Fire and the civil engineer

R. F. LEGGET & G. W. SHORTER

Mr Legget

One cannot predict when fires are going to start. However, Mr Shorter, myself or one of our immediate colleagues were on the site of the fires described as soon as possible, with one exception, and we therefore speak from the experience of seeing the results of fires rather than fires themselves.

73. Structural engineers are associated with the design of engineering structures and buildings. The incorporation in building design of fire prevention procedures and fire prevention principles is becoming increasingly important because of the sudden increase in the number of very tall buildings. These bring special problems and I should like to stress the importance of the chimney effect.

74. The traditional separation of structural design from the general arrangements of building and therefore from fire protection features of design as required by building regulations is gradually disappearing—as it should. An integrated approach is necessary to the provision of fire precautions in civil engineering structures and building design in which the structural engineer and the architect must work so closely.

75. The introduction of continuity into structural design as in buildings is leading to other aspects of general design that are demanding special attention. The prevention of progressive collapse is only one such feature. Since this can occur in a bad fire under extreme circumstances this aspect alone seems to make it essential that the civil engineer must be involved in the fire protective aspects of design.

76. It is regretted that in § 71 Mr R. J. Hansen's initials were given incorrectly.

Mr G. A. Wilson, Consultant

I have been interested in fire protection in the Port of London Authority for about 20 years. There is a London Fire Offices' Committee and unless buildings satisfy their requirements the insurance rates are high.

78. Since 1950 there have been two sizeable fires in London, one destroyed a warehouse and the other a cargo shed about 400 ft long. The difficulty in dock work is that although the building may be designed to be fire-resistant, the contents are frequently high risk. Fire drill is important and in London where a fire engine arrives within a few minutes of a call, the standing instruction is that anyone who discovers a fire, immediately calls the fire brigade before attempting to deal with the blaze.

79. The cargo shed was full of general cargo, and although the fire engine arrived in three or four minutes the shed was completely burnt out. In the case of the multi-floor warehouse, the firebreak wall through the building was an effective reduction of risk.

80. Although experience during the Second World War confirmed the importance of firebreak walls, subsequently storage areas increased for operating reasons to over a million cubic feet.

81. Investigations with the Fire Research Station, the Fire Offices' Committee and users indicated that sprinklers would not be welcome because the damage created by water was often excessive, and it was decided that floor and roof ventilators to get rid of smoke should be provided to enable firemen to reach the site of the fire.

82. The University of Edinburgh is going to inaugurate a Chair and a Department of Fire Engineering.

Mr J. W. Baxter, G. Maunsell & Partners

In Dr Legget's experience have there been any examples of the chimney effect combined with a tunnel fire? A tunnel can be a severe hazard. If a tunnel, particularly a highway tunnel, is on an incline and a vehicle catches fire, the consequences are horrific because the chimney effect would mean that air would be drawn up the tunnel to feed the fire, and above the fire the air would be vitiated and when people tried to drive away from it their cars would stop from lack of oxygen and the people would suffocate.

84. In such a development as the Place Ville Marie were special precautions taken to isolate the buildings above the shopping complex?

Mr D. H. New, G. Maunsell & Partners

Recently I saw a practical demonstration of the value of a firebreak wall. A fire broke out, due to boiling fat being left unattended on a gas stove in one of a pair of semi-detached houses in St Austell. Everything in the house was destroyed, but the presence of the party wall and prompt action by the fire brigade saved the other.

86. The value of prestressed concrete as a material resistant to fire was well demonstrated during the construction of shop floors for the St Pauls Cray housing estate in the early 1950s. A series of squat floor beams, with hollow clay pots between, acting compositely with a concrete floor finish, and plastered beneath, were put under test at the Fire Research Station at Elstree, with a view to obtaining a two hour certificate for the floor. It was possible to keep the test going for four hours and obtain a certificate for this increased period.

