PUBLISHED IN 'FIRE AUSTRALIA' WINTER 1991

# Fire Protection

in the

# *Sydney Harbour Tunnel*

by Rick Foster, Director, Eagle Consulting Group

When completed in August 1992, the 2.3 km tunnel, being constructed by a Transfield-Kumagai Joint Venture, will provide two dual carriageway road links between the Warringah Freeway and the Cahill Expressway (figures 1 and 2).

The tunnel comprises three major sections:

- Twin 900 metre land tunnels between the Warringah Freeway, just north of the High Street Overpass and Milsons Point (figure 3).
- A 960 metre Immersed Tube, made up of eight prefabricated reinforced concrete units, between Bradfield Park and the concourse west of the Opera House (figure 4).
- Twin 400 metre land tunnels between the concourse and the Cahill Expressway, north of the Domain Tunnel (figure 3).

Ventilation Stations for the Tunnel are being built underground at Milsons Point and in the North Pylon of the Bridge. Air is drawn in by fans in the Tunnel Ventilation Station (TVS), circulated through the tunnel, then drawn back via a buried concrete duct between the TVS and Pylon by fans in the Pylon Ventilation Station (PVS), discharging at the top of the pylon.

## Traffic Monitoring and Control

Traffic will be monitored around the clock from a Control Centre with direct links to emergency services. Road-mounted loop detectors linked to computers will alert Tunnel operators to traffic incidents, and all sections of the Tunnel will be monitored by closed-circuit television.

A low-powered radio transmitter will re-broadcast selected AM and FM radio stations and emergency channels, to maintain radio reception in the Tunnel. Operators can override this system to broadcast direct to Tunnel users. Advisory signs in the Tunnel and approaches will be used to inform and instruct drivers.

## Fire Services

Selection and design of the fire services falls into two distinctive areas. For first stage response by either motorist or emergency service personnel, hydrants, hose reels and portable fire extinguishers will be installed adjacent to emergency telephones at approximately 60 metre intervals.

World-wide research and experience indicate that such equipment will adequately provide for any expected incident and the experience in Sydney with the Cahill, domain and Mascot tunnels confirms this.

