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# STUDY REPORT

## NO. 38 (1991)
## MEANS OF ESCAPE IN MULTI-STOREY BUILDINGS

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## PREFACE

This report on a project carried out at the Building Research Association of New Zealand describes an investigation into means of escape in multi-storey buildings in the event of fire.

This report is intended primarily for architects, fire engineers and code writers.

# MEANS OF ESCAPE IN MULTI-STOREY BUILDINGS

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## REFERENCE

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## ABSTRACT

This report explains and discusses aspects of building design for ensuring the safe escape of occupants from the effects of fire and smoke in multi-storey buildings. Traditional practices and assumptions are discussed as well as the implications of more recent research and the possible effects on existing and future provisions for means of escape in New Zealand codes. Although the report is directed toward multi-storey buildings, there are many aspects which also apply to low-rise construction.

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## INTRODUCTION

The purpose of this report is to explain and discuss aspects related to building design for ensuring the safe escape of occupants from the effects of fire and smoke in multi-storey buildings. Many aspects relating to means of escape are universal to all, not just multi-storey buildings, so parts of this report will have much wider application.

Means of escape in buildings are required, not only for fire evacuation, but also in the event of flood, earthquake, and a number of other emergencies. With respect to fire, the building must be provided with the life safety systems by which the occupants are able to safely escape from the effects of fire and smoke.

In multi-storey buildings, this means adequate attention to detection and warning systems such that early warning of fire is ensured. Travel distances should be controlled to limit the extent to which people are exposed to the effects of fire and smoke. The location and sizing of stairwells and exits should be considered so that alternative routes of escape are available and the building occupants can gain access to a safe place within an acceptable time period. A protected escape route must be kept clear of fire and smoke originating from other parts of the building and finally the risk of fire occurring or spreading within the escape route itself must be minimised i.e., by ensuring control over the contents within the exitways.

It will never be possible to guarantee 100% protection from fire because safety systems can fail, maintenance procedures can fall down and people do not always behave as we might expect. Nonetheless, designers must do all in their power to minimise the risks involved given reasonable building management procedures and human behaviour. Detailed study of the behavioural response of building occupants involved in fire incidents is beyond the scope of this report, and readers interested in this area are referred to a useful summary of recent research by Bryan (1988).

## ALTERNATIVE MEANS OF ESCAPE

It is a generally accepted principle that there should be at least two means of escape available to building occupants in the event of fire in a building to allow for the possibility that one exit may become blocked by the effects of the fire, and thereby force the occupants to seek an alternative route for escape. There may be, however, exceptions made to this principle for small, low-rise buildings with restricted travel distances, floor areas, and number of occupants and where two fully protected means of escape could be considered particularly onerous. BIC (1988) investigated the provisions 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 area. They indicated that the bylaw provisions were out of line with many overseas codes and subsequently recommended that the maximum number of storeys be limited to 4 and 2 for low risk commercial and industrial and moderate fire risk occupancies respectively, or 9 and 4 storeys respectively if the building was sprinkler protected.

Furthermore, two exits will not increase the level of safety if they are located such that they both become unaccessible at the same time due to the location of the fire. Therefore the exits should be sufficiently separated to reduce the likelihood of this occurring.

Barnett (undated) describes a detailed method for determining the minimum distance between fire exits. Based on selected design values for fire size, flame temperature, emissivity and a critical human radiant heat flux, he proposed a minimum centre-to-centre spacing between fire exit doors of 7.5 m for office occupancies as being necessary.

The British Code of Practice for Office Buildings (BSI, 1983 A) addresses the separation issue by recommending that if two routes diverge by less than 45° and are not separated by fire-resisting construction, they are considered to provide escape in one direction only and a situation in which this occurs can be considered to be a 'dead end'. SANZ (1984) proposes a similar requirement except that the means of escape must not diverge by less than 90°. In the Building Code of Australia (AUBRCC, 1990) alternative exits must be between 9 and 60 m apart (Class 5 office building). Adequate separation is not defined in NZS 1900 Chapter 5 (SANZ, 1988 A) but left to the discretion of the 'Engineer'. This has been cited as another area of concern in the New Zealand fire bylaw by BIC (1988).

'Dead end' (or cul-de-sac) situations present a greater threat to the occupants of being trapped by the fire and therefore are usually the subject of a more restricted maximum travel distance than would otherwise be considered acceptable. Travel distances associated with dead ends will be discussed in the next section.

## PERFORMANCE BASED CRITERIA FOR EVACUATION

### Time

Determination of the permissible time in which to clear occupants from a building has been traditionally based on judgement and experience. Two and a half minutes has been often mentioned and is reportedly related to the time taken to evacuate the Empire Palace Theatre in Edinburgh in 1911, and also the time it was thought could be allowed without there being a serious risk of panic in the event of fire (Post War Building Studies, 1952). This time of 2.5 minutes has survived to the current day even though its basis is somewhat sketchy. Nonetheless, in recent times it has been clearly established that, in residential fires particularly, the time until conditions become untenable for occupants can be of this order (Ingham, 1981), and for this reason the 2.5 minute limit is not unreasonable.

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 (limited situation).

Malhotra (1986) gives the values in Table 1 for the estimated time to reach critical conditions, for zones with differing protection in the building.

TABLE 1 : TIME AT WHICH CONDITIONS BECOME CRITICAL

| Zone | Time (min) |
|---|---|
| Unprotected / fire zone [1] | |
| normal sized room (=<100$m^2$) | 2.0-2.5 |
| larger compartments / room height > 4 m | 4.0-6.0 |
| Partially protected zone [2] | |
| natural smoke extraction | 5.0 |
| pressurization or extraction system | 10.0 |
| Fully protected zone [3] | |
| natural smoke expulsion, no lobby | 30.0 |
| natural smoke expulsion, with lobby | 45.0 |
| pressurization or extraction system | 60.0 |

Notes
1. where a fire may occur and there is no restriction to the spread of smoke and hot gases
2. has smoke and heat resisting barriers which will remain effective for a limited time (< 30 min)
3. remains acceptably clear of smoke and hot gases for the whole duration for which protection is required in the building

Times given for partially and fully protected zones may be too high if fire spreads via the facade for instance in an unsprinklered building. They also depend on minimal defects existing in the construction of the exitway e.g., adequately fire-stopped service penetrations and smoke-stop doors which are closed at the time of the fire. It is not currently proposed that Table 1 be used for design purposes without further detailed research especially for the fully protected zone.

Malhotra (1986) also proposed a design escape time by adjusting the values in Table 1 on the basis of a human factor, dependent on the occupancy and given in Table 2.

TABLE 2 : HUMAN FACTORS

| Building | Factor |
|---|---|
| Domestic buildings | 0.8 |
| Hotels | 0.7 |
| Hospitals | 0.5 |
| Shops | 0.8 |
| Offices, Schools, Factories | 1.0 |
| Assembly buildings | |
| =< 500 occupants | 0.8 |
| > 500 occupants | 0.7 |

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 untenable or life-threatening conditions to develop, which could take into account fire suppression measures, then the life safety objective has been achieved. In this approach, where modelling techniques are used to calculate the time parameters there should be a considerable margin of safety for the evacuation time over the time taken for development of untenable conditions. A factor of 2 has been suggested (Pauls, 1988). This is to make adequate allowance for the uncertainties associated with egress models, and particularly for the 'human' factor where idealised evacuation behaviour may not occur in practice.

## Distances

In order to limit the distance, and therefore the amount of time people will be exposed to a potentially hazardous environment, it is appropriate to restrict the maximum distance from any point in the fire compartment to the nearest protected lobby, corridor or exit. This maximum travel distance will depend on:

1. The expected fire severity and rapidity of spread.

2. Whether there are alternative exits available or if a 'dead end' exists.

3. The layout of the building and ease of access to a safe place (i.e., open plan or subdivided).

4. The likely occupant response (i.e., are they alert or sleeping?).

5. The mobility and mental state of the occupants.

The maximum travel distance must be reasonable to allow occupants to comfortably reach the exit from a remote point within the time proposed, and allowing for travel at a reasonable speed. According to NFPA (1981) there are no exact criteria for determining travel distances; they are the result of observing people in motion, good judgement, and many years of studying the results of fires.

