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Fire and the Design of Buildings

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Fire is one of the major hazards to life and property in buildings. Regulations in respect of fire safety therefore constitute a major part of every building bylaw. These regulations naturally influence the design of almost every building. Good building codes are based on the best information available, but since they must be written as minimum regulations, they inevitably contain compromises and some features that are almost arbitrary. The careful designer will not be satisfied with merely meeting minimum regulations but will wish to base his design on first principles. In this way he can hope to achieve fire safety as an intrinsic characteristic of his design and not something superimposed upon it and possibly conflicting with it. When this is done, the designer will almost invariably find that his design meets requirements such as those in the National Building Code of Canada and in various building bylaws. It is the purpose of this note to outline and to discuss these basic principles of building design in respect of fire safety.

The starting point in a design that is to be safe from fire must be a consideration of the risks to human life and property. These will depend on such factors as the probability of a fire outbreak and the proportions to which a fire in a building is to be allowed to develop. The probability of fire may be assessed, to a degree, from an examination of the statistical reports issued annually by the Dominion Fire Commissioner. In a very crude way, the probability may also be estimated from a consideration of the special risks that may be involved in the actual use of the projected building. The concept of determining in advance the extent to which a fire will develop before it is controlled or extinguished may appear to be unorthodox but, in fact, the design of the building, together with the availability of fire-fighting resources, will regulate this development within remarkably close limits.

The likelihood of fire and the extent to which it will spread will give an immediate assessment of the over-all property risk. An assessment of the life risk is not so simple but may be approximately formulated by considering whether the prescribed hypothetical boundaries of the fire will cut off the escape routes of the occupants of various parts of the building. It must be remembered that areas unaffected by the fire proper may well become dangerous as a result of the migration of smoke and must therefore be evacuated. Life safety in the immediate vicinity of the origin of a fire often involves a time factor and it is not possible to discuss this question quantitatively. Nevertheless, where time is important it can be said that suitable choices of wall, floor, and ceiling lining materials and the adoption of automatic detection techniques almost invariably reduce life risk.

Fire-Resisting Compartments

The feature that plays the greatest part in reducing the over-all fire risk in a building is the extent to which fire-resisting construction is used to divide a building into fire-resisting compartments that will contain a fire and prevent its propagating to neighbouring compartments. The effect of such construction on property loss is that direct damage is confined to the property in the compartment in which the fire originates. A similar argument applies to life safety and although occupants of compartments remote from a fire may have smoke problems there is every likelihood that no lives will be lost in these areas. The conditions in the immediate vicinity of a fire will, of course, be substantially unchanged but the number of people involved is smaller and there is some likelihood that they will become aware of the fire before being trapped.

One of the best examples of a building which is suitably compartmented and thus can protect most of its occupants under difficult conditions is the Empire State Building. In 1945 an aircraft hit the 78th and 79th stories and a severe fire involving large quantities of gasoline broke out. Despite the severity of the fire, there were no casualties among the many occupants of the floors both above and below the fire area. This record contrasts sharply with those of a number of hotels which have been involved in fires in the present century. A typical example is the Winecoff Hotel fire of 1946 which accounted for 119 deaths.

The size of a compartment should be based on the life and property risk principles already discussed and their application is illustrated by the following specialized examples. A fire-resistant safe in which jewellery is stored may be taken as a limiting case of a compartment from various points of view. The likelihood of fire originating in the safe is remote and the object of the fire-resistant construction is to protect high value property from fire in neighbouring compartments.

The argument for confining a paint spray booth by fire-resistant construction is almost exactly the converse. The value of the materials within the compartment is small but the likelihood of fire substantial. The primary object of the fire-resistant construction in this case is thus to protect property and lives in adjacent compartments.

Where life and property risks are low, compartments may be large and the question arises as to what upper limit should be set. This is still a matter of dispute but a popular concept is that the linear dimensions of a compartment should not exceed twice the maximum effective range of the average fire hose which is of the order 60 to 120 feet.

The enclosed stairwell, serving as an escape route from a multi-story building, is a special case of a fire-resisting compartment which involves additional problems, particularly where smoke is concerned.

The fire resistance requirement of an element of structure constituting part of a fire-resisting compartment is commonly assessed in terms of the fire load (combustible content per unit area) to be expected in the class of building envisaged and suitable assessments are listed in building codes. It is most important that a fire-resisting compartment should be completely enclosed and hence care must be taken to ensure that duct openings and doorways are closed in the event of a fire. In general, fusible links will perform this function sufficiently quickly to ensure that the fire is contained within the compartment. Where it is also desired to restrict the spread of lethal smoke during the early stages, however, automatic release of doors and dampers is necessary. This can be effected by using small solenoid electro-mechanical, instead of purely mechanical, catches to hold doors and dampers open and arranging for a fast-acting fire-detector system to disconnect the power to these solenoids in the event of a fire.

Where only life safety is to be considered the concept of the fire-resisting compartment might possibly be modified and poorer elements of structure chosen which will only perform their various functions for a period sufficient to enable all the occupants of the building to escape. Such an approach must be given careful thought for it can only be valid where adequate warning can be expected from detection and alarm systems and where it is known that the response to an alarm will be the complete evacuation of the building. Special provisions may be necessary where there are infant, senile, or restrained occupants.

Large Uncompartmented Areas

Modern production techniques are more and more frequently requiring large uncompartmented areas, of which the large single-story automobile factory is a common example. Disastrous fires both on this continent and in Europe have illustrated that such circumstances can give rise to very large monetary losses as a result of fire. Where combustible contents cannot be eliminated, there is no perfectly satisfactory solution to the problem. A number of steps can be taken, however, to alleviate the problem. The most obvious measure is to reduce to a minimum the quantity of combustible material in the building. Particular attention should be paid to the roofing materials for in several of the multi-million dollar losses to date flammable roof lining and cladding materials have played a substantial part in creating conditions that have made effective fire fighting impossible.