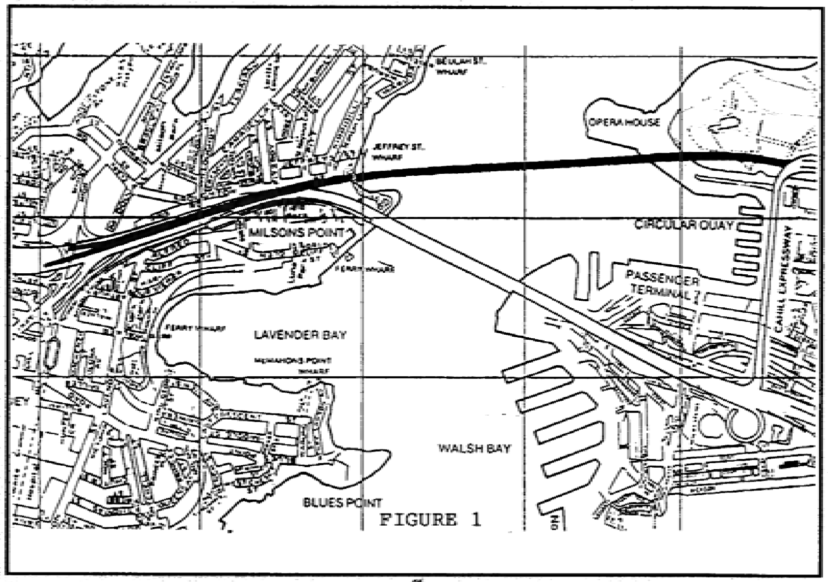



FIGURE 1

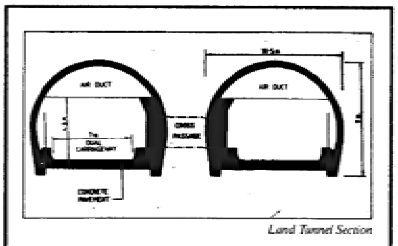



FIGURE 3

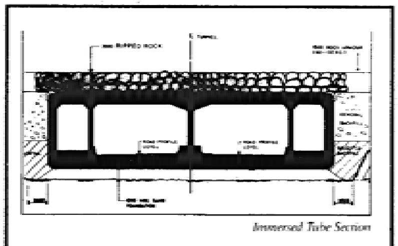



FIGURE 4

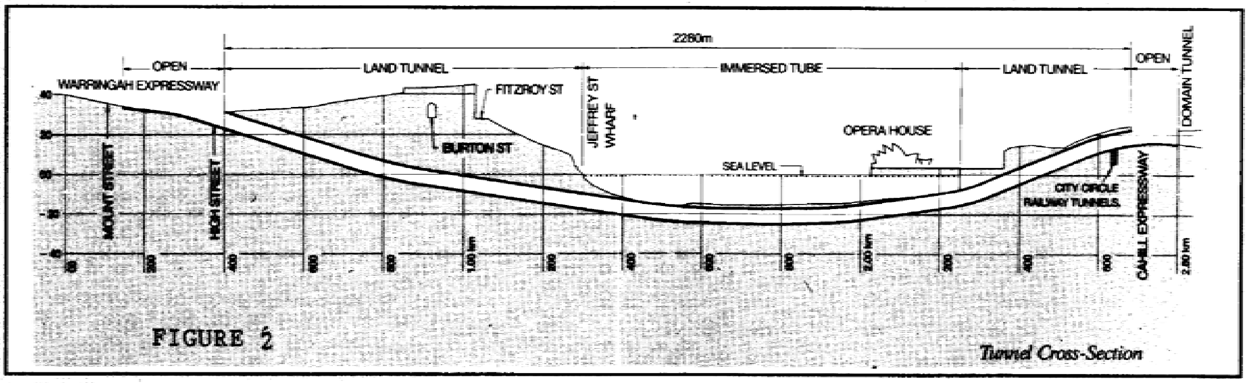



FIGURE 2

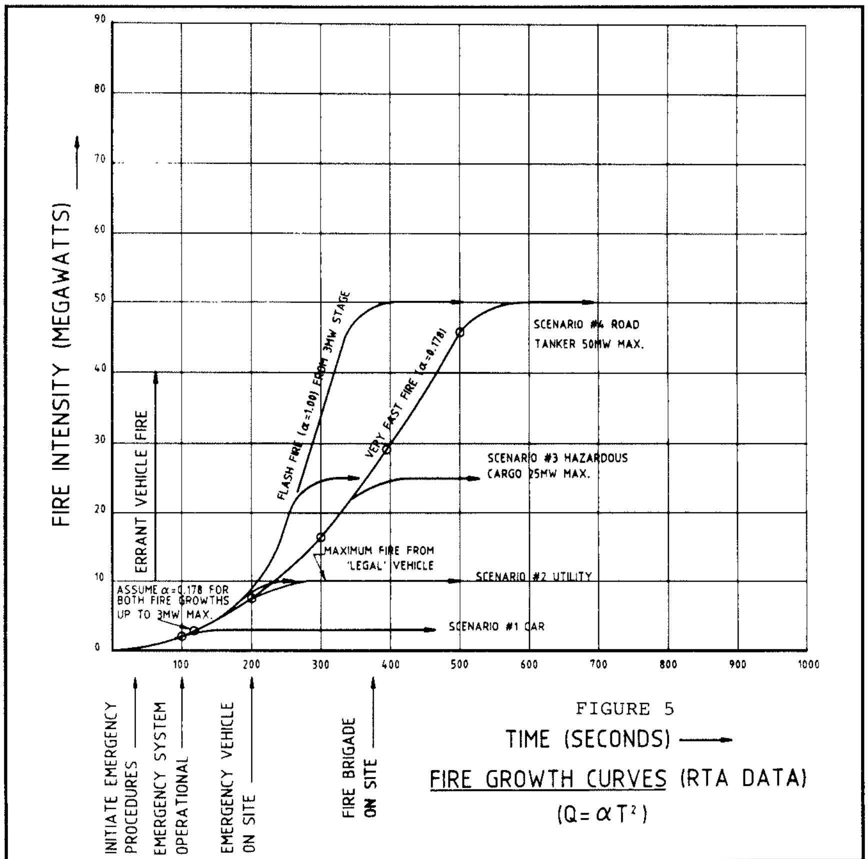



FIGURE 5

TIME (SECONDS) →

FIRE GROWTH CURVES (RTA DATA)

$(Q = \alpha T^2)$

Although vehicles carrying dangerous or flammable goods will be prohibited from using the tunnel, the possibility of an "errant" vehicle being involved in an accident and subsequent fire led to the development of automatic fire detection and manually operated deluge systems.

## Fire Scenarios

The Roads and Traffic Authority of NSW determined that there were two fire scenarios for "legal" vehicles and two for "errant" vehicles, these being:

1. A 3MW car fire. The fire growth characteristics of this type of fire are depicted on figure 5, approximating the NFPRS/ NFPA 13 fire growth curve for a "medium fire" with an alpha value of 0.0115. These are the minimum expected values for any fire in the tunnel.
2. A 10MW utility fire. The growth characteristics of this type of fire are depicted on figure 5, approximating the NFPRS/ NFPA 13 fire growth curve for an "Ultra Fast Fire" with an alpha value of 0.18. These are the maximum expected values for a legal vehicle.
3. A 25MW hazardous cargo fire. The fire growth characteristics of this fire is depicted on figure 5, approximating the NFPRS/ NFPA 13 fire growth curve for an "Ultra Fast Fire" with an 0.18 alpha value.
