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RESEARCH PROJECT:

PROVISION OF SAFE EGRESS FOR MULTI-STOREY BUILDINGS.

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CONTENTS.

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SUMMARY

In our report we have discussed aspects related to building design for ensuring the safe escape of occupants from a burning building. The occupants must be protected from the effects of fire and smoke. We have focused our attention on multi-storey buildings as the principles involved can be readily applied to all buildings. The most important consideration is the safety of life. Therefore the first principle is to ensure that there is adequate provision for speedy and safe escape in case of emergency.

Despite the existence of fire safety regulations, the danger of life loss in fires is ever present. "Lack" of escape from fires is primarily due to delayed awareness, poor design of escape routes, smoke logging and interference with exits. Delayed awareness is one of the major reasons for fatalities.

Life safety systems by which the occupants can escape from the effects of fire and smoke must be provided. In multi-storey buildings, this includes the installation of detection and warning systems such that early warning of a fire hazard is ensured. Travel distances should be minimized, to reduce the exposure time for the occupants. The location, sizing and number of stairways and exits should be provided so that alternative routes of escape are available. The building occupants must be able to gain refuge to a safe place within an acceptable egress time period. The risk of fire occurring or spreading within the escape route must be minimized. The inadequacy of escape routes has often been responsible for tragedies.

> It is certain that two alternative routes must be provided in all buildings, except for small, low rise occupancies with restricted travel distances, floor areas and number of occupants.
>
> Computer based models are available to consider movement of crowds, and behaviour of people in fires. These will be integrated in the near future and will be valuable aids to the design of fire escapes. They should only be used by knowledgeable persons familiar with the factors which effect egress design (Wade 1991).
>
> Techniques like the provision of places of refuge need to be incorporated in the design of large buildings. These can be considered safe zones for people in the event of a fire.
>
> Additional methods to promote safe escape can be employed in the design stages. These include; the provision of a early warning system, the use of fire resistant materials and methods of construction, the inclusion of smoke stop doors and lobbies, the installation of sprinklers and the care management of fire safety systems after installation. Exit ways must be clearly labelled and used as a matter of daily routine. Lighting needs to be provided in the event of an emergency.

It can never be guaranteed that fire safety systems will provide 100% protection. Systems can fail, maintenance procedures can be abused and people do not always behave as we would wish. However, engineers and designers have an obligation to minimise the risk involved given reasonable building management procedures and human behaviour.

INTRODUCTION.

The purpose of this report is to explain and discuss aspects related to building design for ensuring the safe escape of occupants from a burning building. The occupants must be protected from the effects of fire and smoke. We have focused our attention on multi-storey buildings as the principles involved can be readily applied to all buildings.

Despite the existence of fire safety regulations, the danger of life loss in fires is ever present. "Lack" of escape from fires is primarily due to delayed awareness, poor design of routes to escapes, smoke logging and interference with exits. Delayed awareness is one of the major reasons for fatalities.

Life safety systems by which the occupants can escape from the effects of fire and smoke must be provided. In multi-storey buildings, this includes the installation of detection and warning systems such that early warning of a fire hazard is ensured. Travel distances should be minimized, to reduce the exposure time for the occupants. The location, sizing and number of stairways and exits should be provided so that alternative routes of escape are available.The building occupants must be able to gain refuge to a safe place within an acceptable egress time period. Escape routes must be protected to kept the occupants clear of the effects of fire and smoke originating from other parts of the building. The risk of fire occurring or spreading within the escape route must be minimized. The inadequacy of escape routes has often been responsible for tragedies.

It can never be guaranteed that fire safety systems will provide 100% protection. Systems can fail, maintenance procedures can be abused and people do not always behave as we would wish. However, engineers and designers have an obligation to minimise the risk involved given reasonable building management procedures and human behaviour.

SECTION 1: MEANS OF ESCAPE.

Exit design should be based upon an evaluation of a building's total fire defence policy and an analysis of the population characteristics and hazards of the building. The design should be treated holistically. That is, as an integral part of the "whole" system which provides reasonable safety to life from fire.

Designing a means of egress involves more than the analysis of numbers (discussed in Section 3. Evacuation Modelling). Safe exit from a building requires a safe path of escape from fire, ready for use in case of emergency and sufficient to permit all occupants to reach a safe place before they are endangered by fire, smoke or heat.

