. m, a smoke purging system shall be provided to give a purging rate of not less than 9 air-change per hour.

b. The smoke purging system shall be activated automatically by the building fire alarm system. A remote start/stop switch shall be located in the FCC or at FIB if there is no FCC. Visual indication of the operation status shall also be provided.

c. The exhaust air shall be discharged directly to the external of building and shall not be less than 5 metres from any air intake openings.

C. Lobby MV and Re-setting of Fans – SS CP 13 & SS CP 10

a. On the provision of smoke detectors for AHU shutdown upon detection of smoke in the return air system. The Fire Code 1997 do not require the AHU shutdown smoke detection system to form a separate zone to the building fire alarm system.

b. The Fire Code 1997 specified a minimum pressure differential of 50 Pa between the exit staircase and the accomodation area when all doors connecting to the staircase enclosure are closed. The ventilation system shall be of supply mode only of not less than 10 air changes per hour.

c. A manual start/stop switch with visual indication for smoke-stop lobby and fire-fighting lobby mechanical ventilation (i.e. MV) system operation in the fire command centre (i.e. FCC) or near the main fire indicator board if there is no FCC. The intent of this requirement is to allow fire fighting personnel to shut down the MV system temporarily in the event that smoke is drawn into the space through the outdoor air intake as well as manually activate the MV system should the fire alarm system fail to automatically activate it.

D. Pressurisation for Exit Staircase – SS CP 13

a. In any building of which the habitable height exceeds 24 metres or comprising more than 4 basement storeys, any internal exit staircases shall be pressurised.

b. The pressurisation system shall maintain a pressure differential of not less than 50 Pa between the pressurised exit staircase and the occupied area when all doors are closed. The force required to open any door shall not exceed 110 N. Moreover, the system shall also maintain an average airflow velocity of at least 1.0 m/s.

c. The pressurisation system shall be automatically activated by the building fire alarm system. In addition, a remote manual start/stop switch shall be made available to firemen at the FCC or at the FIB where there is FCC. Visual indication of the operation status shall be provided.

E. Atrium Smoke Control System – BR 186 & BR 258

a. Only central void within building exceeding 93m² and with horizontal dimension between opposite edges of the floor opening larger than 6m width can be regarded as atrium. The design shall follow the guidelines in the BR 185 & BR 258 technical publications published by the Fire Research Station (i.e. FRS).

b. Atrium shall be open and unobstructed in a manner such that a fire in any part of the space can be readily obvious to the occupants prior to the time when it becomes a hazard.

c. All building incorporated with Atrium shall be fully protected by sprinkler system. On top of this, an engineered smoke control system operated by dedicated smoke detectors shall be provided.

d. The smoke control system together with fresh air intake provision shall be designed to accepted guidelines subject to approval by the fire authority.

e. No high hazard usage or storage of combustible material may be permitted in the atrium.

F. Primary and Secondary Power Supplies – SS CP 31

Mechanical ventilation/ pressurization systems serving the exit staircases and exit passageways, smoke-stop and fire fighting lobbies, basement carparks, atrium smoke control system, basement smoke control system and engineered smoke control system shall all be supported by secondary source of power supply, e.g. generator power.

2.9 Fire Command Centre and Communication System - SS CP 25

a. For all buildings (excluding residential and industrial buildings) with habitable height between 24 metres and 60 metres, an ordinary public address (i.e. PA) system shall be provided. Two way emergency communication system shall also be provided between the Fire Command Centre (FCC) and every fire fighting lobby.

b. A FCC shall be provided when the building with the exception of purpose group I and II has any of the following installation:

i. Fire Lift,
ii. Emergency voice communication system; and
iii. Engineered smoke control system.

c. For all buildings (excluding residential and industrial buildings) with habitable height of more than 60 metres, one way emergency communication system and a FCC shall be provided. Two way emergency communication system shall also be provided between the FCC and the following areas:-

i. every fire fighting lobby, including 1st storey;
ii. all fire fighting related mechanical equipment rooms inclusive of sprinkler pump room, wet rising main pump room, hosereel pump room, etc.;
iii. all rooms housing smoke control equipment;
iv. all lift machine rooms;
v. any other locations as may be required by the Fire Authority.

d. For Hotel or health care occupancies of less than 24 metres in habitable height, an ordinary PA system shall be provided. Loudspeakers of the PA system shall be strategically located so that all parts and all storeys are within audible distance.

d. For a building of mixed commercial-cum-residential usage, the provisions in a. and b. as mentioned above shall be applicable. However, the habitable height shall be taken to the commercial component of the building.

f. A fire command centre (FCC) shall be of adequate size to house the following equipments and have a free working space of at least 6 sq. m. The FCC will be the command post for fire fighting and it shall be located adjacent to the fire lift lobby at 1st storey or main lobby of building.

i. fire alarm indicator board;
ii. Lift status indication panel;
iii. one way voice communication system via public address system;
iv. two way voice communication system via firemen's intercom set;
v. remote status panel of essential MV fans and fire pumps; and
vi. overriding manual control to start/stop essential MV fans including smoke control extraction fans

FIRE SAFETY ACT & REGULATIONS

INTRODUCTION

1 The Fire Safety Act was passed in Nov 93 and implemented in April 94. The purpose of the Act was to bring about a higher standard of fire safety in our buildings. Buildings must not only be designed to meet the latest fire safety codes, there must also be proper fire safety management in such buildings to ensure that fire safety systems are properly maintained and fire emergency procedures laid down and practised. This requires effort on the part of owners/management of commercial and industrial buildings and the fire safety professionals to work closely with SCDF.

2 The new provisions in the Fire Safety Act have been effectively implemented by the Singapore Civil Defence Force (SCDF) since the Act came into operation on 8 April 94. They include the enhanced enforcement powers against fire hazards, the Fire Safety Manager scheme, the Fire Emergency Plan scheme and the Registered Inspector scheme. FSB has been closely monitoring the implementation of the Act. The Fire Safety Act consists of 7 parts :

a. Part I - Preliminary
b. Part II – Fire Hazard in Buildings
c. Part III – Fire Prevention in Buildings
d. Part VI – Control of Fire Safety Works
e. Part V – Premises used for Dangerous Trades or Purposes
f. Part VI – Control of Petroleum and Flammable Materials
g. Part VII - Miscellaneous

3 The following 7 Regulations, 2 Exemption Orders and 2 Gazette Notifications were made for the purpose of implementation of the Act :

a. Fire Safety (Building Fire Safety) Regulations
b. Fire Safety (Registered Inspector) Regulations
c. Fire Safety (Fire Emergency Plan) Regulations
d. Fire Safety (Fire Safety Manager) Regulations
e. Fire Safety (Dangerous Trades or Purposes) Regulations
f. Fire Safety (Petroleum) Regulations
g. Fire Safety (Composition of Offences) Regulations
h. Fire Safety (Exemption Order)
i. Fire Safety (Designation of Premises Requiring Fire Emergency Plan) Notification
j Fire Safety (Specification of Premises Requiring Fire Safety Managers) Notification

REASONS FOR ENACTING THE ACT

4 There are three main reasons for the proposed new legislation: Firstly, new legislative provisions are needed to enable more effective enforcement of fire safety standards. Secondly, FSB currently administers the fire safety provisions in the Building Control Act, which came into effect in 1974 and then revised in 1989. The legal basis for this arrangement is questionable because the Building Control Act does not have any provision for the Building Authority to delegate powers and duties to officers of the FSB. It is therefore necessary to provide FSB with the required legal powers. Thirdly, there are duplications and overlapping provisions on fire safety in the Building Control Act, the Fire Service Act and the Petroleum Act, administered by FSB. This needs to be regularised.

FIRE HAZARDS IN BUILDINGS
ENFORCEMENT OF FIRE HAZARDS

5 Fire hazards can exist in many forms in buildings, the most common being the obstruction of escape routes, poor maintenance of fire safety equipment and over- crowding. Because of inadequate powers, FSB has limited success in dealing with them. This has to be remedied. The policing of fire hazard is an extremely vital factor in the operation of FSA. Its implementation ensures that fire safety standards and measures established by FSB are maintained and kept in effective working order.

6 Fire hazard can take any of the following forms:

a. Any alteration to any building in contravention of any law relating to building works such as might render escape in the event of fire difficult;

b. The overcrowding of any place of public entertainment or public assembly such as might render escape in the event of fire difficult;

c. Any removal from any building of any fire safety measure which was provided in such building in accordance with plans cleared by the Commissioner;

d. The presence in any building of any fire safety measure which from lack of proper maintenance or for any other reason is not in efficient working order;

e. The obstruction of fire escape routes, passageways, or common property such as might render escape difficult in the event of a fire;

f. Any other matter of circumstances which increased the likelihood of fire occurrence or the danger to life or property or which would hamper the SCDF in the discharge of its duties in the event of fire.