Mr J. P. Bamber, FICE

I had to extend the runway at Manchester Airport and put the local A road in a tunnel. There could be no connexion between the tunnel and the runway above. One does not want the aircraft to stop and drop fuel into the tunnel or vehicles underneath to catch fire and damage the runway. The tunnel was fitted out to make it almost automatic. There were smoke, carbon monoxide and temperature detectors which were all connected back to the airport control office. It was considered that as soon as anything was detected the 'crossing gate' type flashing road traffic lights at the end of the tunnel could be changed to red and that fire engines could be at one end or the other within 2½ minutes. In three years there has not been any trouble.

88. In another unusual case a sewer caught fire in an old part of Manchester. It was a fairly shallow brick sewer of about 18 in. diameter. The Gas Department had cut a main through and this had been damaged. When it caught fire it acted like a gas stove. It was decided that the fire had been going for about ten days because the ground above was warm and the rain dried up immediately it fell. Also steam was coming out of the manholes lower down. It was difficult to extinguish the fire. It was possible to get into the main sewer and look up the branch sewer and see the flames, but the Gas Department had to dig down on each side and cut off the main to stop the gas escaping further.

Mr Wilson

Are there any reliable fire detecting instruments which are actuated by smoke, light or heat? What area can be protected with this type of equipment?

90. When the information is received, what action is taken? This involves the problem of insurance.

Mr F. R. Dinnis, City Engineer and Master of Works, Edinburgh Corporation

A serious underground railway fire occurred under Barcelona in September 1966. The railway runs east to west and north to south so that the system forms a large cross under the city. This railway carries many passenger and freight trains. It is a cut

and cover tunnel. There are strict 'no smoking' notices on all the stations and in the passenger trains.

92. The fire was caused, or at least fed, by a freight train with oil wagons. The driver stopped the train where he thought best—in the station. Drivers of passenger trains on the other lines drove on, thereby saving many lives.

93. I am interested in bridge design and motorway structures. There has been at least one fire in the UK under an elevated road structure constructed recently. Engineers are told that elevated motorways are a blot on the landscape and take up valuable ground. I think there is a current trend for schemes using the space under elevated structures for other purposes. If there is anything but free air under an elevated structure there may be great risks attached to it. Have the Authors any experience of that sort of thing?

94. There is much talk in the UK about the need for adequate fire protection, yet the incidence of fire in multi-storey car parks is very low. I think that current design codes permit unprotected steel in some multi-storey car parks. Is this low incidence of fire true in other countries?

Mr W. A. Morris, Fire Research Station

Since 1969 the Fire Research Station has investigated three fires under motorway bridges. Only one of these bridges was in use; the other two were in the construction stage.

96. The first instance was a case of bad practice on the part of the contractor. It involved a bridge where there was little clearance between the supporting columns and the soffit of the bridge deck. They had to remove timber shuttering which had been around the bridge bearings and decided that the best way to do this was to burn it away using oxy-acetylene. The highly stressed concrete bearings were not badly damaged but the damage to the soffit of the bridge although local was fairly severe.

97. The second instance involved the storage of diesel fuel under a bridge. A fire involving some 40 gallons of fuel resulted in damage to the underside of the bridge.

98. In road construction projects, bridges often provide sheltered locations in otherwise exposed situations and contractors often take advantage of this.

99. The third incident was also due to storing plant and materials under a bridge. In this case a trailer mounted site hut had been parked under the bridge. The fire was quite large involving the hut, the trailer and some cylinders of propane gas. Damage was sufficiently severe for the bridge, which was carrying a trunk road over the motorway, to be closed for a period.

100. After a structure has been damaged by fire the Engineer will want to assess the damage and foremost in his mind will be the re-use of the structure. At the moment this is an area where there are big gaps in knowledge. First, it is necessary to ascertain correctly the degree of damage. A study of the properties of materials at high temperature and a knowledge of their interaction in the performance of structural elements can help in the evaluation of the damage. If the damage is severe the next step is to consider the feasibility of repair and to decide on the repair method. It is important to remember when effecting repair that the reinstated structure must fulfil all its original functions, including that of maintaining fire resistance if this is a requirement. When one uses resin bonded mortars for instance in repair work one must consider that the repair might have to withstand another fire.

101. At least 20–30% of the fires that the Fire Research Station investigates are in buildings in the construction phase. Most of these fires are caused by carelessness and poor housekeeping, often in situations where there is apparently little to burn. Supervision is an important factor in avoiding these fires.