4. A 50MW road tanker fire. The fire growth characteristics of this type of fire are depicted on figure 5, approximating the NFPRS/ NFPA 13 fire growth curve for an "Ultra Fast Fire" with an alpha value of 0.18. These are the maximum expected values and can only be generated by an "errant" or illegal vehicle. This maximum "errant vehicle" fire cannot be constructed as being unlikely as road tankers are not unique in producing fires of this intensity.

## Design and concepts

To meet the various Authority requirements, the following technical criteria were required to be met:

a) Incident monitoring by under road vehicle detectors;
b) CCTV;
c) Thermal fire detection above each carriageway;
d) Manually operated deluge systems covering designated carriageway zones.
e) A control centre with computer facilities to assist - dependent on incident reporting from the vehicle detectors, the air flow direction and velocity and operation of any above carriage-way detectors - selection of which deluge zones should be manually operated. Also audio and visual warnings and instructions may be given to motorists whilst on-site emergency service personnel and fire brigades can be dispatched to any incident.

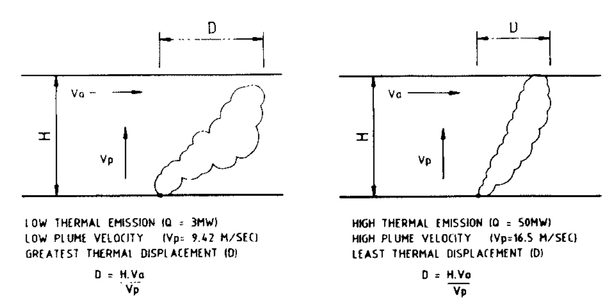



FIGURE 6

PRE FLASHOVER FIRE SCENARIOS SHOWING DIFFERENCES BETWEEN DISPLACEMENT OF FIRE PLUME

The requirement for a manually operated deluge system was developed by the RTA and NSW Fire Brigade to reflect the uniqueness of the tunnel in relation to its length, location and projected traffic volume.

## Ventilation effect

The single most difficult aspect in designing a fire detection and suppression system is the effect of the ventilation on the fire plume and/or hot gases being released from the fire. An added complication is the possibility of a moving fire - especially unseen on a truck.