Depending upon the time required for the fire detection, alerting the building occupants and the location of the fire hazard, the fire or smoke produced may develop enough to prevent the use of the escape route provided. Because of this threat, at least one alternative facility, remote from the first, is essential. Provision of two separate means of egress is a fundamental safeguard except where a building or room is so small and arranged such that a second exit would not provide an appreciable increase in safety. There is no advantage of separate facilities if there is travel through a common space or use of common structural features, resulting in loss of the two separate exits in the case of an emergency.

Not in list of refs.

BIC (1988) investigated the provision for buildings with a single means of egress in response to a concern that the fire bylaw (SANZ, 1988 A) was deficient in allowing unlimited height for single egress buildings of small floor area. They indicated that the bylaw provisions were out of line with many overseas codes. As a result recommendations were made according to the maximum number of storeys to be limited to those described in table 1 for single egress buildings.

Is this correct?

	Commercial or Industrial Building	
	Low risk	Moderate risk
Sprinkler protected	4	2
Non-Sprinkler protected	9	4

Table 1. Number of storeys recommended by BIC investigation into single exit occupancies. Wade (1991)

SECTION 2: EMERGENCY MOVEMENT OF CROWDS DURING BUILDING EVACUATION.

There have been a number of useful publications and reviews published covering modelling of crowd movement. They include a comprehensive treatment by Fruin (1971) which covers basic traffic and space relationships including the "level of service" concept which helps designers to specify the speeds and flows of pedestrians as a function of crowd density.

Pauls (1988) summarises some of the major research findings for design re crowd movement, management and behaviour as follows;

i) Strive for simplicity in all movement routes: this lessons the need for directional graphics.

ii) Capacity-handling channels should be continues walking surfaces.

iii) Ingress systems should be reversible to cater for egress.

Crowd movement in buildings is made up of three basic components which can be represented as follows;

Flow = Speed * Density * Width

where: Speed = speed of crowd travel
Density = population per unit area
Width = width of exit facility under study

also

Population = Flow * Flow time

Population is the number of persons a movement facility can serve in a defined time, flow capacity is the number of persons passing a point in a unit of time, and flow time is the total time required for a crowd to move past a point in the egress system.

Under fire conditions people are likely to be unfamiliar with the various exits from an area and thus neglect alternative means of exit; all exits need to be conspicuously marked. It is also important that all exits from a building are used as a matter of daily routine so that occupants will be familiar with them.

Modelling of people movement during the egress from buildings can be divided into two categories, movement models and behaviour models. The behaviourial models as they have been developed, are essentially of two types, conceptual models which have attempted to include the observed, empirical and reported actions from collective interview or questionnaire studies, and computer models for the simulation of the behaviour of the human individual in the fire incident. The escape activities indicated that the majority of people left by exit stairs they "normally" used whilst others used lifts or waited to be rescued.

For a detailed description of flow modelling see Wade.

SECTION 3: EVACUATION MODELLING AND PERFORMANCE EVALUATION .

3.1 EVACUATION MODELLING.

There are a number of computer-based models for assessing the egress and evacuation of buildings. Some of the more interesting models are as follows;

EVACNET+

A computer program that models evacuation of buildings. It is network model that uses nodes to represent rooms and arcs to represent connecting routes. It is mainly concerned with movement between each element of the egress system. It is a flexible model which will produce an optimal evacuation plan for the building and can be used to evaluate different design options.

BFIRES

This model relates to human behaviour as well as movement. It is mainly a theoretical model. BFIRES considers three interacting components being: the fire and its by products; the building enclosure; and the human occupant.

EESCAPE

The model is applicable to the evacuation of multi-storey buildings via staircases and predicts the flow movement in terms of time with regard to the building's lay-out and the interdependencies between adjacent egress way elements.

Models are extremely useful in the prediction of movement. However models of human behaviour have not been developed to the same degree and models incorporating behaviour and movement will be at least ten years away. (Fire Safety and Engineering. 1989)

3.2 EVACUATION PERFORMANCE EVALUATION.

Time.

The time allowed for the safe egress of occupants has been traditionally based on judgement and experience. Two and a half minutes has often been mentioned. This is thought to be the time that could be allowed without there being a serious risk of panic in the event of fire. Modern studies have shown this time to be reasonable in residential fires, as this is approximately the time it takes for conditions to become untenable for occupants (Ingham 1981).

The means of escape provisions in DZ 4226 (SANZ 1984; Bastings, 1988) is stated to be based on 2.5 minutes clearing time to a protected place where two alternative means of escape are available, and 1 minute where only one means of escape is present.