102. As engineering structures become more complex the problem of repairing fire damaged structures is becoming more evident, because of the tremendous costs involved in demolition and reconstruction. I think that there is the opportunity for close links with the Canadian Research Station in this field.

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103. Civil engineers should be made aware of the need for fire protection during their academic life by including it as part of the curriculum in engineering courses. Engineers tend not to consider fire until they are compelled to and often do not appreciate the damage that can be caused in situations where the apparent fire risk is low.

Mr J. M. Fenton, FICE

In 1968 the Fire Offices' Committee issued the 29th edition of their Rules for Automatic Sprinkler Installations making widespread increases in the degrees of protection required. Firemasters of local fire brigade authorities have also tightened their approach to automatic emergency lighting, escape routes and fire exits.

105. The chimney effect of lift shafts in tall buildings is of great importance. Splitting flights into different shafts of ten storeys or so could help to localize a fire but by suitable construction and lining of the ground-to-roof shaft to give three-hour protection a fire could be confined to the shaft itself and high protection afforded to the occupants of the building.

Mr Wilson

In the National Building Code of Canada are there any regulations for carrying out drills and trials for evacuating people, or is it merely accepted that it would be good if they were carried out? If there is a large fire risk, unless there is a mock exercise one does not know exactly what it going to happen.

Mr S. Rogleff, Senior Research Engineer, Commonwealth Experimental Building Station

Civil engineering structures, other than buildings or warehouses, seldom appear to be involved in major fires. This tends to result in a discounting of the particular danger, but the Authors focus the attention of the civil engineer back to the hazard.

108. Information regarding major fires on civil engineering works in Australia is meagre. There may have been fires in many civil engineering works, mainly during construction, but there is little information in the civil engineering literature.

109. A few years ago I studied the aftermath of a fire that caused considerable damage to part of a heavy industrial plant. The affected part comprised a modern multi-storey framed structure of reinforced concrete that supported bins, hoppers, a system of conveyor facilities and one of the control centres of the plant. The structure was open, except for brick walls around the control rooms only. The possibilities that the particular structure would be involved in a major fire had been considered remote, although the dimensions of the substantial reinforced concrete members were such that they would have satisfied code requirements for structural members with fairly high fire-resistance ratings.

110. The minimum compressive strength of the concrete in columns, beams and slabs was stated to be 4000 lb/sq. in. at 28 days. The coarse aggregates used were natural siliceous river gravel and crushed igneous rock. The thickness of most of the slabs was 8 in., and the dimensions of the beams and columns ranged from 1 ft to 3 ft in cross-section. The heights of columns were 12–15 ft and the spans of beams up to 20 ft. The diameters of the reinforcing bars ranged between $\frac{1}{2}$ in. and $1\frac{1}{2}$ in., and the thickness of concrete cover was from $1\frac{1}{4}$ in. to $2\frac{1}{2}$ in., depending on the structural member. Unprotected steel members supported the conveyor installations.

111. The fire started at ground level—a completely open area. This area had not been intended for storage, but at the time of the fire twenty 44 gal drums of mineral oil and petroleum products awaiting removal were there.

112. It appears that the fire was caused by a spark from an electrical fault that caused ignition of mineral oil residue accumulated close to the base of one of the hoppers above a conveyor belt. The fire spread to the stored drums via the conveyor belt.

Fig. 7 (left). One of the main columns at ground floor level ; spalling on the surface facing the seat of fire
 Fig. 8 (right). Slab and beams above the seat of the fire ; the extensive spalling exposed the reinforcement in the concrete slab

Fig. 9. Section of a beam support control room

DISCUSSION

113. The fire-fighting operations continued for about an hour, during which time the structural damage to the concrete frame and floors, and to the individual unprotected steel members, was substantial.