To accurately determine the dimensional relationship between the virtual point of a spill fire and the point at which detection is likely to be effected, the effect of ventilation on a fire plume must be established.

This can be demonstrated in figure 6 which shows that displacement of the plume is dependent on the plume velocity and the air velocity. The plume velocity is dependent on the thermal emission from the fire.

In the Sydney Harbour Tunnel, with the ventilation station being at approximately mid-point, the ventilation effect is very complex and not uniform over the entire tunnel.

Additionally air velocities may vary widely dependent on traffic volume and can be as high as six metres per second when in the emergency smoke extract mode.

It was principally the above that precluded the adoption of an automatic sprinkler system although the psychological effect of sprinkler operation were also considered.

## Design development

It was recognised that existing fire protection standards (such as AS 2118 - Automatic Sprinkler Systems and AS 1670 - Automatic Fire Detection and Alarm Systems) could not be expected to fully cover the complex and unusual environmental and operational conditions.

Consequently Eagle Consulting Group were invited to join with the RTA and the Fire Brigade to develop additional performance criteria for the system and select candidate equipment for both laboratory and field testing.

## Detector selection

It was originally regarded as essential that a thermal detector with both "fixed temperature" and "rate of rise" characteristics was employed. Use of the computer programme DETACT-QS indicated that for a 50MW "errant vehicle" fire, detectors, dependent on their RTI would operate between 15 to 25 seconds on "rate of rise" and between 71 and 109 seconds for a 57°c fixed temperature setting.

It was accepted that the initial "cue" of an incident would be less than 15 seconds from the traffic movement sensors. This is accepted as being better than the detector response but after the initial incident cue, it was considered necessary for on-going data regarding fire movement to be provided and this would be given by the detection system.

The required spacing for thermal detection is set out in AS 1670 and indicates a maximum spacing of 7 metres. An alternative spacing of 10 metres for corridors not exceeding 3.5 metres wide is also given.

It was considered that this extended spacing could be applied to the tunnel if regarded as a corridor not exceeding 7 metres wide and used two rows of detectors spaced every 15 metres.

The rationale behind this argument was that the expected normal air flow velocity of some 5 metres per second would compensate for the increased spacing.

The use of a standard thermal detector in this environment was still somewhat worrying. Experience in this area led us to believe that the maintenance factor would be very high with frequent detector replacement and, most importantly, an unacceptable degree of false alarms due to condensation and corrosion of detector terminals and general deterioration.

Investigation of alternative detectors resulted in the following two being considered.

The first, and most promising, candidate was the Cerberus D2401 detector which had been specially designed for use in road tunnels, and had found extensive use in road tunnels in Europe, America and Japan. This detector is specially designed and calibrated in its dual level of alarm, that is, first level alarm at 5°c per minute, second level at 10°c per minute and an overriding fixed temperature alarm at 58°c.

The detector was weather-proof to IP66 and would far out perform the standard thermal detector in service life expectancy.

Spacing of this detector was recommended at 20 to 25 metres which means that only about one third of the number is required if spaced at 15 metres in the 30 metre zones. The individual detector cost was, however, very high.

Secondly, the Wormald T54B detector looked like being a promising candidate as it was of stainless steel construction, was weather-proof and the terminals could be fully enclosed.

Unfortunately it had no rate of rise capability although was of the "rate compensating" design.

With the assistance of Wormald Technology, laboratory testing of three types of detectors, the Wormald T56B (Type A electro-pneumatic) Wormald T54B (rate compensated) and Cerberus D2401 were tested in their sprinkler RTI testing apparatus over a range of criteria including air velocities for 5 to 20 m per second and temperature ramps of 5°c to 30°c per minute.

Further testing of the candidate detectors for false alarms was carried out in the Kings Cross Tunnel (picture 1). The detectors were mounted at the expected installation height and the exhaust stack of the turbo-charged diesel truck was positioned directly underneath to simulate a vehicle in stationary traffic.