Malhotra (1986) gives values of time for conditions to become critical in various situations and are listed in Table 2. He also proposed a design escape time adjusted to human factors as given in Table 3.

Zone	Time (min)
Unprotected	2.0 - 6.0
Partially protected	5.0 - 10.0
Fully protected	30.0 - 60.0

Table 2. Time at which conditions become critical.

Building	Factor
Domestic	0.8
Hotels	0.7
Hospitals	0.5
Shops	0.8
Offices, Schools, Factories	1.0
Assembly buildings	0.7

Table 3. Human design modification factors. (Malhotra (1986))

In an engineered approach to means of escape design, the maximum permitted clearing time may not be fixed at all. Provided the time taken to evacuate the occupants to a place of safety does not exceed the time required for life-threatening conditions to develop then the life safety objective has been achieved.

Distance.

It is appropriate to limit the distance of travel from any point to the nearest safe refuge. This will reduce the time occupants are exposed to the effects of fire and also to improve the escape time. The minimum travel distance will depend on;

The expected fire severity and rapidity of spread.
Number of exits.
The use of the building, lay-out of furniture, equipment.
The response behaviour of the occupant.
The mobility and mental condition of the occupant.

In the New Zealand code (SANZ, 1984) travel distances have been related to evacuation time by an arbitrary speed of travel; 12 m per minute for people in unfamiliar surroundings and 18 m per minute for people in familiar surroundings. (These times are very conservative and an able bodied person would have troubled walking this slowly.) This is graphically illustrated in Figure 1.

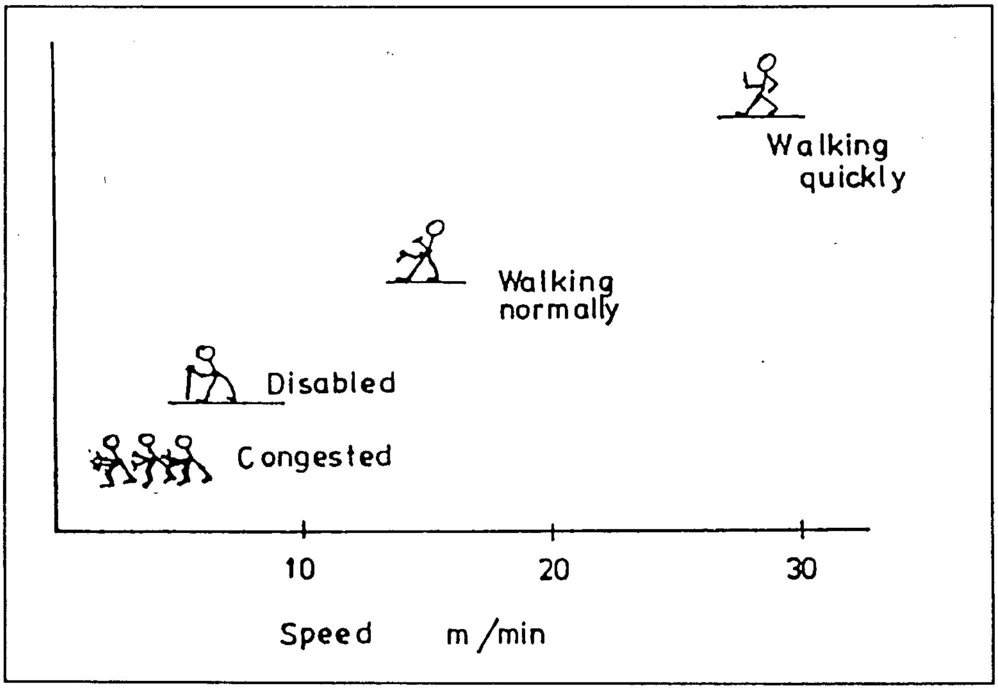

Figure 1. Travel speed assumptions.

Travel distances may be specified in terms of distance along the route of travel taking into account the actual distance to be travelled from any remote point in the building to the nearest exit, or in terms of the direct distance which is the shortest distance from any point to the exit. The direct distance would only be used during the design stage when the final position of partitions is unknown. Measurements of travel distance and direct distance are illustrated in Figure 2.