7 The power vested in the Commissioner, SCDF for the abatement of fire hazards include :

a. Serve a fire hazard abatement notice upon the person concerned requiring him/her to abate the fire hazard within a specified period. Failure of any party to comply with this notice would constitute an offence under the Act.

b. Compound a fine not exceeding $500.

c. Carry out work, remove and seize property causing the fire hazard and recover the expense incurred from the person on which the notice has been served.

d. Order the closure of the premises up to 72 hours of cases that maypose substantial and iminent danger to persons. If a longer period of closure is deemed necessary, the Commissioner may make an application to the Magistrate's Court for an extension.

e. If the abatement notice is not complied with, the Director may apply to a magistrate for a fire hazard order, which may take the form of:

(1) An abatement order, that is to say an order requiring a person to comply with the requirements of the fire hazard abatement notice;

(2) A prohibition order, which is an order which prohibits the use of the premises; and

(3) A closing order which would effectively close the premises; or

(4) A combination of such orders.

Appeals against a prohibition or closing order may be made to the High Court.

FIRE PREVENTION IN BUILDINGS
FIRE SAFETY MANAGER (FSM) SCHEME

8 The Fire Safety Manager scheme aims to enhance the fire safety within buildings. Through the Fire Safety Manager, fire safety activities and fire

prevention measures are also implemented to promote fire safety awareness among the building occupants. The Fire Safety Manager helps to ensure that the fire safety standards in the building are maintained at all times. Engagement of a Fire Safety Manager will help owners of buildings prevent substantial monetary and life losses resulting from fires. With the passing of the Fire Safety Act 1993 and the Fire Safety (Fire Safety Manager) Regulations 1994, it has become mandatory for owners of designated buildings to appoint Fire Safety Managers.

FIRE EMERGENCY PLAN

9 The preparation of the Fire Emergency Plan (FEP) by building owners is yet another requirement to make it a complete process on fire safety for commercial and industrial premises. Their availability during an emergency can make a difference to business in terms of damage caused by fires. The Emergency Plan should contain useful data/information of the premises and its operations. The fire evacuation plan is a step-by-step procedure for the occupants of the building to follow in the event of fire.

10 Fire drills are also required to be conducted annually to familiarise the occupants with the evacuation procedures. SCDF will advise building owners on the conduct of their drills, if requested.

11 Since the implementation of the Fire Safety Act, it is a statutory requirement for owners of all the public buildings (such as shopping centres, office, hotel, hospital) to prepare a FEP for their premises. This scheme will also be extended to cover industrial premises.

DUTIES AND RESPONSIBILITIES OF THE OWNER OR OCCUPIER OF DESIGNATED PREMISES FOR WHICH A FIRE EMERGENCY PLAN SHOULD BE PROVIDED

12 The owner or occupier of designated premises shall :

a Within 6 months from the time the premises designated or fall within the class of premises designated by the Minister under section 21(1) of the Act, prepare a fire emergency plan for the premises.

b Ensure that the Fire Emergency Plan for the premises is prepared in accordance with such guidance as may be used by the Commissioner for that catergory of premises.

c Form a Fire Safety Committee from among the occupants in the premises to assist him to plan, organize and conduct the fire safety programmes including fire evacuation drills in the premises.

d Ensure that the fire emergency plan prepared for the premises is reviewed at intervals not exceeding 12 months or at such other intervals as may be directed by the Commissioner under regulation 4.

e Ensure that up to date records relating to reviews of the fire emergency Plan, conduct of fire evacuation drills and fire safety programmes are kept and maintained at all times.

f Ensure that records specified in paragraph (e) and a copy of the Fire Emergency Plan is kept at the Fire Command Centre or such other place where they can be easily available to the Commissioner at all times.

g Designate one or more places within or outside the premises which is capable of accommodating all the occupants of the premises and which poses the least danger to the occupants of the premises in the event of fire to be used as an assembly area; and

h Notify the Commissioner in writing of the completion of the fire emergency plan within 14 days.

FIRE CERTIFICATE FOR PUBLIC BUILDINGS (FC)

13 Owners of public buildings (occupant load of more than 200 persons) such as hotels, shopping centres, offices, hospitals are required under the Fire Safety Act to have a Fire Certificate (FC). The FC is renewed every year. The owner will engage a professional engineer in the appropriate discipline to check and test the fire protection system in the building before making an application for a FC. As part of the submission procedures, the owner is required to submit among other things, the PE's certificate certifying that the fire protection system in the building have been maintained and tested in accordance with the relevant codes of practice and in good working condition.

14 The fire certificate must be obtained after 12 months from the date of the Temporary Fire Permit (TFO)/Fire Safety Certificate (FSC), whichever is first obtained. The application must be made at least two months before the end of the given time frame. The fire certificate is valid for one year. For renewal cases, an application should be made at least two months before expiry of the existing fire certificate. The application form should be duly completed and returned to FSB within two weeks.

15 The Commissioner may revoke any fire certificate where there is -

a A breach of any terms and conditions of the certificate.

b Any misrepresentation of a material fact in the application for the fire certificate or accompany plans or documents upon the basis of which the certificate was issued or renewed; or

c Knowledge that the fire hazards within the building or part thereof, for which the certificate was issued or renewed, increased without adequate fire safety measures being taken to the satisfaction of the Commissioner.

CONTROL OF FIRE SAFETY WORKS
APPROVAL OF PLAN FOR FIRE SAFETY WORKS

16 The Commissioner, SCDF is given the power under section 23 (1) of the Act to approve plan for fire safety works in buildings. The prior approval is also required for the change of use of the premises. The details on administrative requirements include plan fees for submission and approval of plans are given in the Building Fire Safety Regulations. However, no technical details on fire safety requirements are specified in these regulations, instead refernce is made to the Fire Code and other requirements to be approved by the Commissioner.

PROHIBITION OF FIRE SAFETY WORKS WITHOUT APPROVAL OF PLANS

17 It is an offence to carry out or commence any fire safety works without the prior approval of the Commissioner under section 20 (1) of the Act. The offence carries a fine of not exceeding $50,000 or to imprisonment for a term not exceeding one year or both.

WAIVER OF REQUIREMENTS RELATING TO FIRE SAFETY

18 The Commissioner may grant or refuse the waiver of any of the fire safety requirements. The Act provides the provision for the applicant to appeal against the Commissioner's decision to the Minister, who may seek advice from an Appeals Advisory Board. The decision of the Minister shall be final.

TEMPORARY FIRE PERMIT (TFP)/FIRE SAFETY CERTIFICATE (FSC)

19 The owner is required to appeal and obtain a Temporary Fire Permit for a Fire Safety Certificate from the Commissioner for the completed fire safety works before the building is allowed to be used or occupied. The details on application are stipulated in the Building Fire Safety Regulations. Among other requirements, a certificate by a Registered Inspector (RI) shall be submitted.

REGISTERED INSPECTOR SCHEME (RI)

20 Upon completion of the project, RI would be engaged by the developer/owner to carry out a final check to see that the works carried out are in accordance with the approved plans and relevant standards and codes of practice.

21 While the project QP is responsible for inspecting the fire safety provisions according to approved plans and relevant codes of practice/standards. He also checks and tests the performance of fire fighting /protection facilities. The RI is also required to verify that fire safety works are consistent with the building plans and any amendments made thereto.

22 The RI shall notify the Commissioner of any deviation or non-compliance with the provisions of the Act or any regulations made thereunder in connection with the fire safety designs of any plans of building works : *provided he did not know and could reasonably have discovered.*

23 Acting as an agents, it is the duty of the RIs to inspect the fire safety works specified in Part I and II of the First Schedule as the case may be with a view to determine whether the fire safety works have been complied with.

24 The RIs shall keep record of all the reports, requests and correspondences made with respect to the inspection and shall furnish the Commissioner with a copy of any of the above documents as the Commissioner may required.

25 The RIs shall, without delay after performing his duty in relation to any plans of fire safety works, prepare and submit to the person whom the fire safety works are to be or being carried out :

a A certificate of inspection.

b A declaration that has no professional or financial interest in the building or its fire safety works.

26 The RI shall notify the Commissioner, SCDF within 14 days of his engagement by the owner or the cessation of such engagement.

27 In performing the inspection works, the RI may require the QP to :

a Supply him a complete set of all the approved plans.

b Liaise with him on the time and date of inspections

c Cause to be carried out such rectification works as he may consider necessary

PREMISES USED FOR DANGEROUS TRADES AND PURPOSES

28 Under the First Schedule of Section 31 (I) of the Act, premises that are used for any of the 5 trade activities or purposes are required to obtain a dangerous trade licence from FSB. These 5 activities are storage of acetylene, cellulose solution, calcium carbide, matches and fireworks. Details on licence application, renewal, fire safety measures and new fees payable by the licensees are given in the Fire Safety (Dangerous Trade or Purposes) (Amendment) Regulations 2000.