With only moderate increases in engine revs the Wormald T56B Type A "rate of rise detector" consistently actuated whilst the Cerberus D2401 and Wormald T54B detectors were not affected. Thus Type A detector was eliminated on the grounds of unacceptable false alarm criteria.

The final results indicated that the Wormald T54B rate compensated thermal detector would prove the most cost effective with acceptable response times and minimal false alarm rates.

Picture 1: Testing of candidate thermal detectors in the Kings Cross Tunnel to determine false alarm tendancy from vehicle exhaust stacks

Thus the specification for the detection and spacing was determined:

- Detectors are fixed temperature (54°c setting), rate compensated type of stainless steel construction and hermetically sealed. (Wormald/Olsen type T54B.)
- Detectors are spaced throughout each tunnel as follows:
  - Two across the roadway, one above each lane.
  - An additional row in breakdown bays.
  - Pairs of detectors spaced every 15 metres along the length of the tunnel, one pair at each zone juncture and one pair at the mid-point of each zone.

## Detection and Deluge Control Systems

The only viable option for control and indication was to use modern addressable function technology. Hard-wiring the detectors, pressure switches, manual alarm points and valve operating controls would involve many hundreds of kilometres of cabling.

Consequently, the following design criteria were established.

a) ***Fire Indicator Panels (FIP)***

Two FIPs are provided to receive signals from the detectors. One situated adjacent to the Fire Brigade Booster Room in the TVS structure and the other in Macquarie Street valve house.

The FIPs are of the addressable type (Wormald F200HS). The FIPs also receive signals from flow switches on the two principal incoming fire mains and from the Deluge System pressure switches. The FIPs process the incoming alarm signals and transmit the required data to the CCCS on the Communications Network.

b) ***Mimic Panels***

A Mimic Panel is provided at each FIP, showing a schematic of that portion of the tunnel controlled from that FIP, with red LEDs indicating groups of detectors in alarm at the respective positions on the mimic.

Each Mimic Panel overlaps into the three adjoining zones being controlled from the other FIP.

In addition, the Mimic Panel has, in each zone, a further green LED indicating pressure switch operation from the deluge system. A toggle switch to operate the deluge system is positioned in each zone on the Mimic.

c) ***Deluge Control Panel (DCP)***

Deluge Control Panels are provided adjacent to each FIP to provide control of the deluge systems. The DCPs receive commands from the control Centre to initiate (either on or off) pilot solenoid valves at the deluge valves. An "enable" key switch on the panel fascia is provided to enable the deluge control switches on the Mimic panel to initiate the deluge systems, overriding the remote control. The Deluge Control Panel is a Wormald F200HS, in an adjoining cabinet to the FIP.

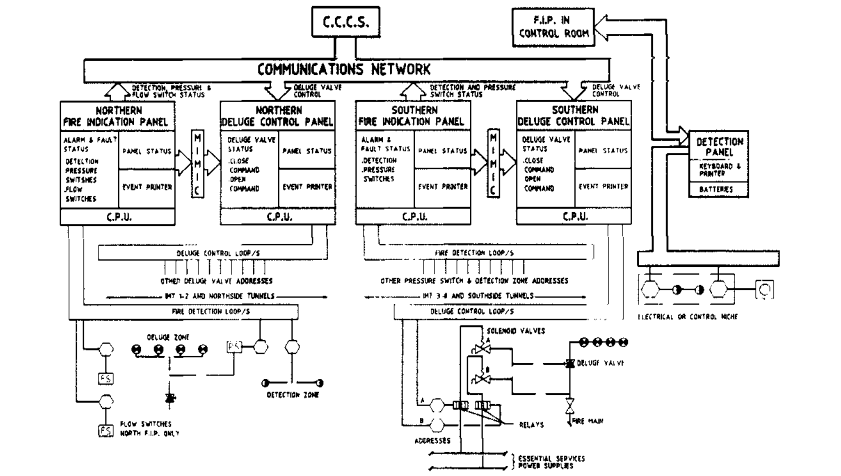
d) ***Panel Configuration***
Both FIPs and DCPs are provided with separate power supplies. The Mimic Panel is installed on top of the two panels. The FIPs and DCPs are capable of independent operation with separate batteries, printers, and EPROMs. A spare fully programmed EPROM for each installed EPROM is mounted in a suitable position in each panel to facilitate prompt changeover in the event of EPROM failure.