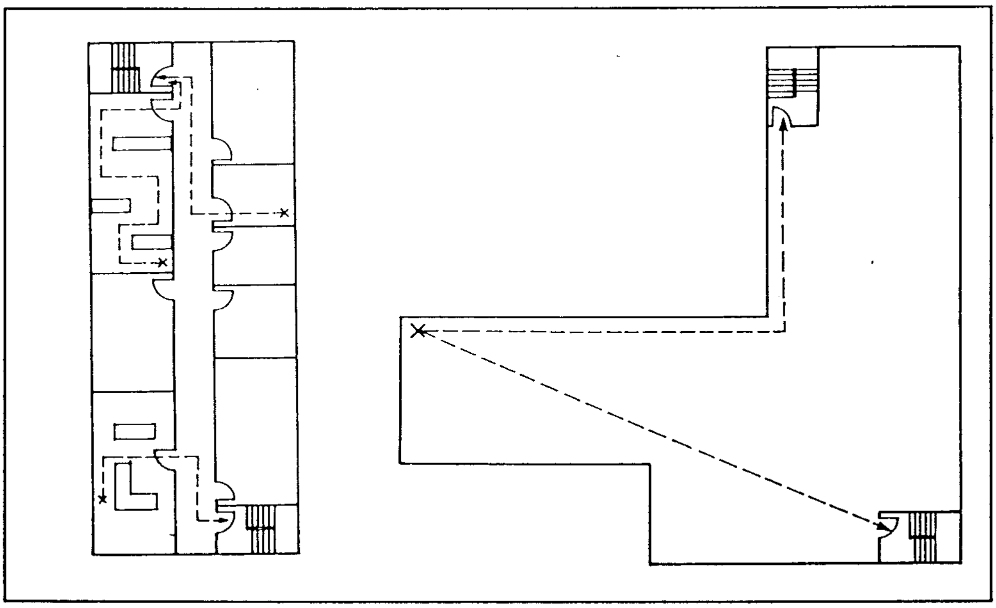

Figure 2. Measurement of travel distance and direct distance.

A comparison of travel distance requirements for some well known codes is shown in Table 4. Some codes recognised the contribution of sprinklers in increasing life safety in buildings and allow for increased travel distances.

Code.	Alternative means of escape available.	Dead- end.
NZS 1900 Ch.5 (1988)	No limitation.	18 m travel to nearest exit.
DZ 4226 SANZ (1984)	68 m travel. 45 m direct.	27 m travel. 18 m direct.
BS 5588: Part 3 (1983)	45 m travel. 30 m direct.	18 m travel. 12 m direct.
NBCC (1990)	40 m travel.	25 m travel.
BCA (1990)	40 m travel.	20 m travel. 30 m on ground level.

Table 4. Travel distance requirements of some well known codes.

SECTION 4: ALTERNATIVE STRATEGIES FOR EVACUATION.

Uncontrolled Simultaneous Evacuation.

This is the simplest and most commonly used strategy and the one appropriate for the majority of buildings. On notification of a fire, in an uncontrolled simultaneous evacuation, all occupants are expected to make their way toward the exits and immediately evacuate the building. In some high-rise buildings where total evacuation times could exceed 30 minutes, an uncontrolled simultaneous evacuation may not be considered realistic or feasible due to the development of severe smoke conditions on floors below the level of evacuating occupants. With lengthy evacuation times it is also more likely that the evacuation process will be impeded by slower or physically disabled occupants.

For these reasons alternative strategies could be considered involving a planned phased evacuation or reliance on safe places of refuge.

Phased Evacuation.

Phased evacuation helps address problems with simultaneous evacuation in multi-storey buildings where demand on the staircases is greatest and delays and queuing can occur at entrances to the staircases. Simultaneous evacuation gives each floor equal priority in accessing the stairway and so occupants of the floors which are under greater threat of fire and smoke may be delayed because of the flow of occupants from floors not immediately threatened by the effects of the fire. A phased evacuation gives priority firstly to the most threatened floors, usually the fire floor and the one above, and then the remaining upper floors can be evacuated followed by the lower floors. For phased evacuation to work effectively there must be building management systems in place to manage a controlled evacuation, with training provided to specified staff to act as fire wardens. There must also be a communications system in operation designed to provide the necessary information to those wardens throughout the building during the evacuation process. A phased evacuation plan would only be justified for relatively tall buildings with the necessary management and communication systems in place.

The New Zealand Fire Service has issued guidelines on controlled evacuation in high-rise buildings (NZFS, 1988). They consider 15 floors or levels as a minimum height before controlled evacuation should be considered and recommended approved automatic sprinkler, manual fire alarm, emergency communications and emergency lighting systems.