114. The extent of spalling of the concrete was extensive, as shown in Figs 7-9. The average depth of spalling varied between 1 in the $1\frac{1}{2}$ in., while the maximum depth was $2\frac{1}{2}$ in. The spalling of beams and columns did not expose the reinforcement, but the spalling of the exposed surfaces of the concrete slabs, particularly above the seat of the fire, extended beyond the bottom layer of reinforcement, leaving the rods exposed. Less spalling of the concrete occurred in sections where crushed igneous rock was used as aggregate, and it occurred mainly in the matrix, leaving the individual rock particles intact. In those sections where river gravel had been used the spalling was pronounced, and across many pieces of the coarse aggregate.

115. Repairs to the structure after the fire represented a major undertaking.

116. In recent years two fires of relatively short duration caused considerable damage to two Australian thermo-electric generating plants. Both started in the vicinity of steam turbo-generators, and both were apparently caused by the ignition of oil supply lines. Although quickly brought under control, the fires caused damage to the turbo-generating units involved and to their appurtenant plant. The damage to the surrounding engineering structures, air-conditioning system, and electrical and mechanical services was also considerable.

117. Warehouses and large civil engineering structures providing storage facilities are usually designed to withstand large fires. Nevertheless some stored materials are considered to be not dangerous or highly flammable, and the fire-resistance requirements for the structures to house them are often relaxed. A major fire in a raw sugar storage terminal in Queensland caused an assessed property loss of approximately \$A10 million. The single storey 1000 ft long by 150 ft wide building of modern steel and concrete construction, without special fire protection, was destroyed. It had

Fig. 10. Milford Haven—damage to underside of pre-cast slabs protecting concrete deck above and damage to prestressed piles

previously been presumed that the probability of a serious fire in a building containing only raw sugar in bulk was so slight that fire considerations should not unduly influence the design of the structure. The fire burned for five days despite the application of 10 million gallons of water during the fire-fighting operations.

118. Good 'housekeeping' can be very important when structures are not designed to be fire resisting.

Sir Harold Harding, Consulting Engineer

In 1960 Esso opened a new concrete jetty at Milford Haven. While the first tanker to berth was being discharged a steel pipe connected to a hose dropped and broke. Oil spread over the water under the jetty and caught fire. I was asked to inspect the damage on behalf of an insurance assessor.

120. The jetty had been designed under the late Mr H. A. Henry for the contractor, J. Mowlem & Co. Ltd. Pre-stressed piles over 140 ft long were driven from self-propelled craft. These were 27½ in. o.d. and 20½ in. i.d. To simplify construction over water and avoid the expense of striking shuttering below the concrete deck with such a high tidal range there was an ingenious arrangement. Light steel trusses to span the pile bents were cast in precast slabs which spanned the bents so that the reinforced concrete deck was cast above this permanent form of shuttering and incorporated the steel trusses.

121. The fire occurred at high tide so only a short length of the piles was damaged. The underside of the precast slabs had been badly damaged exposing reinforcement. The lesson learnt was that by using this form of design the reinforced main deck had been completely protected.

122. In 1931 the turbine house for the Ford Factory power house at Dagenham had to be completed by a series of caissons and compressed air chambers while cooling water tunnels were being driven from a jetty in the river to the land. In case of fire the main compressor shed had been built of steel scaffolding covered with steel corrugated sheeting. Duplicate electric supplies merged on a switch board inside the electricians' wooden shed alongside. Diesel compressors were also installed and on the jetty a second electric supply came off the main jetty contract.

123. In the middle of one winter night an electrician who was working on a drum of transformer oil set his hut on fire which blazed and consumed both electric supplies. Fortunately the diesel compressors kept the caissons going while the second supply on the jetty with its separate compressors looked after the tunnel so there was no damage to the permanent works.

124. Alongside the shed was a considerable timber structure supporting three concrete mixers with loading plant. The cross-examination of the night staff the following day had its points of interest.

125. Why was the 3 in. dia. water pipe feeding the mixers not used? It ran under the electricians' hut so only steam came out. There was a flooded cofferdam a few yards away from a pump—but the pump was electric. Why were the several air pumps not used? The high pressure compressors were electric and there was a 5 ton derrick with 150 ft jib for unloading sand barges—it too was electric. Then why was the steam crane which fed aggregate to the hoppers not used? Unfortunately it ran on a timber gantry which had caught fire and the driver had evacuated.