e)***Addressable Configuration***
Both the FIPs and DCPs are connected to their relevant field devices as follows (figure 7.): *FIPs* - One addressable data unit for each pair of detectors across the tunnel (or, in the TVS and Southern Transition structure, each three detectors where relevant in the breakdown bays). This provides the necessary signal to the FIP to indicate an alarm at all zone junctures and mid-zone points. One addressable data unit for each deluge system pressure switch. One addressable data unit for each flow switch.

A separate FIP is provided for the detectors in the Electrical and Control niches and the Manual Alarm points in the motorists' Emergency Telephone niches.

*DCPs* - Each deluge valve is fitted with twin solenoids and have addressable data units provided for each solenoid. These units switch on or off as appropriate, relays connected to separate 240C AC 50 Hz essential services supplies from an adjacent Distribution Board provide the necessary power supply.

Both solenoids are either energised or de-energised simultaneously to provide fail-safe opening of the deluge valve in the event of solenoid, address or relay failure.




FIRE DETECTION AND DELUGE SYSTEM CONTROL SCHEMATIC - FIGURE 7

e) ***Loop Cabling***
The FIP and DCP loop cabling for all addressable devices is run entirely in fire rated cables. This loop runs along the tunnel over one carriageway to addressable data units mounted inside the junction boxes of one detector every 15 metres. The two detectors at this transverse point are connected in parallel to the address. The second detector of the pair is in a separate junction box (without address unit) and connected to the first detector by a spur cable (fire rated).

## Zone Design

An analysis of available water supplied from the Water Board mains, and extensive hydraulic analysis of various options indicated that the most cost-effective design was for zones of 30 m in length with minor variations in the Tunnel Ventilation Station and Southern Transition Structure-figure8.

With two adjacent deluge zones operating simultaneously the demand of 4,320 litre/minute (72 litres/second) can be met by both of the principal North Sydney mains.

There are a total of 156 zones in the tunnel.

## Nozzle Selection

Without pre-empting the selection of system type, it first had to be established whether or not a sprinkler system (be it closed or open head) would be effective in suppressing any expected fire. Perhaps the simplest method was to treat the tunnel as a storage area and analyse the requirements under AS 2118 - the Sprinkler Code.

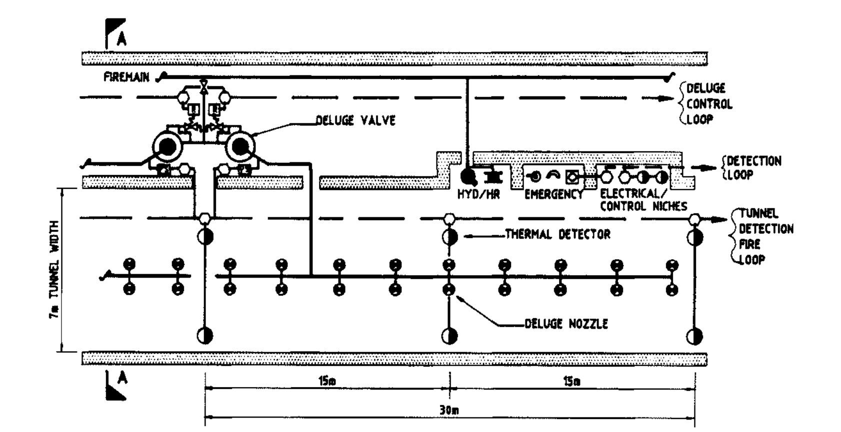
Two trucks, parked side by side, with an overall height of 4.5 m, could be construed to represent block storage of materials - 4.5 m in height. Thus, if they were carrying rolled paper they could be classified as Extra High Hazard - Category 2 and would require 10 l/m/m$^2$ discharge over an area of operation of 260 m$^2$.