Notwithstanding this, in some codes (e.g., SANZ, 1984) travel distances have been related to evacuation time by an arbitary speed of travel, commonly 12 m per minute (30 m in 2.5 minutes) for people in unfamiliar surroundings such as shops and assembly halls and 18 m per minute (45 m in 2.5 minutes) for people in familiar buildings such as offices and factories. These assumed travel speeds are very conservative (in fact it would be very difficult for an able bodied person to walk that slowly). However, they are used because, according to Bastings (1988), they result in "distances set to ensure that all members of a group of occupants of varying physical ability may reach the entry to an exitway even though they will have been delayed by those ahead, so that they will take a greater total time to reach the entry to the protected or safe place".

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, allowing for the presence of partitions and fittings (i.e., the actual distance to be traversed), or in terms of the direct distance which is the shortest distance from any point to the nearest exit ignoring partitions and fittings (but not external walls).

The direct distance would only be applied at the design stage when the position of partitions etc, may not yet be known. Measurements of "travel distance" and "direct distance" are illustrated in Figure 1.

A comparison of travel distance requirements for business or office occupancies in some well known codes is shown in Table 3. The travel distance where alternative means of escape are available typically ranges from 40 m to 60 m although there is no limitation in NZS 1900 Chapter 5 (SANZ, 1988 A). The dead-end limitations are typically in the range 18 m to 30 m. Some codes allow an increased travel distance where the building is sprinklered, recognising the contribution of sprinklers in increasing life safety in the building.

TABLE 3: COMPARISON OF TRAVEL DISTANCES FOR AN OFFICE OCCUPANCY

| Code | Alternative means of escape available | Dead-end |
|---|---|---|
| NZS 1900 Ch 5<br>(cl. 5.37.1)<br>ref - SANZ (1988 A) | No limitation | 18 m travel distance to exit or to point where paths to alternative exits are available and increased to 24 m for Type 2 construction in D1 and D2 occupancies. |
| DZ 4226<br>(table 6.4A)<br>ref - SANZ (1984) | 68 m travel distance<br>45 m direct distance | 27 m travel distance<br>18 m direct distance<br>limited to 240 m² and 150 occupants. |
| BS 5588: Part 3<br>ref - BSI (1983 A) | 45 m travel distance<br>30 m direct distance | 18 m travel distance<br>12 m direct distance |
| NFPA 101<br>(clause 5-6.5)<br>ref - NFPA (1988 B) | 60 m travel distance (unsprinklered)<br>91 m travel distance (sprinklered) | 30 m travel distance but there are limits on the number of people and the arrangement of exits |
| NBCC<br>ref - NRCC (1990) | 40 m travel distance (unsprinklered)<br>45 m travel distance (sprinklered) | 25 m travel distance to egress door; maximum area 200 m² |
| BCA<br>(class 5)<br>ref - AUBRCC (1990) | 40 m travel distance | 20 m travel distance or 30 m where the storey is at level of access to road or open space |

## EMERGENCY MOVEMENT

### Modelling Crowd Movement and 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) in his book "Pedestrian Planning and Design" 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.

Kendik (1986) has reviewed the modelling of people movement during egress from buildings; Pauls (1988) and Nelson and MacLennan (1988) discussed later, cover useful ground; and background and historical perspective can be found in Stahl and Archea (1977) and Stahl et al (1982). A discussion on the principles of crowd movement follows.

Crowd movement through an egress route can be represented by a simple hydraulic model where:

flow capacity (persons/sec) = speed (m/sec) x density (persons/$m^2$) x width (m)

and;

population (no. of persons) = flow capacity (persons/sec) x flow time (sec)

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. Flow time must be distinguished from the total time taken for all occupants to reach a remote place of safety, which we call total evacuation time.

Total evacuation time is more difficult to predict than flow time as it must also include, in addition to flow time, the time taken to traverse the egress route and any associated time related to the behaviour of the occupants both prior to the decision to evacuate and during the evacuation process. These subcomponents of evacuation time are discussed by Pauls (1988).

Extensive research has been undertaken by Pauls at the National Research Council of Canada during the 1970's and 80's resulting in the development of the "effective width model" for the purpose of determining the evacuation time for a building. Pauls' work and the effective width model is described in a number of publications including Pauls (1980, 1984, 1987, 1988) and a brief overview of the model is included here.

The effective width model relates the usable (or effective) width of an egress route to its flow capacity where there is a simultaneous demand on the egress route by a crowd of people. The model describes flow capacity as a linear function of a route's effective width, and is based upon the empirical research finding that mean flow capacity is a linear function and not a step function as commonly assumed in the traditional method of exitway capacity design using "unit widths" or lanes of movement. As Pauls (1984) explains, even very small increments of (stair) width add to the flow capacity.

Observations of building evacuations have shown that not all of the width of an escape route is used by the evacuees. There exists a "boundary layer" clearance to the walls of the corridor or stairwell and from other stationary objects encountered along the way. The overall width of the escape route less these boundary layers is called the effective width. Table 4, taken from Nelson and MacLennan (1988), gives the widths of the boundary layers for different exit route elements and Figure 2 (from Pauls, 1988) illustrates the measurement of effective width in relation to walls and handrails.

TABLE 4 : BOUNDARY LAYER WIDTHS

| Exit Route Element | Boundary Layer (mm) |
|---|---|
| Stairways - wall or side of tread | 150 |
| Railings, handrails (1) | 90 |
| Theatre stairs, stadium benches | 0 |
| Corridor, ramp walls | 200 |
| Obstacles | 100 |
| Wide concourses, passageways | up to 460 |
| Door, archways | 150 |

(1) Where handrails are present, use the value which results in the lesser effective width

Based upon an empirically derived expression between flow capacity per metre of effective width and the population per metre of effective width, Pauls (1988) was able to express the relationship between effective stair width, flow time and population (for stairs with 280 mm treads and 180 mm risers) as follows:

$$W_e = \frac{8040P}{t^{1.37}} \quad \text{where: } P = \text{population (no. of persons)}$$

$$t = \text{flow time (sec)} < 600$$

$$W_e = \text{effective width (mm)}\ .$$

Pauls (1988) also gives an expression for predicting the minimum uncontrolled evacuation time (T) for multi-storey (office) buildings, assuming a 41 second start-up time (based on observations for the time to reach 50% of the mean flow in the stairs) as follows:

$$T = 0.68 + 0.081\left(\frac{P}{W_e}\right)^{0.73}$$

This approach treats a multi-storey building as a single entity in that it doesn't look at individual floor clearing times but only the total evacuation time for a multi-storey building through specific stairways.

Nelson and MacLennan (1988) have developed Paul's effective width model further to analyse the interaction between different parts of an escape route, for instance, where the width changes or paths merge. In doing so, they define a further term called specific flow as the flow of evacuating persons past a point in the exit route per unit of effective width of the route involved.

Maximum values of specific flow are given in Table 5 from Nelson and MacLennan (1988).

TABLE 5 MAXIMUM SPECIFIC FLOW

| Exit Route Element | | Maximum Specific flow (persons/sec/m of effective width) |
|---|---|---|
| Corridor, Aisle, Ramp, Doorway | | 1.3 |
| Stairs | | |
| riser (mm) | tread (mm) | |
| 191 | 254 | 0.94 |
| 178 | 279 | 1.01 |
| 165 | 305 | 1.09 |
| 165 | 330 | 1.16 |

Nelson and MacLennan (1988) further discuss transitions in flow, where the character or width of a route changes or where routes merge. They represent the transition by the following general relationship which equates the total flow arriving at a point with the total flow leaving the same point.

$$F_{s(\mathrm{in}-1)}W_{e(\mathrm{in}-1)}+\dots+F_{s(\mathrm{in}-n)}W_{e(\mathrm{in}-n)} = F_{s(\mathrm{out}-1)}W_{e(\mathrm{out}-1)}+\dots+F_{s(\mathrm{out}-n)}W_{e(\mathrm{in}-n)}$$

where $F_s$ = specific flow, $W_e$ = effective width, and the letter n in the subscripts (in-n) and (out-n) refers to the total number of routes entering or leaving the transition point.