Places of Refuge.

Escape route planning has the aim of providing the occupants from any where in the building the possibility of reaching a place of safety within or outside the building in the time available before the conditions become unbearable. The conventional approach required that all occupants should aim for the outside of the building however, in many situations the escape has to be in stages or phases either because of the occupants or the nature of the building. In high rise buildings it is only necessary for the occupants in the fire zone and the floor above to leave their areas and the rest to follow if the fire proves uncontrollable. To make provision for the simultaneous evacuation of a building with as many as 10,000 occupants would require massive escape facilities. Areas of refuge have been proposed as a means for providing temporary protection for the occupants of high-rise buildings. Areas such as a protected corridor,a protected staircase or an entire protected floor are considered suitable refuge areas as depicted in the Figure 3.

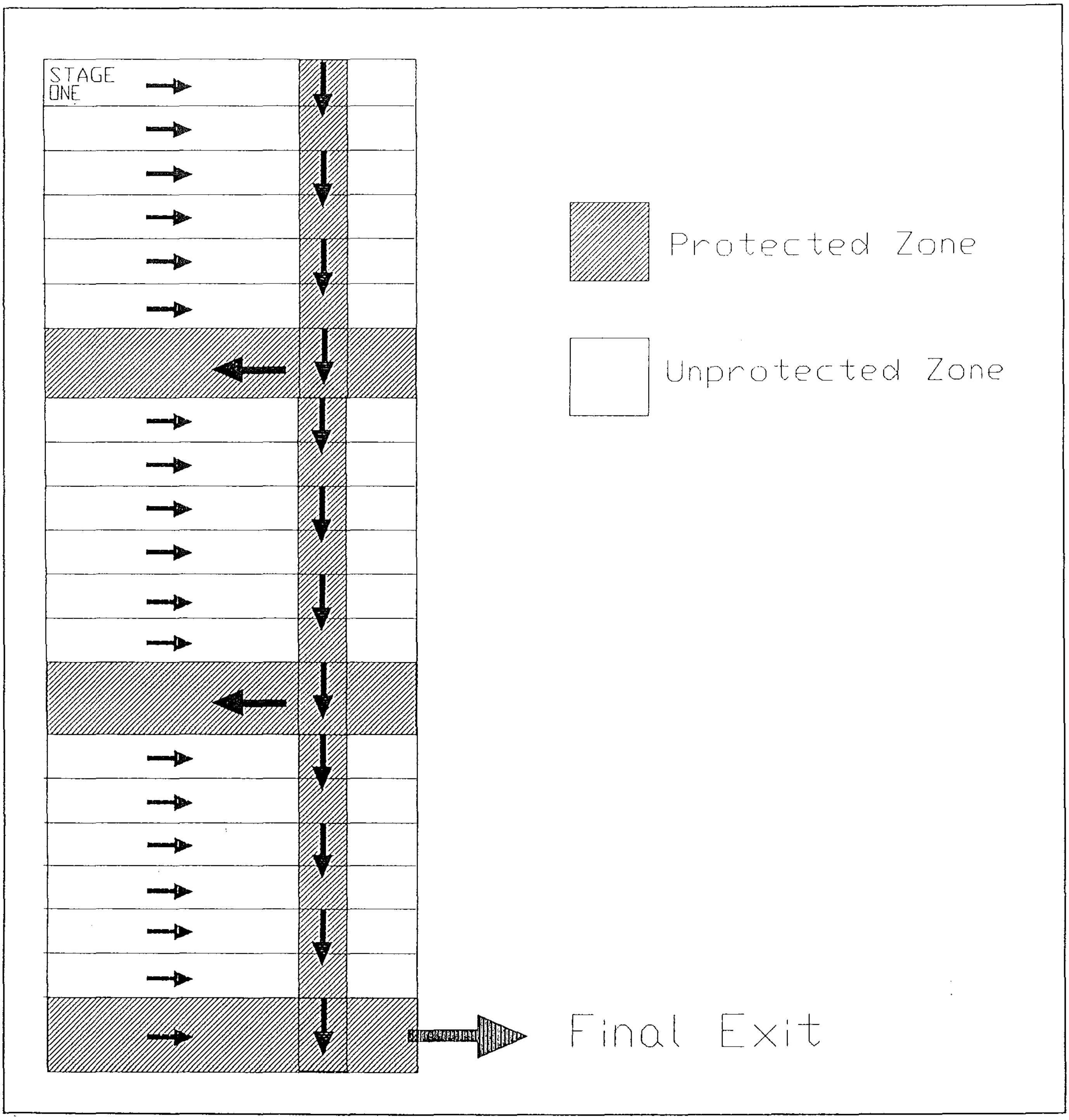

Figure 3. Provision of areas of safe refuge in high rise buildings.