CONTROL ON PETROLEUM AND FLAMMABLE MATERIALS

29 No person shall transport or store any class of petroleum except under and in accordance with the Act and regulations. The dispensing of petroleum is also regulated.

30 Procedures on application for a licence to transport and/or store petroleum, fire safety requirements pertaining to storage and transportation of petroleum are given in the Petroleum Regulations. On fire safety requirements, the regulations prescribed the quantities of any class of petroleum that can be stored in places or transported by vehicles without a licence, the standard and specification for the construction of any premises in which any class of petroleum is be stored, the management of places or vehicles in which the petroleum is stored or transported etc.

THE ROLE & RESPONSIBILITIES OF FIRE SAFETY MANAGER
APPOINTMENT OF FIRE SAFETY MANAGERS

31 Under the 1994 Fire Safety Act, the authority may specify any premises or class of premises owner or occupier to appoint a qualified Fire Safety Manager, With the appointment, Fire Safety Managers are required to assist building owners or occupier in the performance of his duties under the Fire Safety Act or any related regulations. Together with the owner, they are to ensure that the fire safety measures and fire safety practices in the premises comply with the regulations under the Fire Safety Act & Regulations and/or to the standard as specified by the Commissioner.

32 The owner or occupier of specified premises shall:

a. Within 90 days from the time the premises are specified or fall within the class of premises specified by the Minister under section 22(1) of the Act, appoint a FSM.

b. Provide the fire safety manager appointed by him with such facilities, equipment and information as are necessary to enable the fire safety manager to discharge his duties effectively and efficiently.

c. Permit the fire safety manager to attend such courses of instruction and receive such training relating to the work of the fire safety manager as may be required by the Commissioner.

d. Reimburse the fire safety manager for all expenses incurred by him in attending such courses or training.

e. Not make any deduction from the remuneration of the fire safety manager for being absent from work for the purposes of attending such courses or training.

f. Within 44 days of the termination appointment of his fire safety manager appoint another person to be his fire safety manager; and

g. Within 14 days of the appointment or termination of appointment of any fire safety manager notify the Commissioner in writing of such fact.

TYPES OF PREMISES REQUIRING A FSM

33 All public and industrial buildings which have a gross floor area of 5,000 sq metres or more or an occupant load of 1,000 persons or more, are required to

have a Fire Safety Manager. Any industrial building which is classified as a high risk premises, is also required to have a Fire Safety Manager. Examples of buildings that are required to have Fire Safety Managers (FSM) are shopping centres, hotels, office buildings, factories, warehouses etc. Certain public buildings such as hospitals are also required to have FSMs. Examples of high risk premises are those that are involved in chemical and petrochemical activities.

THE DUTIES AND RESPONSIBILITIES OF FIRE SAFETY MANAGERS

34 The owner or occupier of a designated building is required to appoint a fire safety manager and to provide the fire safety manager with the necessary facilities and information to enable him to discharge his duties effectively and efficiently. In assisting the building owner in ensuring fire safety in the building, the fire safety manager is expected to perform the following:

a. Enforcing the fire safety rules as stipulated in the fire emergency plan;

b. Exercising supervision over maintenance of all fire safety measures within the premises;

c. Ensuring that the number of people in any part of the premises does not exceed the authorized maximum number of people for whom means of escape have been provided in accordance with the fire code;

d. Detecting and removing or causing the removal of fire hazards within the premises;

e. Preparing and formulating a fire emergency plan for the premises and organizing regular fire drills in order to ensure that all persons employed in or using the premises or part thereof, are familiar with all means of escape in case of fire;

f. Preparing and formulating fire safety guide books for the premises;

g. Training of staff and persons in the premises in fire fighting and evacuation;

h. Coordinating and supervising of staff and persons in the premises in fire fighting and evacuation in the event of fire or other emergencies;

i. Supervising the operation of the fire command centre in the event of fire or other emergencies;

j. Appointing a responsible person to take over his duties in his absence.

k. Organize campaigns, training courses, competitions, contests and other activities that will develop and maintain the interest of the staff and people in the premises in establishing fire safe environment therein;

l. Any other works necessary for fire safety.

TRAINING/QUALIFICATIONS OF FSM

35 Prospective FSMs are required to undergo a training course. This course is designed to prepare the candidates on how to discharge their duties effectively. Upon completion, the candidates will take an examination, the passing of which may qualify them for employment as FSMs by building owners. The training courses is jointly organised by the SCDF and Ngee Ann Polytechnic.

36 In addition to those who possess the certificate in FSM, other likely candidates to be recognised as FSMs are persons who possess :

a. Certificate in Fire Engineering – CIFE.
b. Diploma in Building Services Engineering (Ngee Ann Polytechnic) obtained on/after 1991.
c. Advanced Diploma in Fire Safety Management.

FSM ANNUAL REPORT

37 The important features of the report are:

a. Information of the building or premises.

b. The kind of training conducted, either internal or external, for their 4 categories of building occupants:
   (1) tenants/occupants;
   (2) fire wardens;
   (3) management and staff;
   (4) in-house fire fighters.

c. Fire safety activities conducted for the reporting period as well as schedule of fire safety activities for the next 12 months.

d. Improvement and other fire safety measures.

e. Fire evacuation drill reports

Train Depot

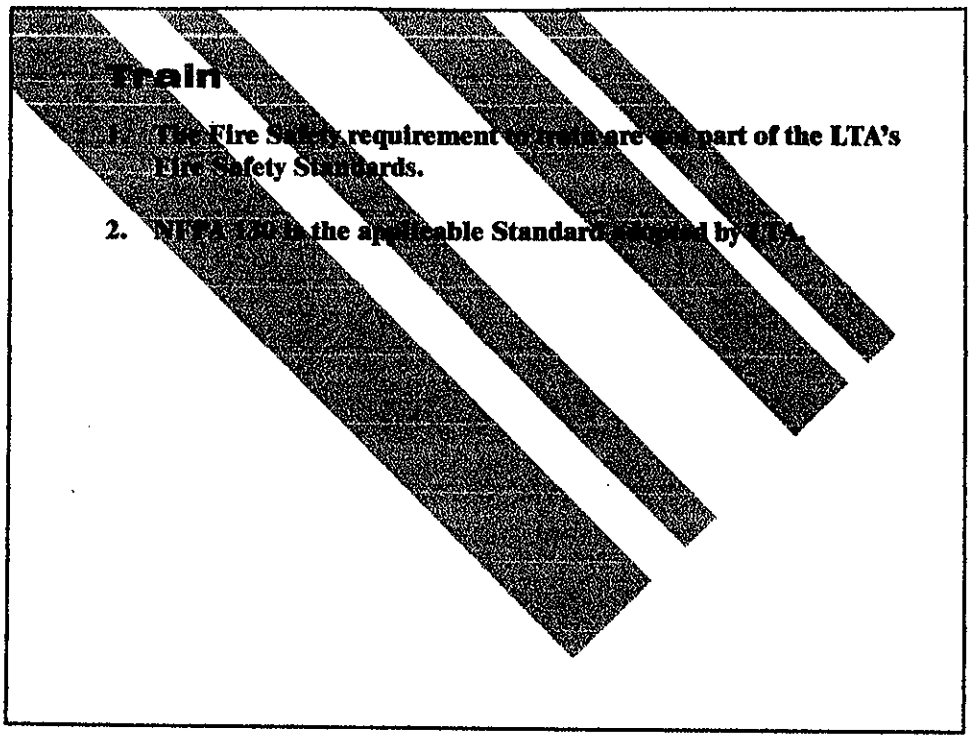
1. The requirements for fire safety measures generally follow the Fire Code.
2. As the Train Dept is usually a large structure and is purposely built to repair service trains, modifications were made on the followings:
   a. Area with traction power not to be covered/ protected by hosereel. A 6m buffer zone is implemented.
   b. Depot falls under Purpose Group VI.
   c. FRP around underground track areas/ siding > 4 hours
   d. 4 hours fire separation between track areas/ siding of the depot and other non-transit occupancy.
   e. Occupant loads for the track areas/ sidings to be determined by the expected no. of people occupying the area.

Train Depot

f. Extended travel distance up to 120m for 2 way travel with sprinkler protection

g. Submission of Fire Safety Report

h. Provision of radio communication facility in frequency band of 470-490 MHz


Train
1. The Fire Safety requirement [illegible] are [illegible] part of the LTA's Fire Safety Standards.
2. NFPA 130 is the applicable Standard adopted by LTA.

Underground Trainway

1. Non combustible construction, no PVC products permitted.
2. FRP not less than 4 hours.
3. Exit shaft and ventilation shaft to have min. 2 hour fire rating.
4. Separation of ancillary area from trainway
   a. 3 hours for underwater line
   b. 2 hours for other tunnel
5. Blue light station not included in LTA Fire Safety Standard.