EXITWAY CONSTRUCTION

In order for exitways and particularly stairs to ensure the safe passage of occupants they must be readily visible, with stair treads of sufficient width to allow for adequate footing on each step. The handrails should be of a reachable height and be easy to grasp and the exit must be of an adequate width. Pauls (1984) gives a useful summary of these aspects of stair construction. Other factors relating to the protection of the exit by controlling surface finishes, fire load, and limiting fire and smoke ingress will be briefly discussed in a later section.

### Stair Dimensions and Geometry

To minimise the risk of missed footing and energy expended, Fitch et al (1974) concluded that risers should be between 100 and 180 mm high and treads between 280 mm and 355 mm long. Pauls' work indicates a maximum flow rate will be achieved with 130 mm risers and 330 mm treads. BIC (1990) draft approved document D1 (Access Routes) specifies a maximum riser height of 190 mm and minimum tread of 280 mm for a common stair (max pitch 37°), and a maximum riser height of 180 mm and minimum tread of 310 mm for an accessible stair (max pitch 32°). A common stairway is a stair used by the public, and an accessible stairway is a stair with enhancements for the benefit of the ambulant disabled.

See also Figure 3 from BIC (1990). NZS 1900 Chapter 5 (SANZ, 1988 A) permits a maximum riser height of 205 mm and a minimum tread of 255 mm. Furthermore, the product of the tread (but excluding nosing) and riser must be between 39000 and 52000. The product of the tread and riser has traditionally been used by architects as a 'rule-of-thumb' for designing comfortable stair flights.

### Handrails

For good graspability, a handrail should ideally be circular in cross section with a diameter of about 45 mm (Pauls, 1984). Some acceptable handrail profiles are given by BIC (1990) and are shown in Figure 4.

Stairs used in descent by crowds of adults should have handrails at a height between 915 mm and 965 mm above tread nosings and spaced no more than 1575 mm apart (between handrail centrelines) according to Pauls (1984). BIC (1990) states handrails should be positioned between 850 mm and 1000 mm high. The latter also specifies the use of at least one handrail on a stair with a total rise of 600 mm or more, stairways greater than 2 m wide requiring handrails on both sides, and where the width exceeds 4 m an intermediate handrail is required. These requirements are for normal usage situations. Pauls (1984) is of the view that in an emergency egress situation everyone on the stair should be able to reach a handrail; it could therefore be argued that where this is not the case the effective width would be reduced further and so the additional width should be ignored for the purpose of calculating exitway capacity of an egress stair.

### Minimum Width of Exitways

BIC (1990) specifies a minimum acceptable width between handrails as no less than 900 mm. Pauls (1984) notes that Fruin recommends at least 1520 mm between walls for everyday use, and Templer recommends 1420 mm between walls to allow people to walk side by side or pass with comfort (Pauls, 1984). The current fire bylaw (SANZ, 1988 A) allows a single exit of unit width to be 610 mm wide. BSI (1983 A) allows a minimum exit width for office occupancies of 800 mm, while NPFA (1988 B) specifies 910 mm. It appears that a minimum width of approximately 800 to 900 mm will accommodate the flow of occupants in single file, but passing with comfort would not be possible.

## EXITWAY CAPACITIES

### Methods of Determining Staircase Width

Post-War Building Studies (1952) discussed different methods for determining staircase widths, and these methods are, in principle, the same used today.

The main methods are:

1. stair width based on the population of one floor

2. stair width based on total population

3. stair width based on capacity of stairs

4. stair width 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 (by NFPA (1988 B) and SANZ (1988 A) for example). In the case of multi-storey buildings this means that a two-storey building would have the same stair width as a ten-storey building even though the total population for the latter may be five times greater. The justification for this appears to be based on an assumption that by the time occupants of a floor reach the floor below, the occupants of the floor below have already left (NFPA, 1981) i.e., that the flow of people from the fire floor is not affected by the flow of people from the floors above and below.

The validity of this assumption is questionable, and therefore, in uncontrolled simultaneous evacuation of multi-storey buildings, the interaction of escape routes may prevent the expected flow times from being achieved due to the occurrence of queuing at the intersection of stairways and floor exits. Phased evacuation of a multi-storey building (discussed later) can be used to address this problem. On the other hand, stair width based on the population of one floor has been used for many years in New Zealand and overseas without apparent problems, probably due to the conservatism associated with the occupant density and the time available for escape.

In order to satisfy the performance requirement of clearing occupants from a floor into a protected exitway in a specified time (say 2.5 minutes) then the logical approach is to base stair width on total population rather than floor population. The required stair width would then become proportional to the number of floors. However, for tall buildings, the stair width requirements would be considered excessive by today's standards particularly where floor levels are separated with fire resisting construction. However, if one assumes there would be an increased urgency for evacuation from the fire floor, such that those occupants are not obstructed by occupants from other floors, then this method would be more acceptable. Queuing on other floors is less serious as the physical separation and distance provided would afford greater protection. Nonetheless, for spaces (e.g., interconnected floors in an atrium) it would be prudent to base stair width on the total population of those interconnected floors rather than on one floor, and this is currently required by at least one large local authority in New Zealand.

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.

The last method was suggested by Post-War Building Studies (1952) where stair width is based on the capacity of stairs and the flow from the final exit. It takes into account the space available in the protected stairway to temporarily accomodate occupants and the number of occupants who can exit the stairway, so that the specified clearing time from each floor in a multi-storey building can be achieved. First, the total number of people able to be accomodated in the stairway is determined and then the additional number of people able to enter the stairway from each floor (determined by the flow through the ground floor exit and assuming flow into the stairway from each floor is equal) is calculated. The total stair width required therefore increases with the height of the building but does not lead to the excessive widths of the previous method. This method has been used in the United Kingdom (BSI, 1983 A) in a code of practice for office buildings having previously been explored by Melinek and Booth (1975).

## New Zealand Requirements

Existing provisions for exitway capacities in New Zealand can be found in NZS 1900 Chapter 5 (SANZ, 1988 A), where the number of units of exit width required for escape from any floor is calculated on the basis of 60 persons per unit of exit width and with the occupant load applying to the number of persons on that floor or storey as per method 1 above (the unit of width is taken as 610 mm for the first and 460 mm for every additional unit). These provisions appear to have originated from early NFPA requirements for stairways and certain ramps, which were based on a flow rate of 45 persons per minute through one unit of exit stair width (559 mm) and later discredited by Pauls (1980) as being too high. The concept of unit exit width is rapidly losing favour with code writers and being replaced with a linearised relationship between exit width and population.

## Comparison with Overseas Codes and Research

The effective width model can be used to estimate the performance, in terms of a flow time, implicit in building codes given the minimum required exit width for a given maximum number of occupants, and given the steepest stair geometry permitted. In order to simplify the comparison, the effect of stair geometry is ignored for now and the flow time can be given as:

$$t = \left(\frac{W_e}{8040P}\right)^{-0.73} \text{(sec) where: } \tfrac{W_e}{P} \text{ is in mm per person}$$

Stair geometry can be considered by adjusting $W_e/P$ as suggested (NFPA, 1988 A) relative to the "reference" stair (180 mm riser; 280 mm tread).

For example, NZS 1900 Chapter 5 (SANZ, 1988 A) allows 120 people to exit through a 1070 mm ($W_e$ = 770 mm) wide stair (2-unit) with a steepest stair geometry of 205 mm risers and 255 mm treads. To correct $W_e/P$ back to the reference stair, in this case means decrease $W_e/P$ by 10%. This gives: $W_e/P$ = 770/120 x 0.90 = 5.8 mm/person; and $t$ = 197 seconds (3.3 minutes).