SECTION 5: EXITWAY DESIGN AND CAPACITY.

> "A means of egress is a continuous path of travel from any point in a building or structure to the open air outside at ground level. "
>
> (Bryan)

The types of permissible exits are; doors leading directly outside or through a protected passageway to the outside, smokeproof towers, interior and outside stairs, ramps, escalators that meet certain specific requirements, and moving walks. Elevators are not acceptable as exits.

Entrances, exits and circulation areas are provided in all buildings for normal use, and means of escape considerations should utilise existing arrangements wherever possible. Exitways need be considered with regard to the existing exits in terms of: position; width; and number.

The Position of Exits.

If the angle made by lines joining the exits to any point on the floor of the storey under consideration is less than 45°, then the disposition of the exits may be inadequate. Ideally, staircases should be located diagonally opposite each other.

Width of Exitways.

It is essential that bottlenecks be avoided when designing means of escape. Thus corridors should not become narrower as they approach a storey exit or staircase.

Number.

The number of exitways has been discussed in Section 1.

In order for exitways and particularly stairs to ensure the safe passage of occupants they must be readily visible, with stairs treads of sufficient width to allow for adequate footing on each step. The handrail should be of a reachable height and be easy to grasp.

The Minimum Width of Exitways.

BIC (1990) specifies a minimum acceptable width between handrails as no less than 900 mm. The current fire bylaw (SANZ 1988 A) allows a single exit of unit width to be 610 mm wide. It has been shown that a minimum width of between

800 and 900 mm will accommodate the flow of occupants in single file, but passing in comfort would not be possible. This is illustrated in Figure 4.