Underground Trainway

6. Provision of exits in tunnels are similar to NFPA130, except the following
   a. 1st cross passage not further than 800m from station exit stair or platform PSD return door, whichever is closer
   b. Spacing of cross passage rounded off to 240m, instead of 244m
   c. Distance to exit stair in tunnel rounded off to 380m from 381m
7. Similar to NFPA 130, emergency lighting is required in tunnels exceeding 15m.
8. Exit signs in cross passages to be designed and controlled to support evacuation strategy

Tunnel Emergency Ventilation System

1. Provision in LTA's Fire Safety Standard similar to NFPA130
2. Fire resistance cables of min. 2 hour rating to be used for operating fans and associated control.
3. Operation of tunnel emergency ventilation sys[illegible]hall be initiated from OCC. Local controls located near [illegible] override OCC control.
4. Design criteria similar to NFPA 130

Tunnel Emergency Ventilation System

Communication

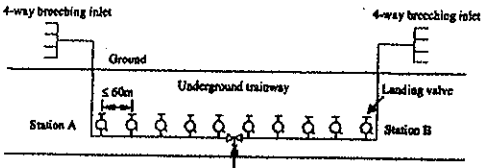
1. To be provided with radio communication fa[illegible]ties in the frequency band of 470 – 490 MHz
2. 2 hour fire rating for communication cables, LCX c[illegible] fire retardant

Tunnel Dry Riser System

1. Required for all tunnels
2. DR pipe in tunnel need not be fire-rated
3. LV to be located at spacing of 60m and positioned next to tunnel emergency exit stair or cross passageway
4. DR pipes from 2 adjacent stations are joined at the mid-point of tunnels

Diagram 2.9.4.1(a)

DRY MAIN SYSTEM IN UNDERGROUND OR ENCLOSED TRAINWAY



No detector in tunnels!

Additional LV at cross-passages.

Linear heat detector in tunnels may be considered in new MSFA 180!

Tunnel Dry Riser System

5. Breeching inlets are to be appropriately labelled

Diagram 2.9.4.2

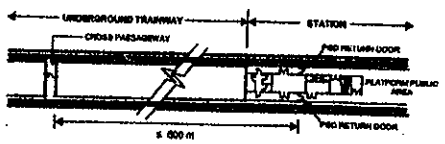
NUMBERING AND LABELLING OF BREECHING INLETS FOR UNDERGROUND OR ENCLOSED TRAINWAY DRY RISING MAINS



6. 2 Standby fire hoses to be provided at corridor outside PSD return doors on platforms. Total 8 nos. fire hoses at 4 locations.

Diagram 2.9.7.3(a)

LOCATION OF FIRST CROSS PASSAGEWAY IN UNDERGROUND TRAINWAYS



+ motorised trolley with battery to transport fire fighting equipment

Exiting Calculation

1. Time to clear platform, t_p

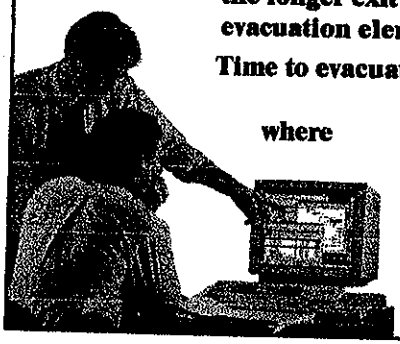
$$t_p = \frac{\text{Platform occupant load}}{\text{Platform exit capacity}}$$

Requirement < 4 minutes

2. Time to evacuate station.
Usually the point of safety is located at grade.
The evacuation time is the sum of the walking time for the longer exit route and the waiting time at various evacuation elements or bottlenecks.

Time to evacuate station = $T + W_p + W$

where
- T = Total walking time
- W_p = Platform exit walking time
- W = Waiting time at other circulation elements



Exiting Calculation

3. Exit capacity of escalator not to exceed 50% of total exit capacity on every level.

4. One escalator has to be discounted from the exit capacity. A few calculations may be needed to examine the results of discounting escalators at different locations to confirm that the longer exit time will still be kept under 6 minutes.



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PASSIVE FIRE PROTECTION FOR ROAD TUNNELS

BY IAN R HOLTS
B.Sc (Building Services Engineer)

1 Introduction

Fires in tunnels are a major hazard to human life and cause costly damage to the infrastructure. The limited escape facilities and the difficulties encountered by intervention forces in gaining access call for extensive safety arrangements which must be complementary and mutually coordinated.

Tunnels and underground transport facilities are important means of communication, not only in terms of shorter journeys, but also increasingly out of consideration for the local population and the environment. Generally speaking, important underground transport links are expected to be available without any restrictions and to operate smoothly round the clock. Interruptions due to accidents, technical malfunctions or maintenance work quickly cause traffic jams and delays, and figure in transport policy statistics as economic losses.

Rising traffic densities and the growing demand for underground communication links result in a higher probability of accidents, injuries and damage. Added to this are other factors which increase the potential hazards of traffic tunnels:

- the increasing length of modern tunnels
- the transport of hazardous materials
- two-way traffic (with undivided carriage ways)
- higher fire loads due to growing traffic volumes and higher loading capacities
- mechanical defects in motor vehicles

When considering a tunnel(s), it is usually in relation to road and rail infrastructure, however, use of the word tunnels can be slightly misleading, as the following details apply equally to pedestrian walkways, underground rail stations, underground car parks etc, in fact, to any concrete structure. Therefore although this document will refer to tunnels throughout, all details apply also to underground spaces of any description.

It is usually assumed that because a structure is constructed using concrete, that it is inherently fire resistant, and therefore requires no additional fire protection measures to be taken. Unfortunately, experience over the years has shown that this is not necessarily the case and consideration must be given to the performance and behaviour of concrete structures under fire conditions. In addition, where tunnels and underground spaces are concerned, consideration must also be given to the provision of services protection, e.g. smoke extraction systems, protection to cables and wiring servicing emergency equipment etc.

This document is intended to provide some background into the behaviour of concrete under fire conditions, To show proven methods of protecting structures against fire, and of providing protection to services within tunnels and underground spaces.

Why Protect Tunnels ?

There are three reasons for providing protection against fire within tunnels, firstly, there is the matter of life safety, this is not necessarily a function of structural performance under fire, although a collapsing structure would not enable people to exit a structure in safety, but more to do with the function of services such as emergency lighting, smoke extraction systems etc.

As an example, we shall detail below some of the tunnel fires which have occurred in recent years, and the resultant death toll.

- Salang Tunnel, Afghanistan 700 dead
- Vierzy Tunnel, France 108 dead
- Mont Blanc, France 42 dead
- Bosnia Tunnel 35 dead
- Hokuriku Tunnel, Japan 34 dead
- Kings Cross, UK 31 dead
- O Shimizu Tunnel 16 dead
- Tauern Tunnel, Austria 12 dead
- Pecorile Tunnel 8 dead
- Caldecot Tunnel, USA 7 dead
- Nihonzaka, Japan 7 dead
- Isola delle Femmine, Italy 5 dead
- Palermo Tunnel, Italy 5 dead
- Velsen Tunnel, Netherlands 5 dead
- Huguenot Tunnel 3 dead
- Pf nder Tunnel, Austria 3 dead

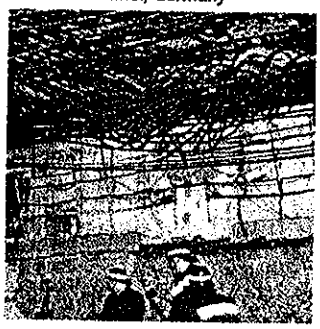
The above are just a small example of accidents in tunnels which have resulted in lose of life.

Secondly there is the performance of the structure itself, will it remain in-situ, will it collapse, possible causing collateral damage to other structures and injuries to people passing by etc.

Thirdly, there is the economic damage caused as a result of the failure of a tunnel etc. This economic cost is not related solely to the repair or rebuilding of the structure; more usually it is the knock on impact of loss of business, traffic diversions etc which result in the largest costs. A prime example of this is the fire inside the Channel tunnel where the economic damage was estimated to be over twice the cost of the actual tunnel repairs, the direct repairs to the tunnel cost some 87 million, the additional costs in lost business, replacement of infrastructure, materials e.g. lorries, train carriages etc bring the economic loss alone to some 211 million. Using Mont Blanc tunnel as an example for a simple road tunnel, the differences are not so marked, with the cost of repair being estimated at some 189 million and the economic cost at some 203 million in addition.