126. Fords had refused to extend their road to the site so all material had to come by rail or water or on foot from the main gate. So when the fire brigade arrived they had to carry what portable extinguishers were available for nearly half a mile across the water front, by which time the fire was over. What is the moral?

Mr J. G. Frost, Consulting Engineer

The fact that there are few published papers referring to fire in relation to civil engineering structures may be evidence of the attention which fire protection has received in this connexion.

DISCUSSION

128. Since publication of the Paper a fire has occurred in the Montreal Metro system in the switchover section beyond a terminal station. The origin of the fire was electrical caused by a train of nine coaches being derailed through high speed switching which was against the operating rules.

129. The fire was minor to start with but spread rapidly, probably due to the operation of the forced ventilation system. The result was loss of the train, severe damage to the general area, loss of operation of the section of the Metro system for several weeks, estimated loss of \$2.5 million and the death of the train operator. Fire fighting was hampered by dense smoke generated and spread through the tunnel by the ventilation system and the lack of water connexions in the area of the fire. This all shows that preparation for fire fighting in tunnels is necessary.

130. The Authors confined their attention to six major fires in certain projects completed or under construction. If all works under construction are considered civil engineering projects, I believe the list of projects damaged and delayed by fire would be endless. In my experience it is a rare project which does not suffer from fire damage in a minor or major way during construction. Fires in formwork during winter construction are not unusual. Fires due to welding slag dropping on construction debris are common. Construction is generally considered a civil engineering responsibility and so the civil engineer must give consideration to fire prevention and proper housekeeping in connexion with his projects.

Mr H. L. Malhotra, Fire Research Station

A great deal of attention is paid to fire protection measures for domestic buildings, offices, shops, factories and warehouses but only little for civil engineering works. The incidence of fires is relatively small but the Paper shows that fires occur and can cause a great deal of damage.

132. A recent fire involved the Menai Bridge. The steel structure was provided with an enclosed tunnel covered principally with combustible materials including a great deal of bitumastic material. The lesson to be learnt is that fires occur in the most unlikely places and there must be plans prepared for dealing with such emergencies.

133. Another fire took place in the cableways of the Battersea Power Station—also where normally a fire would not have been thought a hazard to be catered for. The presence of combustible insulation, an enclosed tunnel situation and difficult access make such fires difficult to deal with.

134. There have also been fire incidents involving concrete bridges during construction over new motorways. In one case the timber shutter close to a highly stressed bearing was being burnt off for quick removal and caused a fire responsible for only local damage which could have, if it had been more extensive, created a serious problem for the repair of the supports. In another instance a builder's hut on fire under a bridge was responsible for damage to the concrete beams.

135. Fires can occur wherever combustible materials are present. It is the responsibility of management and engineers to be aware of this and ensure that emergency procedures are available.

136. One problem dealt with at the Fire Research Station is the assessment of damage after the incident and the remedial measures that may be taken. A research programme on the reparability of fire-damaged concrete structures has been initiated and it is expected that positive recommendations should emerge when the study is complete. The most important aspect is expected to be the quantitative assessment of damage suffered by concrete and steel during the fire and their residual strength properties.

137. Close links already exist between the Canadian Fire Research Establishment and the Fire Research Station in the UK. It is to be hoped that civil engineers are made aware of the need for fire protection by having this as a part of the curriculum.

Mr W. H. Paterson, General Manager, Subway Construction, Toronto Transit Commission

Reference is made to two fires in tunnels which the Authors say in § 61 'raise the most difficult questions'. It is apparent that the manner in which ventilation is provided in tunnels, i.e. the location of fan shafts and vent shafts in relation to points of access, is most significant in the event of a serious and unexpected fire. The accumulation of smoke and intense heat may create a barrier prohibiting the firemen from attacking the fire.

139. It is apparent, therefore, that in designing the ventilation system in a tunnel it is necessary to consider the location and size of shafts and ventilation equipment to produce the necessary air changes at acceptable pressures and velocity to meet the normal ventilation requirements, and also to keep in mind the location of fan shafts and vent shafts in relationship to the points of access so that the smoke and heat, if at all possible, may be withdrawn in a manner that will help fire fighting crews.