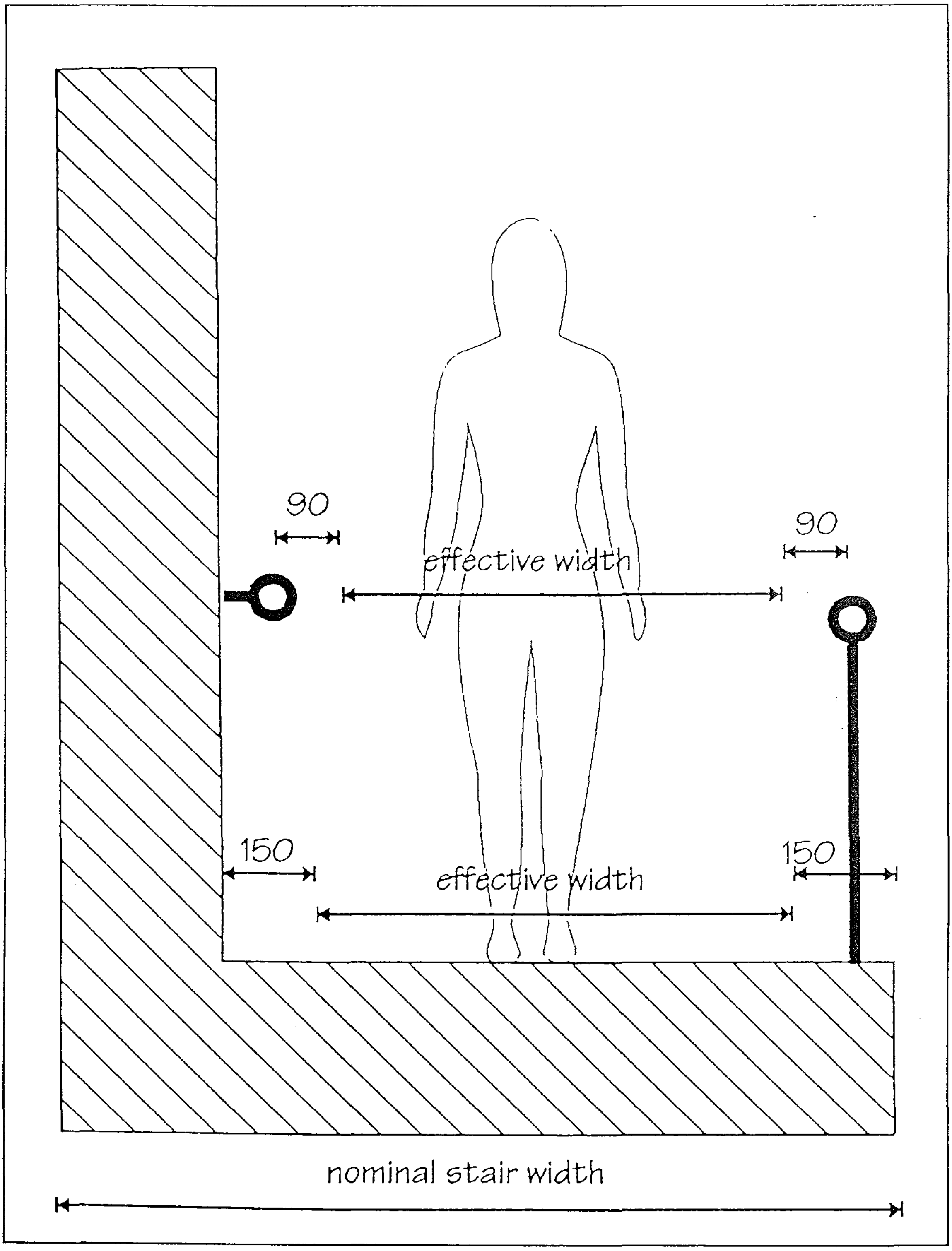

Figure 4. Measurement of effective stair width in relation to walls and handrails. (Wade 1991).

EXITWAY CAPACITIES.

The main methods of determining staircase width are;

(1) based on the population of one floor,
(2) based on total population,
(3) based on capacity of stairs,
(4) based on capacity of stairs and flow from final exit.

Stair width based on the population of one floor appears to be the most common, and least conservative method adopted. This means that a two-storey building would have the same stair width as a ten-storey building. This is based on the assumption that by the time occupants of a floor reach the floor below, the occupants of the floor below have already left.
The value of this assumption is questionable (Wade 1991). The interaction of escape routes may prevent the expected flow rates from being achieved. Phased evacuation of a multi-storey building can be used to address this problem.

In order to satisfy the performance requirements of clearing occupants from a floor into a protected exitway in a specific time then the logical approach is to base stair width on total population. However, for tall buildings, the stair would have to be excessively wide. This method is not used and the New Zealand requirements of basing stair width on the single level population has operated without apparent problem.

Stair width based on the capacity of stairs relies on there being available space in the stairway to accommodate all the occupants. By allowing sufficient space per person for reasonably free movement this method can result in excessive stair width.

New Zealand Requirements.

Existing provisions for exitway capacities in New Zealand can be found in NZS 1900 Chapter 5 (SANZ 1988 A). These provisions appear to have originated from early NFPA requirements for stairways and ramps, and later discredited by Pauls (1980) as being too high.

Wade provides a detailed comparison between the current requirements and those derived by using the effective width model. The relationships have been summarised in Table 5.

Code.	Requirement
NZS 1900 Chapter 5	width = 150 + 7.67 N N > 60
BIC (1990) level of safety = two unit stair in NZS 1900	width = 300 E +5.9 N + 180 H
BIC (1990) level of safety = 2.5 minute evacuation time.	width = 300 E + 8.6 N + 180 H

Where N = number of occupants;
H = number of handrails;
and E = number of exitways available for escape.

Table 5. Comparison between current requirements and the effective width model (Wade 1991).

SECTION 6: ADDITIONAL METHODS TO PROMOTE SAFE ESCAPE.

Life safety design for a building is difficult. It involves more than a provision for emergency egress. It requires attention to who will be using the building, and what they will be doing most of the time. Then consideration must be given to communication and the protection of escape routes and temporary areas of refuge for a period of time reasonable for the building occupants to reach safety.

A number of features may be required to ensure the safety of the routes, some of which are outlined below.

Early Warning System.

The earlier the detection of the fire, the sooner occupants will decide to evacuate, and the longer is the time available for escape. Of course the fastest early warning system of all is an alert occupant in the vicinity of the fire, who is able to raise the general alarm. However, as spaces are not usually continuously occupied an automatic detection and alarm system may be necessary. The advantages of smoke detectors in providing an early warning of fire is universally accepted due to the earlier stage in the fire development at which smoke detectors respond.