Another rewarding complementary approach is to arrange for automatic ventilating and curtaining of the building on the outbreak of a fire. The various effects of these measures are at the moment not fully understood and are currently being investigated by a number of organizations throughout the world. Venting alone, i.e. the opening of holes in the roof, might well increase the rate of spread of fire throughout the building, but it can render a great service by improving the visibility in the region of the fire to allow effective fire fighting. It is still desirable that structural members should have some measure of fire resistance, although some relaxations might result from the findings of investigations currently being undertaken.

Wall Linings and Furnishings

The fire problem in a building must be approached in a number of ways not the least of which is the consideration of limiting the likelihood and the initial rate of development of a fire. A discussion of possible sources of ignition is not included in this note but careful attention must be paid to such factors as heating and electrical systems and the possibility of introducing into the building materials that are capable of igniting spontaneously, e.g. paint rags or fibre-insulation board stored in bulk.

It can be said, qualitatively, that the choice and treatment of furnishings and linings will in general influence the likelihood of the development of a fire from a small igniting source and also the rate of spread of the fire. So many other factors are involved, however, that quantitative statements are not at the moment possible. Methods of rating materials in sequence of merit are available, e.g. the ASTM fire hazard test, and appear to be valid. The limit of their application, however, is, in general, relative.

Nevertheless one particular component of a building, a corridor, merits special attention as it often plays the most substantial part in spreading a fire in a building and yet it is almost unique in that it has very few furnishings. It can thus be designed so as to be unable, of itself, to sustain and propagate a fire. Small-scale fire tests have indicated that a corridor will not of itself sustain and propagate a fully developed fire if a composite spread of flame index relating to the wall, ceiling and floor linings is lower than a certain limiting value. The index is derived from the ASTM flame spread rating for the lining materials and if these are W, C, and F respectively for the wall, ceiling, and floor, the criterion is that $C + 2W + F/2$ must be less than 75.

Exits and Escape Routes

The general concept of the provision of adequate escape routes and exits in a building is sufficiently fundamental as not to need developing here. To reduce the likelihood of fire developing in the escape route itself, it is desirable that the flame spread ratings of the wall, floor and ceiling lining materials should at least meet the requirement given in the previous section and in the case of escape stairwells it is generally accepted that the linings should be virtually incombustible.

Stairwells should constitute totally enclosed fire-resisting compartments and care should be taken to ensure that the doors leading to them are closed in the event of a fire. Where the maximum protection against smoke is desired, access to the stairwell should, at all levels, be via an area maintained at atmospheric pressure by direct communication with the outside atmosphere. Such an arrangement ensures that the slight pressure differences created by fire in a building will not directly give rise to high smoke densities in the stairwell. Most authorities on the subject of escapeways recommend that alternative routes should be available and thus in multi-story buildings the provision of more than one escape stairwell is advisable.

Application of the above principles will ensure a high degree of safety for occupants of areas somewhat removed from the fire. The problem of evacuating the occupants of the compartment of origin of the fire who, by virtue of room divisions, may not be immediately aware of the fire is not so readily solved. Their chances of escape can only be high if a fast-acting fire-detector and alarm system is installed or, of course, if each individual room has an alternative exit direct to the exterior.

Fire Protection Systems

The structural design of a building can set an upper limit to the magnitude of the loss of property and life to be expected under circumstances associated with the average fire. Substantial additional reductions in both losses can usually be achieved by installing automatic fire-detection equipment. The primary function of such systems should be to notify the occupants and the fire department of the occurrence of fire.

It is also desirable that the system should close the doors to the area of origin of the fire (whether the doors be fire-resistant or not), various other appropriate doors, such as those to stairwells, and fire-resisting doors bounding the compartment involved. Closure of most of the doors can actually be effected by conventional door closers and the only essential function of the fire-protection system in this respect would be to release the electro-magnetic door latches which should be used in place of the more conventional mechanical devices to hold a door open. Various ducts and other gaps in fire-resisting partitions should be adequately sealed by fire dampers and other closures following the operation of the detection system. Most commercially available fire-detection systems sense temperature, temperature rise or smoke and the choice of system will depend on the nature of the fire to be expected.

The further protection provided by automatic fire fighting is often desirable and in some circumstances there can be almost certain guarantee that the fire will be completely extinguished. This is particularly true with specialized risks such as flammable liquids in unoccupied enclosures. An appropriate combination here would be an infra-red detection system and a CO_2 flood extinguishing system.

Automatic sprinklers constitute a very convenient combined detection and fire fighting system and, despite their slowness in operation, years of experience have shown them to be remarkably effective. It is customary merely to require a sprinkler head to discharge water, sound a local alarm and alert the fire department, but it is desirable that it should perform more of the functions suggested previously.

Conclusions

This note has discussed basic principles of design with reference only to conditions created by a fire within a building. There are corresponding hazards associated with the spread of fire from one building to another. These are extremely important since their neglect in the past has led to some of the most serious large-scale conflagrations. The separation of buildings in order to minimize this danger is therefore another important part of building regulations. This subject is naturally a prominent feature in the National Building Code of Canada. Designers who are concerned with the separation of buildings will find available in the literature some useful publications. The Division of Building Research will gladly assist with inquiries in relation to this aspect of fire-safe design. The Division has an active program of research in the fire field, and is steadily adding to publications such as this note, which are being made available to provide basic information for the use of designers with the objective of reducing fire losses in Canada.

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