140. At present a research project is in progress to investigate and provide information on ventilation and control of environment in underground rapid transit structures. Having in mind fires which have occurred in subways in America a research group has been asked to investigate and report on design criteria for environmental control during emergencies in tunnels.

Mr T. R. Durley, Consultant

Good fire prevention has developed a number of basic principles which cannot be ignored by the architect, engineer or building inspector. The National Building Code of Canada seeks to provide safety to life and property in various types of structures. It is a minimum requirement and must be changed as new construction materials are developed and their hazards made known. The Code regulates only the building and the general weakness is the lack of control over the occupancy. As a result combustibles are introduced into buildings without thought of the amount of fire load or safety to the individual.

142. The fires in the Paper all violate one or more of the basic principles of good fire prevention. They are:

- (a) combustibles should be kept at a minimum in both the structure and its contents
- (b) since the contents of most buildings are combustible, automatic fire protection usually in the form of sprinkler systems, backed by an excellent water supply should be mandatory
- (c) machinery and equipment should not be stored in any building in advance of completion of the fire protective system; many losses occur through disregard of this principle
- (d) in any building adequate training should be made available to the operating and maintenance staff, visits should be made by the local fire department and first aid equipment must be available on all floors of the building, inspected at regular intervals and ready for instant use.
- (e) equipment already on fire should not be moved into restricted areas such as a tunnel where water and ventilation are either not available or insufficient to handle the smoke which may be developed.

143. At the Montreal and Toronto railway tunnel fires, there was no water nor suitable ventilation. In the Ottawa bridge fire a combustible deck of wood and asphalt and little or no first aid equipment made the loss inevitable. The loss at Chat Falls powerhouse was fed by combustibles in the form of oil and compound. Lack of fireproofing the building steel and lack of a good water supply made the loss certain. The army warehouse and the hydro-electric plant at Kelsey were typical construction

DISCUSSION

losses: combustibles in large quantity, failure to complete the fire protection system, together with a roof adhesive of asphalt and unprotected steel frame, were contributing factors.

Mr H. A. Smith, Chief Engineer, Hydro Electric Power Commission of Ontario

Sharing the responsibility of the civil engineer involved in projects of the Hydro Electric Power Commission of Ontario are architects, electrical and mechanical engineers and others. In many cases, the substructure and superstructure of a project may be reasonably safe from fire but not when the contents of the structure create a large fire load.

145. Ontario Hydro have structured into their organization continuing groups (or committees) responsible for establishing standards and procedures relative to fire prevention and protection encountered in the design, construction, operation and maintenance of their many diversified plants. Since 1960 the construction of generating sources has changed from predominantly hydraulic to fossil-fuelled, using coal, natural gas, residual and crude oil as fuels, and nuclear using the Candu principle, all with their corresponding fire hazards, many of which are different from those in hydraulic plants. To maintain a high order of customer supply, considerable attention has been given to transformer stations. This involved the elimination of spread of fire between main transformers or other essential equipment which otherwise might de-energize the complete station with the resultant loss of customer supply.

146. Fire tests of various sizes are also a main responsibility of the committees. Some are undertaken to establish standards (e.g. transformer spacing and other fire prevention measures) and other small fires to train staff in the detection of fire hazards and the use of fixed and portable fire fighting equipment. Training also uses audio-visual aids because it is vital for all staff to be aware of the ever-present fire hazard and the corresponding fire prevention, protection or safety standard.

Messrs Legget and Shorter

The confirmation that the contributors to the discussion make to our suggestion as to the importance of recognizing the possibility of fires on civil engineering works is welcome.

148. In the discussion there are nearly twenty further cases of fires on civil engineering works mentioned. **Mr Morris** indicates that 20–30% of the fires studied by the Fire Research Station are on construction sites. This suggests that the subject matter of the Paper is not as infrequent as we thought at first. It makes all the more surprising the lack of papers on this topic. In the publications of the American Society of Civil Engineers, over one hundred years, only one paper of significance has been found.¹³

149. **Mr Wilson** showed the importance of the contribution to fires that the contents of buildings can make. The concept of the 'fire load' in buildings is now well accepted in fire protection engineering. It is a matter to which much current research is directed. The objections to the subdivision of large areas of warehouse space are understandable but anyone who has ever seen the satisfactory protection that can be given by a fire wall by dividing a large open space into compartments will appreciate that a judicious balance must be sought as between fire safety and operating convenience.