Table 6 compares the estimated flow times derived from the stated requirements in a number of well known building codes.

TABLE 6 : COMPARISON OF EXITWAY FLOW TIMES[1] DERIVED FROM VARIOUS BUILDING CODES

| Code | Estimated flow time (sec) |
|---|---|
| BCA (AUBRCC, 1990) | 153 |
| NZS 1990 Chapter 5 (SANZ, 1988) | 197 |
| NBCC (NRCC, 1990) | 198 |
| NFPA 101 (NFPA, 1988 B) | 207 |
| UBC (ICBO, 1988) | 238 |
| UK Building Regulations (Clarke et al, 1985) / BS 5588 Part 3 (BSI, 1983 A) | 265 |
| DZ 4226 (SANZ, 1984) | 318 |

Note 1 : standard reference stair 180 mm riser; 280 mm tread

The estimated flow times in Table 6 range from the often quoted 2.5 minutes for the Building Code of Australia (AUBRCC, 1990) to in excess of 5 minutes for the now unadopted draft New Zealand standard DZ 4226 (SANZ, 1984). As the latter three codes in Table 6 calculate the capacity more conservatively than the rest, the differences in flow time may not be as great as it appears. For example, in DZ 4226 when two equal sized exits are provided, it is designed such that one of those exits is considered unavailable (blocked by fire). However, if both exits were in fact used to escape, the flow time then becomes just half the Table 6 value (i.e., = 159 seconds).

The reader is reminded that these flow times are not the evacuation times for a floor, but the time taken for the crowd to pass a given point in the egress path. Evacuation times require further allowances for pre-evacuation behaviour and travel times to be added. The flow times do, however, allow a comparison of the relative level of safety for different exitway capacity requirements to be made and demonstrate that, under maximum demand, the floor clearing times implicit in most codes (New Zealand and overseas) will almost certainly be in excess of the commonly assumed 2.5 minutes.

Figure 5 compares current requirements (SANZ, 1988) for the relationship between the number of occupants and the stair width, with those derived using the effective width model. This figure takes into account the common stair maximum slope (37°) proposed by BIC (1990) and assumes only one exitway is available for use and that no intermediate handrails are provided. The relationships can also be stated by the following expressions.

1) Existing requirements (NZS 1900 Chapter 5)

total nominal width (mm) = 150 + 7.67 N $(N > 60)$

2) Providing an equivalent level of safety as a 2-unit (1070 mm) stair in NZS 1900 Chapter 5 (i.e., flow time = 3.3 minutes) but using the maximum slope for a common stair as proposed by BIC (1990).

Stairs: total nominal width (mm) = 300 E + 5.9 N + 180 H

Level Passageways: total nominal width (mm) = 300 E + 3.9 N + 180 H

3) Providing a level of safety such that a flow time of 2.5 minutes is achievable using maximum slope for a common stair as proposed by BIC (1990).

Stairs: total nominal width (mm) = 300 E + 8.6 N + 180 H

Level Passageways: total nominal width (mm) = 300 E + 5.1 N + 180 H

Where N = number of occupants; H = number of intermediate handrails provided; and E = number of exitways available for escape. Minimum widths of exitways are also desirable, as discussed previously in this report. They will in some cases be greater than that calculated by the above expressions, and in these cases the minimum width would govern. Level passageways are calculated assuming a specific flow of 1.3 persons/sec/metre of effective width. By making some basic assumptions these expressions could be simplified for code specification purposes.

## Occupant Loading

Occupant load or density tables provide information on the area per person (or inverse thereof) to be assumed for different types of occupancy when determining the numbers of occupants in a building for the purpose of escape route capacity calculations. They are not intended for use in the normal architectural design and space planning of the building. As Pauls (1984) says "figures derived fom code occupancy load tables for office buildings may overestimate by a factor of two or three times the real population", in any case, the value used should not be less than that for which the space is designed. An example of an occupant density table is shown in Table 7 from SANZ (1984).

Existing code requirements in New Zealand make use of both gross and net area values per person. The gross area figure includes all the circulation and service spaces such as stairways, toilets etc., and is only used when the detailed interior layout cannot be defined and hence the net area figure is not known.

## TABLE 7 OCCUPANT DENSITIES

| Activity on any floor or storey | Number of occupants per m2 |
|---|---|
| Assembly activities | |
| standing space | 2.6 |
| bar standing areas | 2.0 |
| stadia and grandstands | 1.8 |
| space with fixed seating | (see clause 6.3.2.2) |
| space with loose seating | 1.3 |
| areas without seating or aisles | 1.0 |
| exhibition areas, trade fairs | 0.7 |
| concourses, lobbies, and foyers | 1.0 |
| bar sitting areas | 1.0 |
| dancehalls | 1.0 |
| stages for theatrical performances | 1.3 |
| spaces with loose seating and tables | 1.0 |
| restaurants, dining rooms | 0.9 |
| dining, beverage and cafeteria spaces | 0.8 |
| indoor games areas/bowling alleys, etc | 0.1 |
| classrooms | 0.5 |
| reading or writing rooms and lounges | 0.5 |
| teaching laboratories | 0.2 |
| vocational training rooms in schools | 0.1 |
| Sleeping activities | |
| bunkrooms | as number of bedspaces |
| bedrooms | " " " " |
| dormitories, hostels | 0.2 |
| detention quarters | 0.09 |
| wards containing more than two beds | 0.2 |
| Office and personal service activities | |
| interview rooms | 0.2 |
| personal service facilities | 0.2 |
| offices and staffrooms | 0.1 |
| computer rooms | 0.04 |
| Shopping activities | |
| supermarkets, bazaar shops | 0.5 |
| sales floors | 0.4 |
| showrooms | 0.15 |
| Industrial and storage activities | |
| workrooms, workshops | 0.2 |
| manufacturing and process areas, staff rooms | 0.1 |
| commercial laboratories, laundries, | 0.1 |
| warehouse storage | 0.03 |
| heavy industry | 0.03 |
| aircraft hangars | 0.02 |
| bulk storage | 0.01 |
| parking buildings | 0.02 |
| Space in a factory in which layout and normal use of fixed equipment or plant determines the number of persons using it in working hours | (as approved) |
| Auxiliary activities | |
| boiler rooms, plant rooms, service units and maintenance workshops | 0.03 |
| storage garages | 0.02 |
| laundry and house keeping facilities | 0.2 |
| kitchens | 0.1 |
| vehicle parking | 0.02 |
| storage | 0.02 |
| toilets and subordinate spaces | 0.0 (no occupants counted) |
| exitways (for that purpose alone) | 0.0 (" " " ) |

from SANZ (1984)

## EVACUATION (COMPUTER) MODELLING

There are a number of computer-based modelling programs reported in the literature for assessing various aspects related to egress and evacuation. A useful paper has been published by Watts (1987) discussing the different types of computer models of emergency evacuation. Some of the relevant programs are summarised here.

EVACNET+ (Kisko et al (1984); Kisko and Francis (1985)) is a computer program that models evacuation of buildings on a personal computer. It is a network model that uses nodes to represent rooms or spaces and arcs to represent the connecting routes between them. EVACNET+ produces an optimal evacuation plan for a building and therefore is useful for comparing minimum evacuation times for alternative design options.

BFIRES (Stahl 1979, 1980) is a simulation model for the behaviour of people during an emergency evacuation and is based on a stochastic dynamic model of building fire events. BFIRES considered three interacting components being: the fire and its by-products; the building enclosure; and the human occupants. The program is written in Fortran for a mainframe computer.

EXITT (Levin, 1989) simulates occupant decisions and actions in fires. It is mainly intended for small residential fires and therefore is not strictly applicable to multi-storey building scenarios.

EESCAPE (Kendik, 1988) is a PC-based computer programme for an egress model based on data provided by Predtechenski and Milinski (1978). According to Kendik, - "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 layout and the interdependencies between adjacent egress way elements".