Figure 1: Examples of Fire Damage

Example 1
Moorfleet tunnel, Germany



Example 2
Mont Blanc tunnel, France



Example 3
Velsen tunnel, Netherlands



Example 4
Channel tunnel, UK

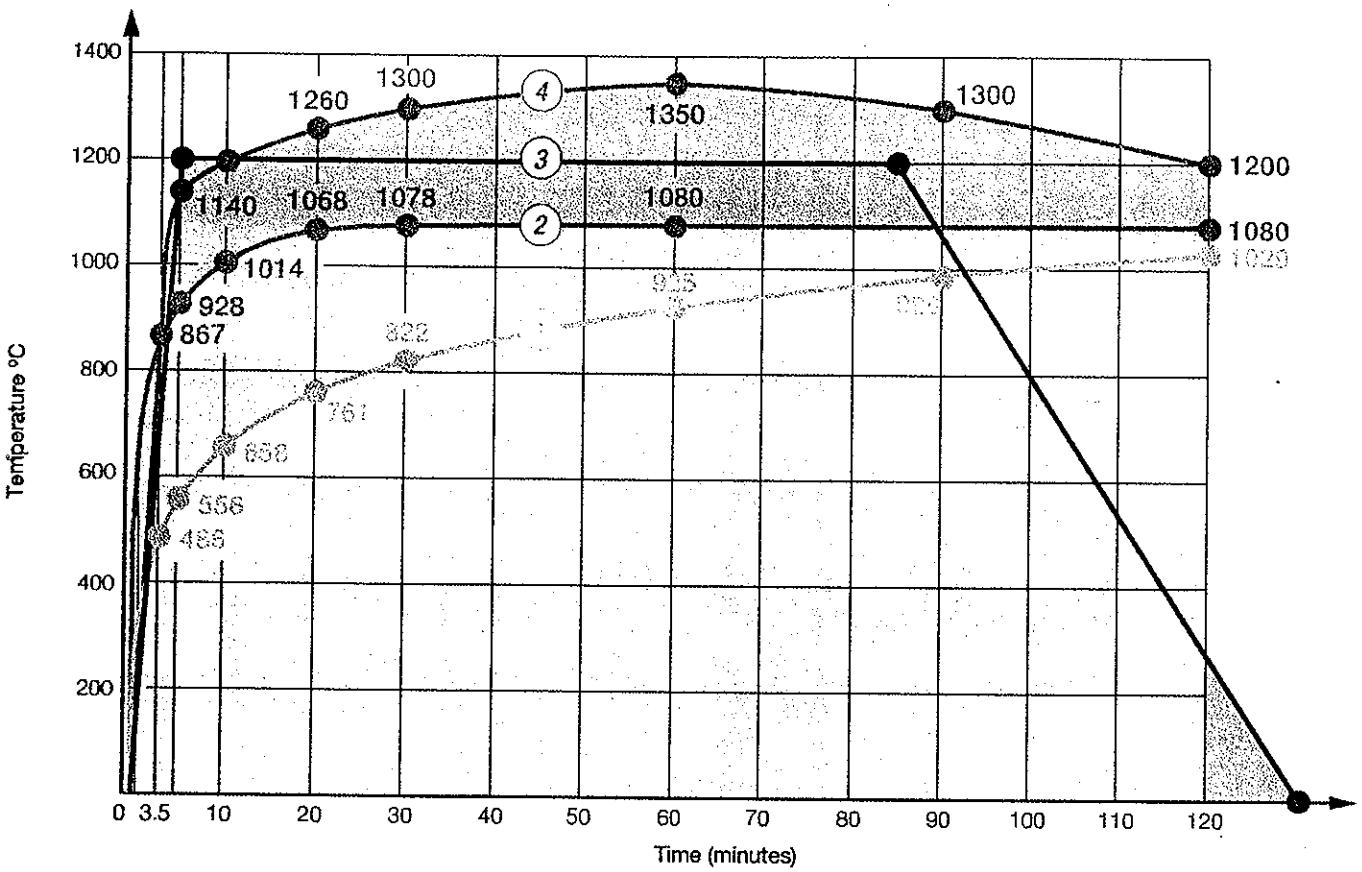


Thus in terms of fire protection within tunnel and underground systems, the following items require consideration:

- Enhancing the fire resistance of the structure
- Air supply systems
- Smoke extract duct systems
- The provision of fire and smoke resistant safe havens in long tunnels
- Active and Passive detection systems
- Fire extinguishing systems

In recent years, a great deal of international research has taken place to define the types of fire which could occur in tunnels and underground spaces. This research has taken place in both real, disused tunnels, and under laboratory condition. As a consequence of the data obtained from these tests, a series of time/temperature curves for the various exposures for tunnels have been developed and outlined below.

Figure 2: Time/temperature Curves



1 = Cellulosic Curve ***2 = Hydrocarbon Curve 3 = RABT Curve 4 = RWS Curve***

Cellulosic Curve

Standard fire tests to which specimens of constructions subject to are based on the use of the Cellulosic Time/temperature Curve, as defined in various national standards, e.g. ISO 834, BS 476 : Part 20, DIN 4102, AS 1530 etc. Although there are other types of fire test curve e.g. BS 7436, the curve as detailed below for this exposure is the lowest used in normal practice.

This curve is based on the burning rate of the materials found in general building materials and contents, although in itself, this curve is based upon research dating back to the late 1940 s, and it is recognised that with the use of thermoplastic and other modern materials, the Cellulosic Curve could be considered to be less onerous than it should be when applied to modern building design and contents.

As will be seen from Table 1, and the following tables, the time period for Cellulosic fires, with durations of tests up to 6 hours, is far in excess of those for Hydrocarbon and RWS fires.

Table 1: Cellulosic Fire

Time (minutes)	Furnace temperature (C)	Time (minutes)	Furnace temperature (C)
0	20	90	1006
5	576	120	1049
10	678	150	1082
15	738	180	1110
20	781	210	1133
30	842	240	1153
45	902	300	1186
60	945	360	1214

Hydrocarbon Curve

Although the Cellulosic Curve has been in use for many years, it soon became apparent that the burning rates for certain materials e.g. petrol gas, chemicals etc, were well in excess of the rate at which for instance, timber would burn. As such there was a need for an alternative exposure for the purpose of carrying out tests on structures and materials used within the petrochemical industry, and thus the Hydrocarbon Curve was developed. Initially, this time/temperature curve was developed separately by various gas and oil companies, and all had slight differences, however, today, the curve as detailed in Figure 2 is as per the relationship between time and temperature that is generally in use for testing.

The Hydrocarbon Curve is applicable where small petroleum fires might occur, i.e. car fuel tanks, petrol or oil tankers, certain chemical tankers etc. In fact, although the hydrocarbon curve is based on a standardised type fire, there are numerous types of fire associated with petrochemical fuels, some of which are detailed below.

- Cloud Fire
  A transient fire resulting form the ignition of a cloud of gas or vapour and not subject to significant flame acceleration via the effects of confinement or turbulence. It can therefore only occur after a relatively slow release of hydrocarbon and in an open, free space.
- Fireball
  The rapid turbulent combustion of fuel as an expanding, usually rising ball of flame. It is more intense than a cloud fire and can be close to an explosion.
- BLEVE
  A Boiling Liquid Expanding Vapour Explosion which results from the sudden failure of a vessel containing a pressurised liquid at a temperature well above its normal (atmospheric) boiling point. E.g. a LPG tanker.
- Pool Fire
  A turbulent diffusion fire burning above a horizontal pool of vapourising fuel under conditions where the fuel vapour of gas has zero or little initial momentum. A burning pool fire is extremely difficult to control. It may accompany a jet fire where burning liquid is spilling from the jet stream.
- Running Fire
  A fire from a burning liquid which flows by gravity over surfaces.
- Jet or Spray Fire
  A turbulent diffusion flame resulting from the combustion of a fuel continuously released with some significant momentum in a particular direction.

Table 2: Potential Fire Duration

Fire types	Potential duration
Cellulosic fire	Hours
Hydrocarbon fires	
Cloud fire	Seconds
Fireball	Seconds
BLEVE	Seconds
Pool fire	Hours
Running fire	Hours
Jet or Spray fire	Hours

Hydrocarbon fires are different from Cellulosic in the manner in which the temperature increase is far more rapid, as can be seen in Figure 2 above, and that after the initial 30-minutes rise, the temperature follows an almost straight horizontal line.

Table 3: Hydrocarbon Fire

Time (minutes)	Furnace temperature (C)	Time (minutes)	Furnace temperature (C)
3	887	60	1150
5	948	90	1150
30	982	120	1150
30	1110	120+	1150

RWS (Rijkswaterstaat) Curve

The RWS Curve was developed during a collaboration between the Rijkswaterstaat in Netherlands, and its counterpart, the Ministry of public works in Belgium. This curve is based on the assumption that in a worst case scenario, a fuel oil or petrol tanker fire with a fire load of 300MW lasting up to 120 minutes could occur.