150. The indication given by **Mr Wilson** of the establishment of a Chair of Fire Protection Engineering at the University of Edinburgh gives news that will be widely welcomed. Canadian experience will be made readily available to those responsible for this development.

151. **Mr Wilson** asked about instrumentation for fire detection. This is now an active subject, covering a wide field. In summary it may be said that there are a number of reliable detection devices available, the choice of a particular device depending upon the situation in which it will be used.¹⁴

152. The question raised by **Mr Baxter** as to the possibility of the chimney effect being combined with fires in tunnels, or underground spaces, is serious, especially in view of the steady increase, at least in North America, of underground shopping centres in urban complexes. Fire doors must be located at all strategic points, as they are in the Place Ville Marie complex in Montreal, and they must be maintained in a normally closed position. There are few, if any, locations where accepted fire prevention measures are so essential as in such underground spaces, since the chimney effect will be of serious consequence if temperature conditions are appropriate and it can work in the reverse direction to that normally experienced in tall buildings.

153. We welcome **Mr Dinnis's** reference to the Barcelona tunnel fire; it is clearly a case of unusual importance. We have had no experience with fires under elevated structures such as roadways but share Mr Dinnis's concern for this possibility. We do not know of any serious fires in North American car parks. This is probably linked with the open character of these structures but is also associated with the difficulty of getting a fire started with standing automobiles that are in good order, as shown by tests carried out by the Joint Fire Research Organization.¹⁵

154. The liaison between the Joint Fire Research Station (now part of the Building Research Station, Department of the Environment) mentioned by **Mr Morris** and **Mr Malhotra** is only briefly referred to in the Paper (§ 70). However, for twenty years it has been a source of the greatest satisfaction to us and our colleagues as it now continues to be under the Division of Building Research, National Research Council of Canada Directorship of Dr Hutcheon. Similar close links exist between Canadian fire research work and that carried out by the National Bureau of Standards in Washington, DC. International liaison in the fire research field, supplementing valuable personal links, has been greatly assisted by the continuing work of Commission W14 of the International Council for Building Research, Documentation and Studies.

155. Mr Morris mentions the difficulty of determining how much damage has been done to a structure by exposure to fire. Concrete, so widely used in civil engineering structures, raises the difficult questions since its appearance after fire may be no useful guide. Research is being carried out on this matter.¹⁶

156. The increased attention now being given by local fire authorities to fire prevention measures noted by **Mr Fenton** is to be welcomed. Only by constant attention of this sort can fire losses be controlled. The chimney effect in lift shafts is a focal point in current research work into fires in tall buildings.^{10,17}

157. All we can say in answer to **Mr Williams** about leaking diesel oil is that we hope it is not a common experience; it is clearly dependent upon good 'housekeeping' which is so basic to all phases of construction safety.

158. The provisions for fire evacuation measures in buildings occupied by people, asked about by Mr Wilson, constitute part of the National Fire Code of Canada,¹⁸ now under extensive revision. The Building Code covers all aspects of building related to design and construction. Once a building is occupied, its safe maintenance is aided by the provisions of the Fire Code. Work on the two documents is done in close collaboration, there being a joint technical committee responsible for the inevitable points of overlap between the two documents.

159. The contribution of **Mr Rogleff** was especially welcome as our links with the fire research work of the Commonwealth Experimental Building Station have been close, with valued reciprocal visits of staff.

160. The two fires described by **Sir Harold Harding** were unusual and of great interest. After the Paper was prepared, Mr G. B. Williams, Senior Assistant Deputy Minister of Public Works, Canada, provided us with a list of wharf fires that have taken place on structures with which his Department was concerned. With his permission, this is reproduced as Table 1. It shows the importance of fires even with this type of civil engineering structure.