## ALTERNATIVE STRATEGIES FOR EVACUATION

### Uncontrolled Simultaneous Evacuation

This is the simplest and most commonly used evacuation 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 conmmunication 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 recommend approved automatic sprinkler, manual fire alarm, emergency communications and emergency lighting systems.

Few building codes make explicit allowance for this type of evacuation in the calculation of exit width for example. An exception is BS 5588 for office buildings (BSI, 1983 A) which provides separate tables of persons accommodated versus exit width for uncontrolled total evacuation, and for evacuation of two adjacent floors at a time.

### Places of Refuge

In a high-rise building total evacuation may be a daunting and time-consuming task with there being many people for whom evacuation will be extremely difficult due to physical disabilities. Areas of refuge have been proposed as a means for providing temporary protection for these people. The concept of refuge areas is not new, with protected staircases performing this function to some extent. Fire protected horizontal exits may be used to connect the occupied space to the area of refuge, which could be in the same or a neighbouring building. There should also be a standard exit available from the place of refuge.

The Canadian code requirements make allowance for the use of places of refuge in their measures for fire safety in high buildings (NRCC, 1977). In this case the area of refuge may include normally occupied space, and because fire may occur in one of these spaces, provision is made for alternate groups of refuge areas. The areas of refuge are also generally required to be pressurised to prevent the flow of smoke from the fire zone to the area of refuge.

Study of safe refuge performance and effectiveness in actual buildings overseas should be done before consideration of their use in New Zealand.

## ADDITIONAL MEASURES TO PROMOTE SAFE ESCAPE

It is not intended to discuss the fire protection of escape routes in detail here; however, this section gives the reader a brief overview of a number of features that may be required to ensure the safety of escape routes.

## Early Warning Systems

The key to safe evacuation is early warning to occupants about the presence of a fire. 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 over thermal 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.

Canter et al (1987) carried out an investigation of Informative Early Warning Systems (IEW) developed using micro-processor technology, to identify the contribution they make to effective evacuation and to examine how the information carried can most effectively promote rapid and safe evacuation of a specific building. They suggest that time savings of the order of 1 to 2 minutes could be achieved through appropriate use of IEW systems in large complex occupancies.

## 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, which could be 30 minutes or more for a tall building and much less for a low-rise building. Connecting doors between the exitway and the rest of the building should be fire-resisting. 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, a smoke-stop door is defined in the fire bylaw as a door complying with NZS 4232 (SANZ, 1988 B) having integrity of 30 minutes and a leakage level of not more than 16 $m^3/hr$ per metre of perimeter of the leakage path, when tested in accordance with BS 476 Part 31.1 (BSI, 1983 B) at a maximum pressure difference of 100 Pa. This requirement will normally necessitate the use of smoke seals, effective in restricting the passage of relatively cool smoke. Intumescent seals only become effective at a later stage in the development of the fire when higher temperatures are reached, necessary to activate the seals. Because the doors must be in a closed position to be effective they must be fitted with self-closing devices, and furthermore must be able to be readily opened by escaping occupants.

Fire and smoke-stop doors have traditionally suffered from poor practices on the part of building occupants in that they are commonly wedged in an open position, rendering them useless in the event of fire. Current technological advances provide the means for minimising the impact of this type of occurrence in the design of electro-magnetic hold-open devices, which hold the door open in normal operation and automatically release the door on the activation of a smoke detector or alarm.

Hold-open devices are most appropriate in occupancies where wedged fire doors are a problem, and to ensure they operate at the earliest possible stage, they should preferably be wired into an early warning (alarm) system where present.

Lobbies are a safeguard against smoke penetration of a stairway and are especially advisable for enclosing elevator or 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. It should also be appreciated that a negative pressure in the escape route should be avoided as it will attract smoke from adjacent areas, and hinder escape. Negative pressure can be caused by extracting smoke from the top of a stair shaft. Such extraction systems should only be provided for use by the fire service.

The pressure difference must not be so great as to make the doors difficult to open. The initial force required to move the door from its closed position must not exceed 180 N and the maximum force required to operate the door through its full travel must not exceed 110 N (SANZ, 1988 A). It has been recommended (SAA, 1979) that the pressure difference across each doorway (when all other doors are closed) should not exceed 50 Pa. There has been no specific guidance published in New Zealand on pressurised escape route design but there is a British Code of Practice available (BSI, 1978) and an Australian code (SAA, 1979) covering aspects of stairway pressurisation for designers seeking further information.

## Smoke Control

In buildings where extensive spread of smoke is likely to occur due to the presence of voids through floors and interconnected spaces, such as in atrium buildings, engineered smoke control systems may be required to limit the spread of smoke in the building for a period sufficient for the occupants to escape. These systems may be used in conjunction with a sprinkler system which will control the maximum fire size and therefore the likely volume of smoke produced. The smoke control systems can then be designed to accommodate this maximum amount of smoke, and also ensure the underside of the smoke layer is maintained above the heads of escaping occupants. Smoke control systems increase the time available for escape by delaying the onset of smoke logging.

## 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 nearer to the fire have less heat and smoke to combat and more time to escape.

In terms of controlling the amount of smoke in high buildings, sprinklers are considered to be most effective and reliable in comparison with other measures that could be taken e.g., pressurisation or ventilation (McGuire and Tamura, 1979). Sprinklers will limit the amount of combustible material involved in the fire and subsequently the amount of smoke produced which therefore increases life safety in the building by increasing the time available for escape. The longer is the evacuation time for the building (i.e., the higher the building is) the greater the influence on life safety a sprinkler system will have. The recent development of fast response sprinkler heads also make sprinkler systems a more attractive life safety feature by ensuring their operation at an earlier stage in the fire development. The design of automatic sprinkler systems in New Zealand is covered in NZS 4541 (SANZ, 1987).

BIC (1988) recommended that the building height at which sprinklers are required should be lowered from 46 m to 25 m for low risk occupancies, and to 15 m for moderate and high fire risk occupancies with a place of assembly on an upper floor. These height were considered by BIC to be such that the life safety advantages of sprinklers disappear because evacuation can be completed before the escape routes become impassable due to the fire. This view is not shared by the New Zealand Fire Service.

## Surface Finishes

The surface finish of lining materials is commonly controlled within the exitway to minimise the risk of serious fire, as wall and ceiling surfaces in particular can have a significant influence on the development of a fire. In New Zealand, the Early Fire Hazard test (SAA, 1989) is used to assess behaviour of wall and ceiling linings to a small developing fire by exposing samples to heat from a radiating panel. Flammability of textiles and drapes in exitways is controlled by AS 1530 Part 2 (SAA, 1973), which involves exposing a vertical strip of material to a small ignition source placed at the lower end.

The test methods produce various indices which are most useful as a means of ranking the behaviour of systems under a standardised set of conditions. They do not necessarily reflect the hazard existing in a real fire scenario.

## 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 primary purpose of providing a protected place from fire. Few codes appear to restrict the fire load in exitways, however DZ 4226

(SANZ, 1984) is an example where applied fire load in exitways is controlled.

## 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. The fire bylaw allows emergency lighting in accordance with NZS 6742 (SANZ, 1971).

## 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 (lifts) has been discouraged for evacuation purposes traditionally because of lack of control over when or where they may open. Fire deaths have occurred where elevators have stopped and opened at the fire floor or where the power supply has failed. This can happen when heat sensitive call-buttons are used. Lifts may also stop when vertical guide rails become distorted in the vicinity of the fire floor. It is common for elevators to be programmed to return to the ground floor on the notification of a fire, where a physical head count of the lift occupants can be done, with lifts then designated as fire-fighting lifts if necessary at the disposal of the Fire Service for transporting personnel and equipment and for assisting in the evacuation of disabled persons.

## CONCLUSIONS

1. To ensure life safety, egress provisions cannot be considered in isolation from the total fire safety systems of the building, which may include the provision of sprinklers, smoke control systems and pressurised escape routes. This report gives an indication of the safety systems which can be used to aid means of escape.