This equated almost exactly to the pre-determined design criteria of a 30 m zone (225 m$^2$) with a manually operated deluge system discharging 10 l/m/m$^2$.

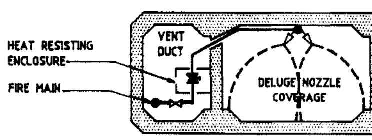
It is important to note that tests carried out in 1988 by Underwriters' Laboratories for the NFPRF/NFPA quick response sprinkler project reported that in tests on plastic commodities using 10.175 l/m/m$^2$ water density - the fire was not fully extinguished, although control was effected. It was only when the discharge density was increased to 20.35 l/m/m$^2$ that effective extinguishment was achieved.

This supports the limitation of vehicles with the potential for fire scenarios in excess of the 10MW legal vehicle and demonstrates that although control can be achieved with a density of 10 l/m/m$^2$ on fires in excess of 10MW, that manual fire fighting techniques would still have to be employed to guarantee total extinguishment in those cases.

In addition, for a sprinkler to function successfully and extinguish a fire, the droplets must be capable of penetrating the fire




TYPICAL DETECTION/DETECTION ZONE - FIGURE 8
(ONE SIDE OF IMMERSED TUBE UNIT SHOWN)




SECTION AA

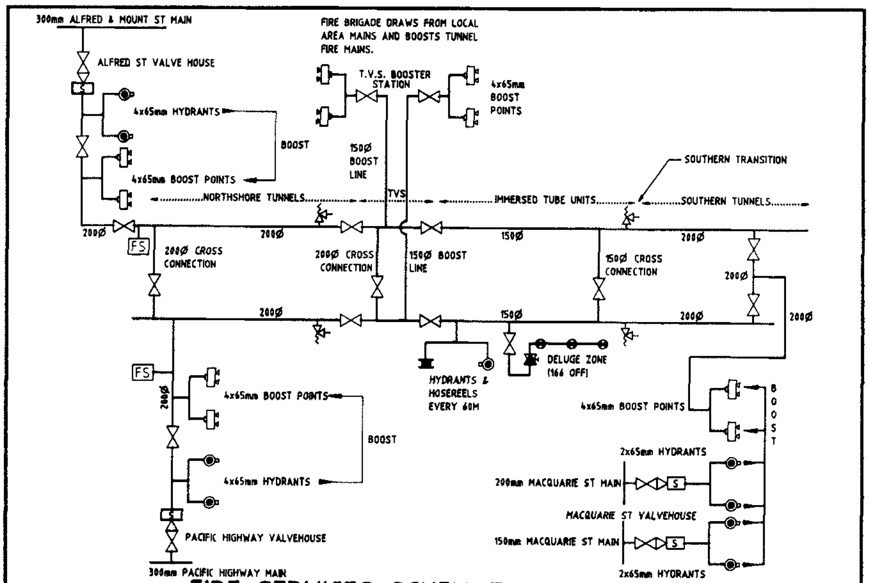
plume to reach the burning fuel surface. Researchers have identified two regimes, one in which the total downward momentum of the spray was sufficient to overcome the upward momentum of the plume, while in the other the droplets were falling under gravity. In the gravity regime, the terminal velocity of the air droplets would determine whether successful penetration could occur.

It was with this in mind that the performance criteria of the nozzles was determined. Candidate nozzles were tested in the sprinkler testing laboratory at Wormald Technology - Dee Why and a modified Wormald HV60 was selected.