The RWS Curve was based on the results of testing carried out by TNO in the Netherlands in 1979. The difference between the RWS and the Hydrocarbon Curve, bearing in mind that they are both using as the fire load similar materials, is that the latter is based on the temperatures that would be expected from a fire occurring within a relatively open space, where some dissipation of the heat would occur, whereas the RWS Curve is based on the sort of temperature you would find when a fire occurs in an enclosed area, such as a tunnel, where there is little or no chance of heat dissipating into the surrounding atmosphere.

The RWS Curve simulates the initial rapid growth of a fire using a petroleum tanker as the source, and the gradual drop in temperatures to be expected as the fuel load is burnt off.

Table 4: RWS Fire

Time (minutes)	Furnace temperature (C)	Time (minutes)	Furnace temperature (C)
3	890	60	1350
5	1140	90	1300
10	1200	120	1200
30	1300	120+	1200

In the Netherlands and Belgium, the RWS Curve is applied for durations of up to 120 minutes, at which time it is assumed the fire load has reduced sufficiently for fire fighting personnel to be able to gain access to the source and start in their attempts to extinguish the fire, however, in Switzerland, where tunnels through mountains intend to be far longer in length and more remote in their location, the RWS Curve is also applied, but extended to 180 minutes exposure.

The failure criteria for specimens exposed to the RWS Time/temperature Curve is that the temperature of the interface between the soffit of the concrete and the protective covering should not exceed 380°C and the temperature on the reinforcement should not exceed 250°C.

RABT ZTV Curve

The RABT Curve was developed in Germany as a result of a series of test programmes such as the Eureka project. In the RABT Curve, the temperature rise is very rapid up to 1200°C within 5 minutes, faster than the Hydrocarbon Curve which rises only to 1150°C after 60 minutes. The duration of the 1200°C exposure is shorter than other curves with the temperature drop off starting to occur at 30 minutes (see Figure 2).

Table 5: RABT Fire

Time (minutes)	Furnace temperature (C)	Time (minutes)	Furnace temperature (C)
3	890	60	850
5	1200	90	500
10	1200	120	100
30	1200	120+	terminated

This test curve can be adapted to meet specific requirements, in testing to this exposure, the heat rise is very rapid, but is only held for a period of 30 minutes, similar to the sort of temperature rise you would expect from a simple truck fire, but with a cooling down period of 110 minutes. If required, for specific types of exposure, the heating period can be extended to 60 minutes or more, but the 110 minute cooling period would still be applied.

The fire tests carried out using the RABT Curve have slightly different failure criteria to the RWS requirements. For exposure according to the RABT Curve, the failure is regarded as the time the steel reinforcement reaches or exceeds 300°C.

The requirements of other countries who strictly apply fire protection to tunnels is as follows:

- France applies a curve similar to RWS but with 50°C lower maximum temperature;
- Japan applies 120 minutes RABT Curve for all fire protected tunnels;
- Ireland applies 180 minutes Hydrocarbon Curve to all new tunnels.

As can be seen from the prescribed, Ireland would generally apply the Hydrocarbon Curve in tunnel applications, but would extend the exposure period to which the structure must be protected against, this provides a trade off between a lower, less severe temperature rise, against the longer exposure period.

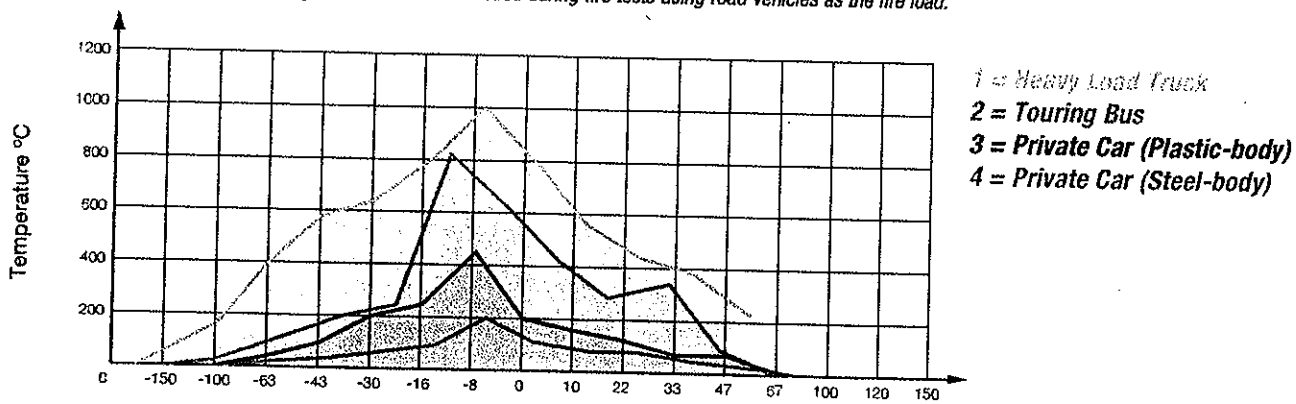
As can be seen from the table below detailing the typical fire loads and exposure periods, it is possible to utilise a Hydrocarbon Curve in place of using the RWS, provided the exposure period is extended.

Table 6: Fire Load / Fire Curves

Traffic type	Fire exposure period	Representative nominal fire curve
Pedestrian	0	None (negligible)
Bicycle	2 minutes	None (negligible)
Hay wagon	90-120 minutes	Hydrocarbon
Car (5-10 MW)	30-60 minutes	Cellulosic / Hydrocarbon
Container / Shuttle	120 (+) minutes	Hydrocarbon / RABT
Lorry (100 MW)	120 (+) minutes	Hydrocarbon / RABT
Tanker (300 MW)	120 minutes 240 minutes	RWS and/or Hydrocarbon
Bus	90-120 minutes	Hydrocarbon
MTR / Light rail (40 MW)	120 minutes	RWS / Hydrocarbon
Train	120 minutes 240 minutes	RWS Hydrocarbon

Figure 3: Temperature at Ceiling Level during Tunnel Fires

Maximum temperatures in the ceiling area of a tunnel recorded during fire tests using road vehicles as the fire load.



The temperatures detailed in Figure 3 above, are those taken from a series of fire tests carried out in disused tunnels, as part of a European research programme. The highest temperature shown of 1200°C was recorded in the area of a small lorry carry timber furniture. This shows that even loads which could be considered relatively safe to carry through a tunnel, can have a marked effect on the heat generated by a fire within an enclosed space. It should be noted that none of the vehicles used in the tests detailed above would in general be regarded as hazardous. It is estimated that a tanker load of petroleum spirit or liquefied gas would burn much hotter and for a greater duration than any of the above. As an example of this, take the scenario of a petrol tanker loaded with 45,000 litres of petroleum spirit, the fire load in this instance equates to almost 300MW with a fire duration of at least two hours before the spirit burns off.

This is based on the assumptions of the combustion energy of petrol of 2MJ and a pool area of fuel of 150m² (approximately a square area with sides equivalent to a standard tunnel width of 12 metres).

Tunnel fires are an animal of a different colour compare to the types of fire experienced in normal buildings with very hot temperatures lasting much, much longer. The tunnel itself sometimes works like a convection oven, drawing air in to fuel the fire. The air temperature during the Channel tunnel fire reached more than 1000°C , heating the concrete to nearly 1300°C.

Over the past hundred years or so, as stated in the introduction, millions upon millions of people have come to regard concrete as a solid and dependable product, used in every conceivable type of structure; for buildings, bridges, tunnels and sometimes even ships.

Concrete has always been thought of as behaving well in a fire. Not just because it is non combustible, but also because as part of a structure, concrete has better fire-resistant properties than, say, unprotected steel. Yet if we compare the loss of strength in concrete and steel as temperature rises we find that the two materials differ very little in this respect.

The fire resistance of a concrete structural member is derived from the following properties.

Low Coefficient of Thermal Conductivity

This term refers to the fact that the heat generated by exposure to fire is less able to penetrate structural members.

High Thermal Capacity

This means that the rise in temperature in the outermost surface layer of the concrete is far more rapid than in that within the depth of the concrete. As a result, the average rate of temperature rise in a concrete member is relatively low.

Mass

Because concrete has less inherent strength than steel, the cross sections of concrete structural members are always larger, given the same loadbearing capacity, than those of steel members. Only reinforced or prestressed concrete can absorb tensile stresses. However, the behaviour of the reinforcement is important not only in structural members subjected to bending and tension but also in reinforced concrete members subjected to compression.

In a fire, the rate of temperature rise to the critical temperature (approx. 500°C) in reinforcement subjected to tension is comparable to that in a steel girder, assuming that the steels are of approximately the same type and the maximum tension is of roughly the same order of magnitude. Experiments using standard fires (see Figure 2) have shown that where reinforcement lacks the protection afforded by the concrete this critical temperature of approx. 500°C is reached within 10 minutes of exposure to the sort of temperatures that would be expected under fire conditions.