2. Two alternative means of escape should be provided in all buildings, except for small, low-rise occupancies with restricted travel distances, floor areas, and number of occupants.

3. Adequate separation (by distance) of alternative escape routes requires definition in New Zealand code requirements. This may be defined in terms of an angular separation or minimum defined distance apart. A minimum separation distance of 7 to 8 m in office occupancies is appropriate.

4. Performance criteria for escape can be explicitly stated in terms of design escape time and maximum travel distance. The floor clearing times implicit in current code requirements are, under conditions of

maximum demand, likely to be in excess of the 2.5 minutes usually assumed.

5. There should be a limitation provided in New Zealand code requirements on the maximum permitted travel distance from a remote point to the nearest entrance to an exitway where two alternative means of escape are available. This distance should take into account the expected fire severity, ease of access to a safe place, likely occupant response and mobility.

6. Research into exitway capacity design allows dynamic exitway calculations to be undertaken and indicates that the unit of exit width concept is no longer appropriate and should be replaced with a linearised relationship between exit width and population.

   It is possible to design exitway capacity to an equivalent level of safety as contained in published code requirements by calculating an equivalent flow time but by varying stair geometry, handrail location and stair width. To achieve a flow time of 2.5 minutes, assuming a maximum stair slope of 37°, the following expressions can be used to relate nominal stair width, number of occupants, number of intermediate handrails provided and number of available exitways:

   Stairs: total width (mm) = 300 E + 8.6 N + 180 H

   Level Passageways: total width (mm) = 300 E + 5.1 N + 180 H

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

7. Computer-based models are available to consider certain aspects of evacuation performance and for optimising that performance. They should only be used by knowledgeable persons familiar with the many other inter-related features which affect egress.

8. Predictions of total egress performance and evacuation times should make allowance for the time associated with human behaviour prior to and during the evacuation.

# REFERENCES

## Codes and Standards

Australian Uniform Building Regulations Co-ordinating Council (AUBRCC). 1990. Building Code of Australia (BCA). Australia

Clarke, H.W., Nelson, J., and Thompson, E. 1985. Knight's Building Regulations (with approved documents). Charles Knight Publishing. Croydon, UK

British Standards Institution (BSI). 1978. Code of Practice for Fire Precautions in the Design of Buildings. Part 4. Smoke Control in Protected Escape Routes Using Pressurization. BS 5588 : Part 4. London

British Standards Institution (BSI). 1983 A. Fire Precautions in the Design and Construction of Buildings. Part 3. Code of Practice for Office Buildings. BS 5588 : Part 3. London

British Standards Institution (BSI). 1983 B. Methods for Measuring Smoke Penetration Through Doorsets and Shutter Assemblies: Section 31.1 Method of Measurement under Ambient Temperature Conditions. BS 476 Section 31.1. London

International Confererence of Building Officials (ICBO). 1988. Uniform Building Code. California, USA

National Fire Protection Association (NFPA). 1988 B. Life Safety Code. NFPA 101. National Fire Protection Association, Massachusetts, USA

National Research Council of Canada (NRCC). 1977. Measures for Fire Safety in High Buildings. Ottawa

National Research Council of Canada (NRCC). 1990. National Building Code of Canada (NBCC). Ottawa

Standards Association of Australia (SAA). 1973. Test For Flammability of Materials. AS 1530 Part 2. North Sydney, Australia

Standards Association of Australia (SAA). 1979. Fire Precautions in Buildings with Air-Handling Systems. AS 1668 Part 1. North Sydney, Australia

Standards Association of Australia (SAA). 1989. Simultaneous Determination of Ignitability, Flame Propagation, Heat Release, and Smoke Release. AS 1530 Part 3. North Sydney, Australia

Standards Association of New Zealand (SANZ). 1971. Code of Practice for Emergency Lighting in Buildings. NZS 6742. Wellington, New Zealand

Standards Association of New Zealand (SANZ). 1984. Draft New Zealand Standard Design for Fire Safety. DZ 4226. Wellington, New Zealand

Standards Association of New Zealand (SANZ). 1987. Automatic Sprinkler Systems. NZS 4541. Wellington, New Zealand

Standards Association of New Zealand (SANZ). 1988 A. Fire Resisting Construction and Means of Egress. NZS 1900 Chapter 5. Wellington, New Zealand

Standards Association of New Zealand (SANZ). 1988 B. Performance Criteria for Fire Resisting Closures. NZS 4232. Wellington, New Zealand

General

Barnett (undated). Minimum Distance Between Fire Exit Doors in Buildings. MacDonald Barnett Partners Ltd. Auckland

Bastings, D. 1988. Background to DZ 4226 Draft New Zealand Standard: Design for Fire Safety. Building Research Association Study Report SR9. Building Research Association of New Zealand, Judgeford

Bryan, J.L. 1988. Behavioural Response To Fire and Smoke. In Section 1 Chapter 16 of The SFPE Handbook of Fire Protection Engineering. National Fire Protection Association, Massachusetts, USA

Building Industry Commission (BIC). 1988. Report to Minister of Internal Affairs. Fire Sprinklers and Means of Egress. Building Industry Commission. Wellington

Building Industry Commission (BIC). 1990. Approved Document D1: Access Routes (Draft). Building Industry Commission. Wellington

Canter, D. Powell, J. and Booker K. 1987. Psychological Aspects of Informative Fire Warning Systems. Building Research Establishment Report 127. Department of the Environment, Borehamwood.

Fitch, J.M., Templer, J.A. and Corcoran, P. 1974. The Dimensions of Stairs. Scientific American 231 (4) pp 82-90

Fruin, J. 1971. Pedestrian Planning and Design. Metropolitan Association of Urban Designers and Environmental Planners. New York

Ingham, P.E. 1981. The Flammability of Polyurethane-Upholstered Furniture, III. House Fire Tests. Communication No. 73. Wool Research Association of New Zealand. Christchurch

Kendik, E. 1986. Methods of Design for Means of Egress: Towards a Quantitative Comparison of National Code Requirements. Proceedings First International Symposium Fire Safety Science, pp 497-511

Kendik, E. 1988. Means of Escape - 1988 How Close Are We To Modelling Egress From Buildings In Fire ?. Paper presented at 4th International Fire Conference (Interflam '88), Cambridge

Kisko, T.M., Francis, R.L. and Noble, C.R. 1984. Evacnet+ User's Guide. Department of Industrial and Systems Engineering, University of Florida, USA

Kisko, T.M. and Francis, R.L. 1985. Evacnet+: A Computer Program to Determine Optimal Building Evacuation Plans. Fire Safety Journal 9(2), pp 211-220

Levin, B.M. 1989. EXITT - A Simulation Model of Occupant Decisions and Actions in Residential Fires. In Technical Reference Guide for the HAZARD I Fire Hazard Assessment Method, NIST Handbook 146, Volume II. National Institute of Standards and Technology, USA

Malhotra, H.L. 1986. Fire Safety in Buildings. BRE Report. Building Research Establishment, Fire Research Station, Borehamwood, UK

McGuire, J.H. and Tamura, G.T. 1979. The National Building Code Smoke Control Measures - An Overview. DBR Paper 872, Division of Building Research, National Research Council of Canada, Ottawa

Melinek, S.J. and Booth, S. 1975. An Analysis of Evacuation Times and the Movement of Crowds in Buildings. BRE Current Paper CP 96/75. Building Research Establishment, Hertfordshire

National Fire Protection Association (NFPA). 1981. Life Safety Code Handbook 2nd edition. National Fire Protection Association, Massachusetts, USA

National Fire Protection Association (NFPA) 1988 A. Manual on Alternative Approaches to Life Safety, Chapter 2 - Alternative Calculations for Stairs Width. NFPA 101M. National Fire Protection Association, Massachusetts, USA

Nelson, H.E. and MacLennan, H.A. 1988. Emergency Movement. In Section 2 Chapter 6 of The SFPE Handbook of Fire Protection Engineering. National Fire Protection Association, Massachusetts, USA