Fire Resisting Construction.

Fire-resisting construction is used to protect the escape route from the fire for a period of time sufficient for the occupants to have evacuated the building. The exitway provides a temporary "protected or safe place" for occupants as they make their way outside the building and therefore affords them with additional time to complete the evacuation before being endangered by the effects of the fire.

Smoke Stop Doors And Lobbies.

Used to limit the ingress of smoke into the escape route. Because the doors must be in a closed position to be effective they must be fitted with self closing devices if required, and furthermore must be able to be readily opened by escaping occupants.

Lobbies are a safeguard against smoke penetration of a stairway and are especially advisable for enclosing elevator of lift suites where it may be impractical to adequately smoke-stop lift-landing doors to minimise vertical smoke spread up the lift shaft. Lobbies can also be used to extend the protected part of the escape route, to meet travel distance restrictions, or afford greater safety to occupants attempting to evacuate into a vertical staircase and faced with the possibility of delays due to queuing. They can also be an important staging post for the fire service to fight a fire, especially in taller buildings.

Pressurisation of Escape Routes.

Pressurisation is a means of preventing the ingress of smoke into the escape route by maintaining a pressure difference across the openings to the stairway to ensure the air flow is from the staircase to adjacent spaces rather than the reverse. It is based on the assumption that a fire is unlikely to originate within the exitway.

Sprinklers.

Sprinklers have commonly been associated with protecting buildings and their contents (property) from fire loss. However, they can also play an important role in increasing life safety. By preventing widespread conflagration, people remote from the fire location are unlikely to be unduly threatened, while occupants near to the fire have less heat and smoke to combat and more time to escape.

Surface Finishes.

The surface finish of lining materials is commonly controlled within the exitway to minimise the risk of serious fire, as well and ceiling surfaces in particular can have a significant influence on the development of a fire.

Fire Load.

It is not acceptable to store combustible materials in an exitway, not only because they may impede the flow of occupants during an evacuation of the building but also because the presence of significant fire load increases the risk of a fire ignition occurring within the exitway, defeating its purpose of providing a protected place from fire.

Emergency Lighting.

Provision should be made for lighting escape routes should the main electricity supply fail for some reason. The emergency lighting should enable occupants to see directional signs associated with the escape route, changes in floor level, and the location of fire alarms and extinguishing equipment.

Exitway Marking.

The need for signs will depend on the nature of the occupancy. Where people are unfamiliar with their surroundings e.g., hotels, shops or places of assembly the need for signs will be greater. To be effective, the location colour and design of the sign should be considered, including a means to illuminate the sign.

Elevators.

The use of elevators has been discouraged for evacuation purposes traditionally because of lack of control over when or where they may open. Elevators can be designed as fire-fighting elevators if necessary at the disposal of the Fire Service for transportation of disabled persons.

CONCLUSIONS.

The most important consideration is the safety of life. Therefore the first principle is to ensure that there is adequate provision for speedy and safe escape for the occupants in case of emergency.

To ensure life safety, egress provisions cannot be considered in isolation from the total fire safety system, which may include the provision of sprinklers, smoke control systems, pressurised escape routes, alarm and detection systems and a comprehensive fire evacuation plan.

It is certain that two alternative routes must be provided in all buildings, except for small, low rise occupancies with restricted travel distances, floor areas and number of occupants.

The performance of an escape route can be evaluated in terms of design escape time and maximum travel distance. However the floor clearing times usually stated as 2.5 minutes will be longer in conditions of maximum demand.

Computer based models are available to consider movement of crowds, and behaviour of people in fires. These will be integrated in the near future and will be valuable aids to the design of fire escapes. They should only be used by people knowledgeable persons familiar with the factors which effect egress design (Wade 1991). Predictions of total egress time need to consider the time associated with human behaviour during the evacuation.

Alternative strategies for evacuation exist and should be employed in high rise buildings. Techniques like the provision of places of refuge need to be incorporated in the design of large buildings. These can be considered safe zones for people in the event of a fire.

Additional methods to promote safe escape can be employed in the design stages. These include; the provision of a early warning system, the use of fire resistant materials and methods of construction, the inclusion of smoke stop doors and lobbies, the installation of sprinklers and the care management of fire safety systems after installation. Exit ways must be clearly labelled and used as a matter of daily routine. Lighting needs to be provided in the event of an emergency.

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