Given that a concrete member has inherently good fire resistance, the question naturally arises why, then, it is necessary in certain circumstances to protect it with fire-resistant cladding. Laboratory tests have shown that concrete structures subjected to compression generally fail when their compression strength is exceeded. In practice it will be rare for an entire structure to be subjected to compression, except perhaps where prestressed concrete has been used.

In the laboratory the concrete cross-section is heated by a standard fire. As a result of this the strength of the concrete falls until the critical temperature is reached. The critical temperature depends on the load. Netherlands standard NEN 6071 sets out, in 10.1.2.1, a simplified method of calculating this. There it is assumed that a cross-section is fully loadbearing at a temperature of 500°C or less. However, this 500°C is not the critical temperature: the hotter shell continues to bear some of the load while the core is not 100% loadbearing.

What is Spalling?

When mature dried concrete is exposed to extreme heat for long periods of time, the chemical bonds between the water molecules in the concrete break, destroying molecular bridges that bind together the various materials that make up concrete.

As the water molecules are pulled out of the skeleton through dehydration, the concrete loses its cohesion and weakens, pushing pieces of the concrete off the tunnel walls in very thin layers resembling peel.

This phenomenon, called spalling, can eventually work its way through the entire concrete ring lining a tunnel, layer by layer.

- Free and chemically bound water combine to cause steam pressure build-up;
- Expansion ratio of water-to-steam = 1 : 1700;
- Temperature in excess of 500°C;
- Concrete grade dependant;
- Moisture content over 3% = spalling almost 100% within 30 minutes of exposure.

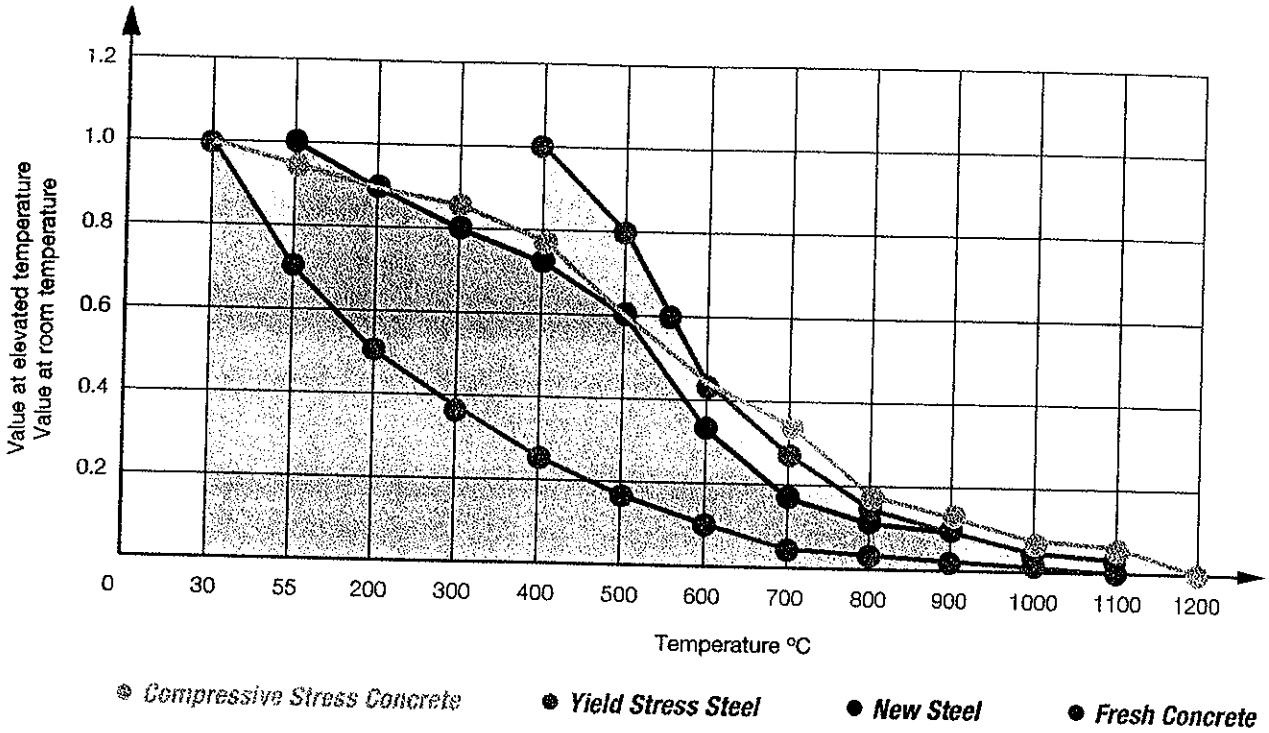
NOTE: On recent tests carried out on tunnels in Netherlands, the average moisture content of the concrete 10 years after construction was approximately 6-7%.

Figure 4: Spalling



Figure 5: Influence of Temperature on Concrete

Influence of elevated temperatures on the mechanical material properties of concrete and steel.



Rapid rates of heating, large compressive stresses or high moisture contents (over 5% by volume or 2% to 3% by mass of dense concrete) can lead to spalling of concrete cover at elevated temperatures, particularly for thicknesses exceeding 40mm to 50mm. This moisture is not only physically present, but also chemically bound within the concrete.

The latest investigations into the fire performance of concrete show that even the addition of polypropylene fibres into the concrete mix, will not suffice to reduce this water vapour pressure, and thus has little effect on reducing the incidence of spalling.

Such spalling may impair performance by exposing the reinforcement or tendons to the fire or by reducing the cross-sectional area of concrete. Concretes made from limestone aggregates are less susceptible to spalling than concretes made from aggregates containing a higher proportion of silica, e.g. flint, quartzite s and granites. Concrete made from manufactured lightweight aggregates suffer a lesser degree of spalling. The use of high strength concrete has been introduced as it can reduce the necessary thickness required to obtain a certain structural performance, however, high strength concrete is particularly prone to severe spalling when exposed to fire, as such, because the depth of the concrete has been reduced already, the effects of spalling are even more severe than normal.

Figure 6: Spalling in Brick Lined Tunnel



In addition to surface spalling, the in depth research that has taken place, both after real fires, and when tests have been carried out in disused tunnels (e.g. the Eureka project) show that deep cracks will appear in the concrete after the substrate has cooled down.

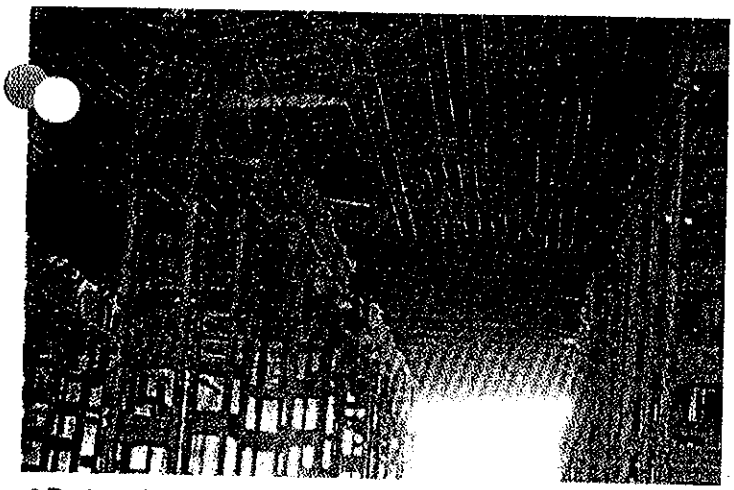
When spalling occurs - which can also be dangerous for the immediate environment due to the explosive nature of the spalling on some types of concrete the reinforcement is exposed. In a normal fire ordinary reinforced concrete is unlikely to fail completely but repair costs can be considerable. Where prestressed concrete has been used the detrimental effect of spalling is greater and more dangerous.

Criteria for The Fire Resistance of Concrete

As explained above, unprotected concrete with a moisture content of over 3% of the mass will suffer surface spalling in a fire, probably after between 5 and 30 minutes. It is also possible for aggregates in the concrete (e.g. quartz) to have undesirable effects on its behaviour in a fire.

The criteria for fire resistance has been drawn up by a number of official bodies. The Dutch standard gives it as a rule of thumb that in the case of loadbearing members account should be taken only of cores whose temperature is less than 500°C. At the tensions at which reinforcing steel is commonly used today, the steel starts to flow at 500°C. In statistically determinate structures this leads to failure. In statistically indeterminate structures redistribution of the moments is often possible, so that a higher temperature of the reinforcing steel need not necessarily lead to failure.