New Zealand Fire Service. 1988. Controlled Evacuation - Interim Policy Guidelines. Fire Safety Information Bulletin No.17/88. Wellington

Pauls, J. L. 1980. Building Evacuation: Research Findings and Recommendations. In Fires and Human Behaviour edited by D Canter. John Wiley and Sons Ltd

Pauls, J.L. 1984. The Movement of People in Buildings and Design Solutions for Means of Egress. Fire Technology, 20 (1) pp 27-47

Pauls, J.L. 1987. Calculating Evacuation Times for Tall Buildings. Fire Safety Journal, 12, pp 213-236

Pauls, J.L. 1988. Movement of People. In Section 1 Chapter 15 of The SFPE Handbook of Fire Protection Engineering. National Fire Protection Association, Massachusetts, USA

Post War Building Studies No 29. 1952. Fire Grading of Buildings. Ministry of Works. Her Majesty's Stationery Office, London

Predtechenskii, V.M. and Milinskii, A.I. 1978. Planning for Foot Flow in Buildings. Amerind Publishing, New Dehli

Stahl, F.I. 1979. Final Report on the "BFIRES/Version 1" Computer Simulation of Emergency Egress Behaviour During Fires: Calibration and Analysis. NBSIR 79-1713. National Bureau of Standards, Washington

Stahl, F.I. 1980. BFIRES/Version 2: Documentation of Program Modifications. NBSIR 80-1982. National Bureau of Standards, Washington

Stahl, F.I. and Archea, J. 1977. An Assessment of the Technical Literature on Emergency Egress from Buildings. NBSIR 77-1313. National Bureau of Standards, Washington

Stahl F.I., Crosson, J.J. and Margulis, S.T. 1982. Time-based Capabilities of Occupants to Escape Fires in Public Buildings: A Review of Code Provisions and Technical Literature. NBSIR 82-2480. National Bureau of Standards, Washington

Watts, J.M. 1987. Computer Models for Evacuation Analysis. Fire Safety Journal, 12 pp 237-245