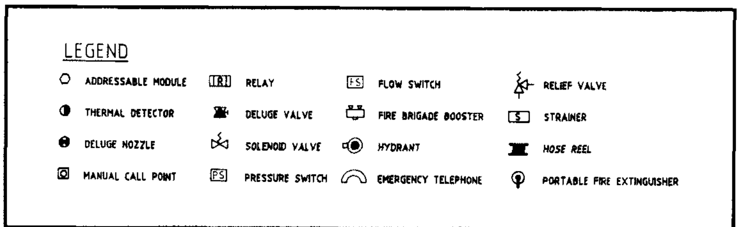
The size, type and orientation of the deluge nozzles was tested to provide an average density of water discharge of 10 l/m/m². An allowable variation of +/- 20% in any one square metre of operation was permitted.

When two adjoining zones were operating simultaneously, the distribution pipe design and any required orifice plate area was required to limit the water demand at those two zones to -0% to +5% of the total flow to achieve the average design density.

This limitation of -0% to +5% of the total flow was imposed to equate the flow of water into the tunnel to the design criteria of the drainage pumps and rising mains.



FIRE SERVICES SCHEMATIC - FIGURE 9




## Deluge Valves

*In order to meet the design criteria for a* manually controlled deluge system with both "on" and "off" control, selection of an appropriate control valve was between motorised ball valves or "cycling" deluge valves.

An approved (UL/FM) cycling deluge valve operated by a pilot solenoid was finally selected. The Viking deluge valve is diaphragm operated, has a top chamber which, when pressurised by water from the fire main, hold the seat closed. The water supply to this cham-ber is via a series of valves and a restricted orifice. When the pressure in the chamber is relived by means of a solenoid valve, the deluge valve opens. If the solenoid is then closed the deluge valve shuts.

Picture 2. Performance testing of deluge valve assembly at Wormald Fire Systems, Ashfield NSW. From left to right: Peter Setright, Bill Fleming - Transfield Kumagai, Berndan White - Roads and Traffic Authority and Rick Foster - Eagle Consulting Group.

Function testing of the selected deluge valve was carried out at Wormald Fire Systems - Ashfield to determine the opening and closing times of the valve under the specified flow and pressure conditions. Opening and closing times of less than 5 seconds each were recorded (picture 2). Generally deluge valves are installed in pairs within a common fire rated enclosure with a single 150 mm connection to the fire main.

## Fire Mains

Figure 9 shows the arrangement of the fire mains within the tunnel with permanent connections to two principal North Sydney supplies.

Provision for Fire Brigade Boosting of the fire main is provided at each of the connection pints together with further provision at the TVS structure and at the southern extremity from the Macquarie Street mains.

The fire mains feed all 156 deluge valves together with hydrant and hose reel stations paced at 60 metre intervals along each tunnel.

The fire mains are in galvanised steel with roll grooved couplings and fittings. An analysis of this method of installation was carried out which proved significant cost performance benefits over a welded or flanged systems.

The use of Victaulic HP70ES couplings with "Fire-R" gaskets was permitted by the Fire Brigade in order to maintain integrity of the water supplies during any fire condition.

## Conclusion

The development of the various detection and suppression systems for the Sydney Harbour Tunnel has been an interesting project. Considerable International interest has been shown in this project to the extent that the concepts and techniques developed may well be adopted by PIARC (Permanenct International Association Road Congress) for future tunnel fire detection and suppression systems.

It should be emphasised, however, that the design concepts adopted for the Sydney Harbour Tunnel, in particular the deluge system which was considered acceptable for this project, should not be arbitrarily applied to every tunnel constructed without taking into account all relevant factors relating to each individual project.

**Acknowledgements** The writer would like to acknowledge the following for their assistance and direction: Roads and Traffic Authority of NSW - in particular Brendon White and Bruce Judd; Transfield-Kumagai - in particular Bill Fleming, Peter Lukins, Jeff Tullock and Peter Setright; NSWFB - in particular Barry Eadie; Wormald Technology - in particular Tim Magee; Wormald Fire Systems - in particular Richard Raine and Paul Mamo. The Sydney Harbour Tunnel is a Transfield-Kumagai Joint venture. Design Consultants - Mechanical and Electrical Works: GHD, Maunsell, Parsons Brinkerhoft Int Joint Venture. ■