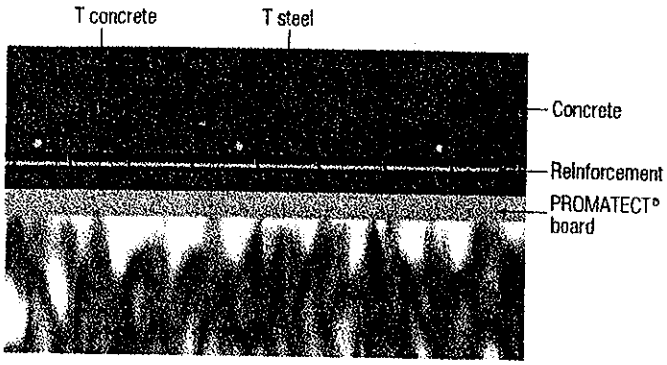
Figure 7: Spalling of Concrete After Real Fire



- Rectangular tunnels are typically constructed using a grade C30 concrete;
- Failure of rectangular structures is usually due to the premature development of sagging plastic moment caused by elevated temperatures of the concrete and the reinforcement;
- Rectangular structures suffer from less spalling than circular tunnels and have limited compression loads;
- ular tunnels constructed from segmented reinforced concrete sections typically use a C50 grade concrete;
- After completion, the reinforcement in circular tunnels is more or less obsolete, it is really only required to assist handling during installation;
- The reinforcement in circular tunnels is not required to take tension forces in sagging moment because the concrete is typically in compression;
- The higher strength concrete (C50) suffers a higher percentage and depth of spalling, the reinforcement will help retard the effect of explosive spalling though;
- The depth of spalling under fire conditions is an average 100% deeper on these types of circular tunnels.
- Concrete of close, small pore (e.g. B75) will also suffer substantial spalling in the event of exposure to fire.

Figure 8: Reinforcement Temperatures

Based on the requirements for exposure to an RWS type fire.



- Temperature on the concrete interface should not exceed 380°C (for bored tunnels this limit is 200-250°C)
- Temperature on the reinforcement should not exceed 250°C with a minimum of 25mm concrete cover (NOTE: For exposure to RABT, the reinforcement temperature should not exceed 300°C)

Bored Tunnels Using Concrete Segments

A bored tunnel refers to a Construction method for tunnels which involves digging a tube-like passage through the earth. Usually refers to tunnelling through rock, as blast tunnelling is not widely used these days. Bored tunnels are created using a full face boring machine this is a tunnelling machine which has cutting teeth at its front. It creates the tunnel opening while passing the waste material through the rear. Many types of tunnel boring cut small sections which are progressively enlarged. A full face boring machine cuts the complete cross section of the tunnel at once.

The TBM consists of a long machine with a circular cutting head that rotates against the face of the tunnel. Attached to the cutting head is a series of steel disk cutters that gouge out the rock on the face as the machine rotates and the cutting head is pushed forward by hydraulic power. TBM s provide several advantages over drilling and blasting. The tunnel can be bored to the exact size desired, with smooth walls, thus eliminating the condition called overbreak, which results when explosives tear away too much rock. The use of TBM s also eliminates blasting accidents, noise, and earth shocks. Workers need not be concerned with fumes or noxious gases and can clear away broken rock without stopping for blasting intervals. A TBM can advance about 5 metres (about 250 feet) a day, depending on the diameter of the tunnel and the type of rock being bored. Despite these advantages, TBM s have some drawbacks. They are very costly and the cutting head must be the same diameter as that required for the tunnel. They are useless in soft ground and mud, which may collapse as soon as the machine digs in and removes spoil.

Often the TBM is part of a long train of machines, at the rear are stored circular concrete sections, which are installed as the TBM moves along the route, thus the tunnel is simultaneously lined as it is being drilled. This was the method used for the construction of the Channel tunnel between England and France.

Immersed Tunnel

Immersed tube is a method of construction method using pre-fabricated tunnel sections. While the ends are sealed, it is lowered into position under the water and attached to other sections. Also sunken tube.

Another method of underwater tunnel construction uses a caisson, or watertight chamber, made of wood, concrete, or steel. The caisson acts as a shell for the building of a foundation. The choice of one of three types of caissons, the box caisson, the open caisson, or the pneumatic caisson depends on the consistency of the earth and the circumstances of construction. Difficult conditions generally require the use of the pneumatic caisson, in which compressed air is used to force water out of the working chamber.

Another method of constructing underwater tunnels, such as those like the Noord tunnel in the Netherlands, have been built by fabricating short tunnel sections in a trench in or near the riverbed or seafloor. Each section, after completion is then sealed at the ends, floated out and located in position, where it is then sunk onto the riverbed. After sinking the sections are then attached by oversized bolts to the previously sunk section in line. Heavy, thick concrete walls prevent the tunnel from floating once the water is pumped from the completed sections.

Cut & Cover Tunnels

A construction method which involves excavating a large trench, building a roof structure, then covering it with earth. Commonly used for subways and relatively flat locations.

The cut-and-cover method can also involve digging a trench; building the concrete floor, walls, and ceiling, or installing precast tunnel sections; and then refilling the trench over the tunnel. In built-up areas in cities, use of this method is often not possible. In soft earth or mud, a large-diameter pipe like device can be driven through the ground by jacks or compressed air. Workers remove the earth as the pipe moves forward, its edge cutting into the earth.

One method of building a form of cut and cover tunnel is detailed in this document (see page 10), in the instance detailed, the diaphragm walls are constructed within a trench, the roof is then built over the earth and once the concrete has set, the spoil within the tunnel is removed. In this manner, the earth left in position between the diaphragm walls can be used to act as a base for the formwork.

Where daily use of a road or rail tunnel involves high traffic loads, the demands placed on means of attachment will be more onerous. Traffic passing through a tunnel causes high suction loads on ceilings due to the displacement of air by vehicles. This suction load depends on the type of vehicle (e.g. car, train or tram) and the headroom. The value usually taken is 100kg/m². The weight of the cladding and the number of attachment points can be determined by means of a load simulation for traffic passing through a tunnel. The manufacturer of the pertinent cladding material should provide reports which show the exact types of fixing methods employed, and the loads from suction etc that the systems are designed and tested to take.

Attention need also be paid to the material from which the fixings are manufactured, e.g. fixings can be zinc galvanised steel, stainless steel etc; and the condition of the concrete itself.

Therefore, before any choice of fixing can be made, consideration has to be given to three important elements. The likely corrosion to which the anchors may be subject, the crack width if any, and the compressive strength of the concrete.

Corrosion

Following extensive research, anchors made from stainless steel grade 1.4401 and 1.4571 have been banned from use in chloride contaminated atmosphere. An atmosphere with extreme chemical pollution such as road tunnels have an extremely corrosive environment, caused by traffic pollution (sulphur oxide); the ingress of underground water (sodium chloride, sodium sulphate, calcium sulphate); materials and chemicals used for de-icing, and the possibility of salt laden air in coastal regions and by rivers. Combined with the fluctuating air pressure from passing vehicles, this leads to ideal corrosive conditions and thus stainless steel fixings of these grades are unsuitable as the atmospheric pollution can possibly result in stress corrosion cracking of the fixing.

As a result of the recent research carried out, only anchors made from high alloy stainless steel should be permitted for use in tunnel applications.

Crack Width in Concrete

In accordance with many international standards (e.g. BS, DIN, Euro codes), the maximum acceptable crack width in reinforced concrete is limited to wk=0.3mm under semi permanent loadbearing conditions. If structures are subject to exceptional loading i.e. seismic, then there is a possibility that wider cracks could occur. Recent analysis shows that the cracks in reinforced concrete structures could be as wide as 1.5mm after being subjected to earthquakes to the maximum design load.

Anchors could be situated near to, or even within cracks in the concrete, and as worst case, could even be positioned at the intersection point of two cracks. Tests have confirmed that in the event of concrete cracking, there is a high probability that at some point, these cracks would radiate into contact with the fixings. This is particularly true of expansion bolts, because there are local tensile stresses in the area surrounding the fastening due to the expansion forces of the bolts.

The type of bolt to be used should be chosen with due consideration of the possibility of the concrete cracking, and an appropriate type of fixing utilised.

Compressive Strength of Concrete

If a tunnel is constructed using high strength concrete, the nominal compressive strength of the concrete would be approximately 60N/mm², however, it is often the case that the compressive strength is far higher than this, at around 90 to 100 N/mm².

Anchors in which the fastening is by means of torque control or displacement controlled friction locking are not suitable for use in this type of high strength concrete, torque controlled anchors are not capable of creating the deformation in the concrete which is required for the bolt head to expand into, and thus the load would be held by friction of the bolt within the drilled aperture only, because a drilled hole tends to be smooth, the friction between the anchor and the hole is minimal and the loading that can successfully be applied is rather low.

For fixing into high strength concrete, undercut anchors should be used, as these do not rely on the compressive strength of the concrete, nor the smoothness of any drilled hole.

With the research that has taken place over the last ten years or more, both by fixing manufacturers and independent research bodies, it has been determined that the optimum material for fixings in tunnels should consist of stainless steel of grade 1.4529. This material is resistant to all types of corrosion, surface pitting, and corrosion induced stress cracking.