161. The Montreal Metro fire, mentioned by **Mr Frost**, was a serious and tragic

Table 1. Fires involving waterfront properties

Date	Location	Description	Cause	Loss, \$
25 October, 1960	Middle Caraquet, NB	Wharf	Electrical short circuit	21 342
3 July, 1960	Tignish, Prince Edward Island	Breakwater	Unknown	20 478
14 August, 1960	Lord's Cove, NB	Wharf	Unknown	46 058
9 June, 1963	Forestville, PQ	Wharf	Smoking	300 000
21 August, 1963	Little Cape, NB	Breakwater	Unknown	93 124
11 February, 1963	Quebec, PQ	Wharf	Internal combustion engine	629 000
3 August, 1964	Saanichton, BC	Wharf	Smoking	4 450
17 August, 1964	Terence Bay, NS	Wharf	Unknown	14 750
21 October, 1964	Orleans Island, PQ	Wharf	Exposure to a fire	1 000
6 July, 1965	Roddington, Newfoundland	Wharf and Shed	Oxy-acetylene cutting	153 676
30 August, 1965	Point Edward, NS	Jetty	Electrical short circuit	225 000
30 August, 1966	Bonavista, Newfoundland	Wharf	Exposure to a fire	11 030
31 July, 1967	Douglas Town, Gaspe, PQ	Wharf	Unknown	1 033
	Anse St. Jean, Chicoutimi, PQ	Wharf	Unknown	13 000
5 August, 1967	Lower Caraquet, NB	Wharf	Incendiarism	22 700
8 August, 1967	Egmont Bay, Prince Edward Island	Wharf	Petrol explosion	40 000
5 October, 1967	Green Bay, Newfoundland	Wharf and shed	Cutting torch	30 000
8 December, 1967	Pinkney's Point, NS	Wharf	Petrol vapours and propane heater	65 000
15 December, 1967	Wood Islands, Prince Edward Island	Wharf	Wood stove heating and drying sand	40 000
31 March, 1968	Redonda Island, BC	Wharf and pier	Exposure to a fire	8 530
13 May, 1968	Port-aux-Basques, Newfoundland	Ferry terminal	Welding-petrol exposure to a fire	50 000
30 May, 1968	Cocagne Cape, NB	Wharf	Exposure to a fire	14 000
28 June, 1969	Constance Island	Dock	Exposure to a fire	5 570
14 June, 1969	Noel, NS	Wharf	Smoking	53 000
9 September, 1969	Pilley's Island, Newfoundland	Wharf and shed	Children, matches	5 000
16 October, 1969	Miscou, NB	Wharf	Exposure to a fire	73 521
28 July, 1970	St. John's, Newfoundland	Wharf	Exposure to a fire	11 150
4 June, 1970	Tahsis, BC	Wharf and shed	Smoking	95 000

happening. It lasted for 24 hours. In view of the major elements in this case, involving the newest of North American subways (the first to be equipped with rubber-tired vehicles) it is hoped that it will be described in engineering literature so that others may benefit from this sad experience.

162. Having read about the fire at the Menai Straits Tubular Bridge, and knowing something of the critical effect it had upon rail transport to Anglesea, we are surprised that the only reference to it was the mention made by Mr Malhotra.

163. We know of Mr Paterson's interest in safety in subway operation, and especially in connexion with fire. The research programme he mentions is to be welcomed; it is indicative of the close co-operation that is maintained between major transit authorities in North America.

194. Mr Durley, who has contributed much to the National Building Code and the National Fire Code of Canada, presents some of the more important principles of fire protection engineering. We are sure he would be ready to recognize that not all of the measures he outlines could have been applied to the structures noted in the Paper. However, it is useful to have his reminder of what should be done, when possible and when practicable.

195. We are grateful to Mr Smith for his summary of the active measures continually being taken by Ontario Hydro in an effort to maintain the remarkable safety record of their extensive system, now supplemented by nuclear powerplants with their own special hazards.

196. We hope that the discussion generated by the Paper may be the means of attracting attention to this hazard on all civil engineering works and of preventing fires that were not expected.

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