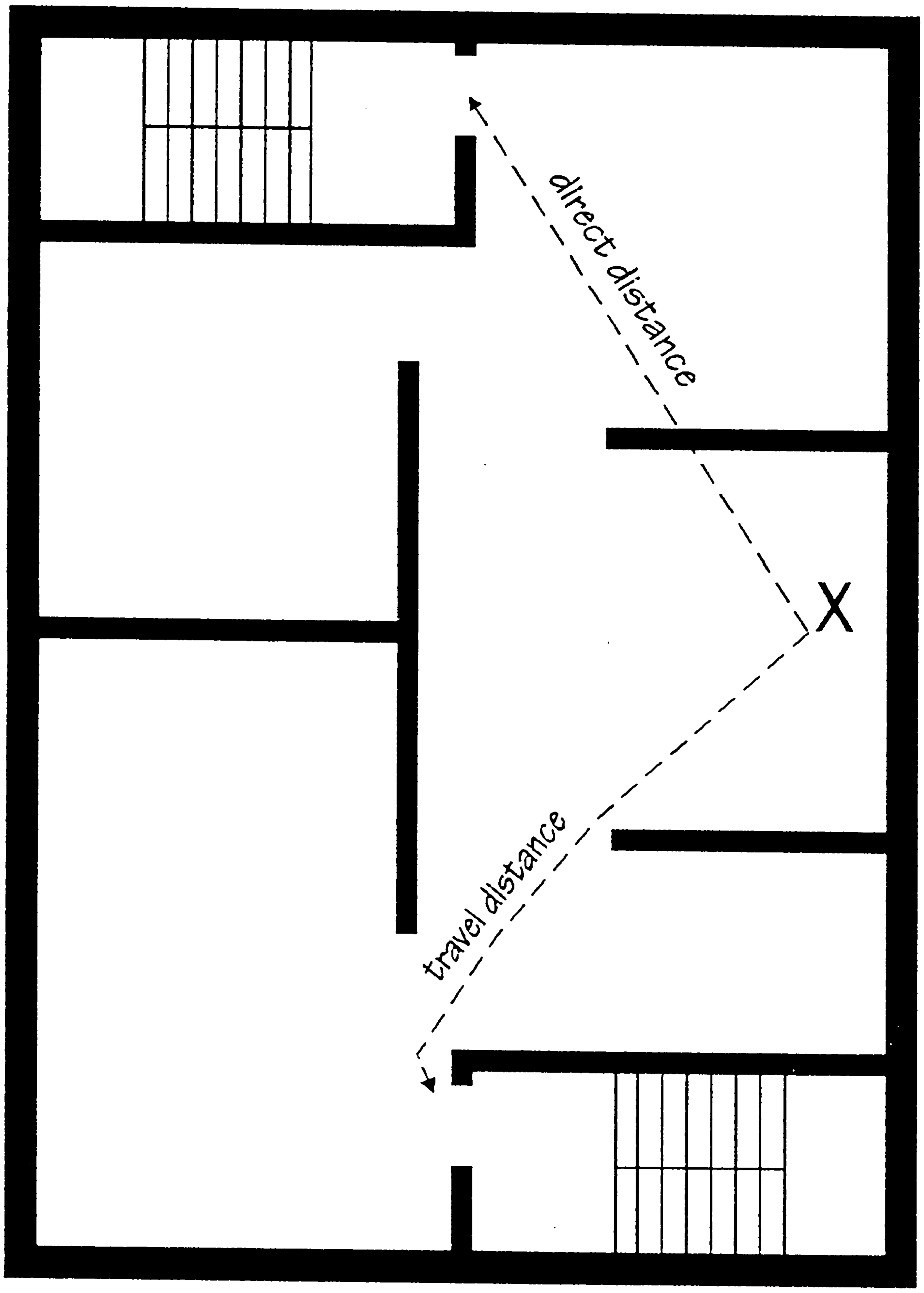


Figure 1 : Measurement of travel distances and direct distances

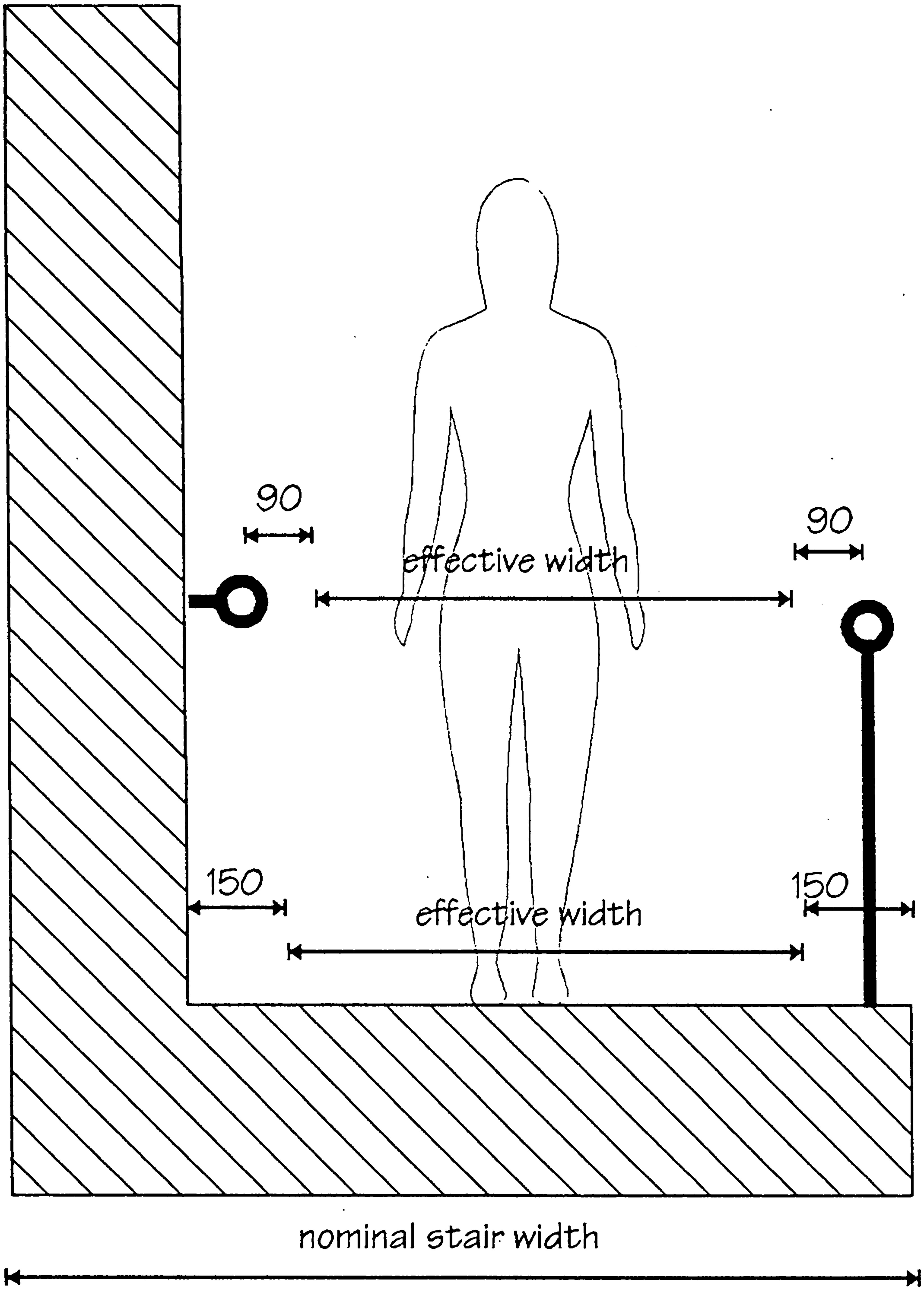
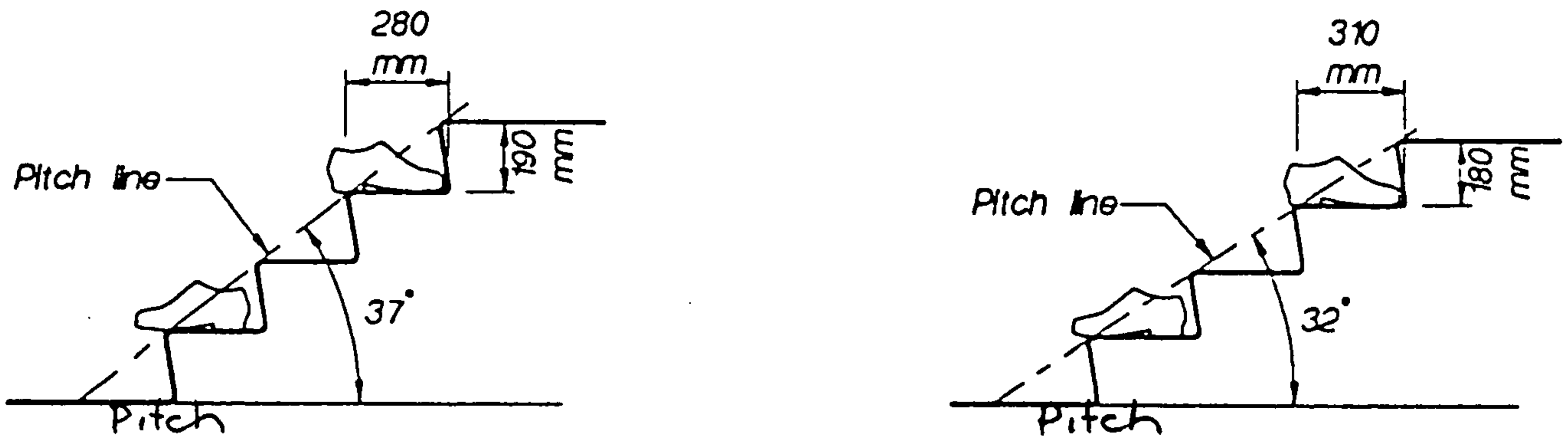


Figure 2 : Measurement of effective stair width in relation to walls and handrails



Maximum Pitch for common stairways

Maximum Pitch for accessible stairways

Figure 3 : Pitch, risers and treads for stairs from BIC (1990)

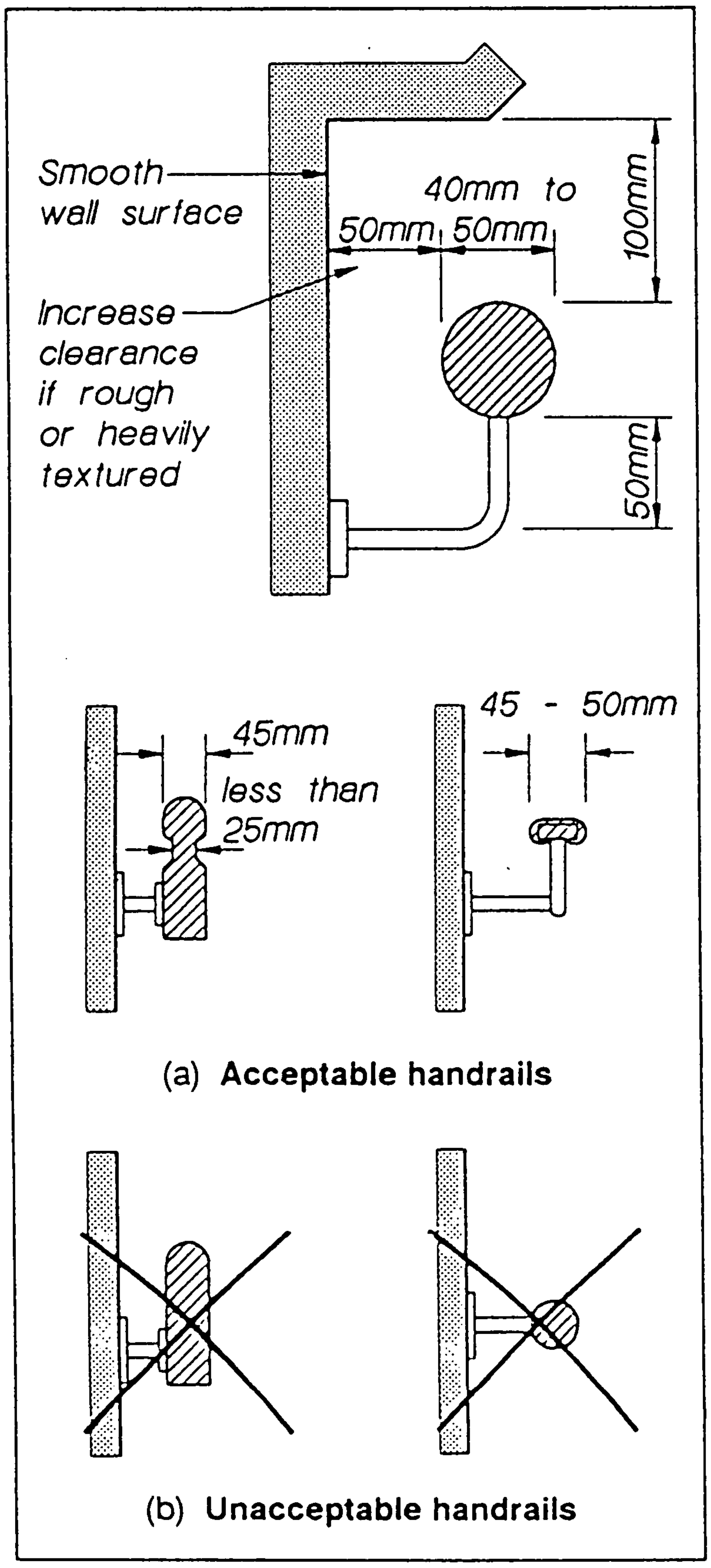


Figure 4 : Handrail profiles and clearances from BIC (1990)

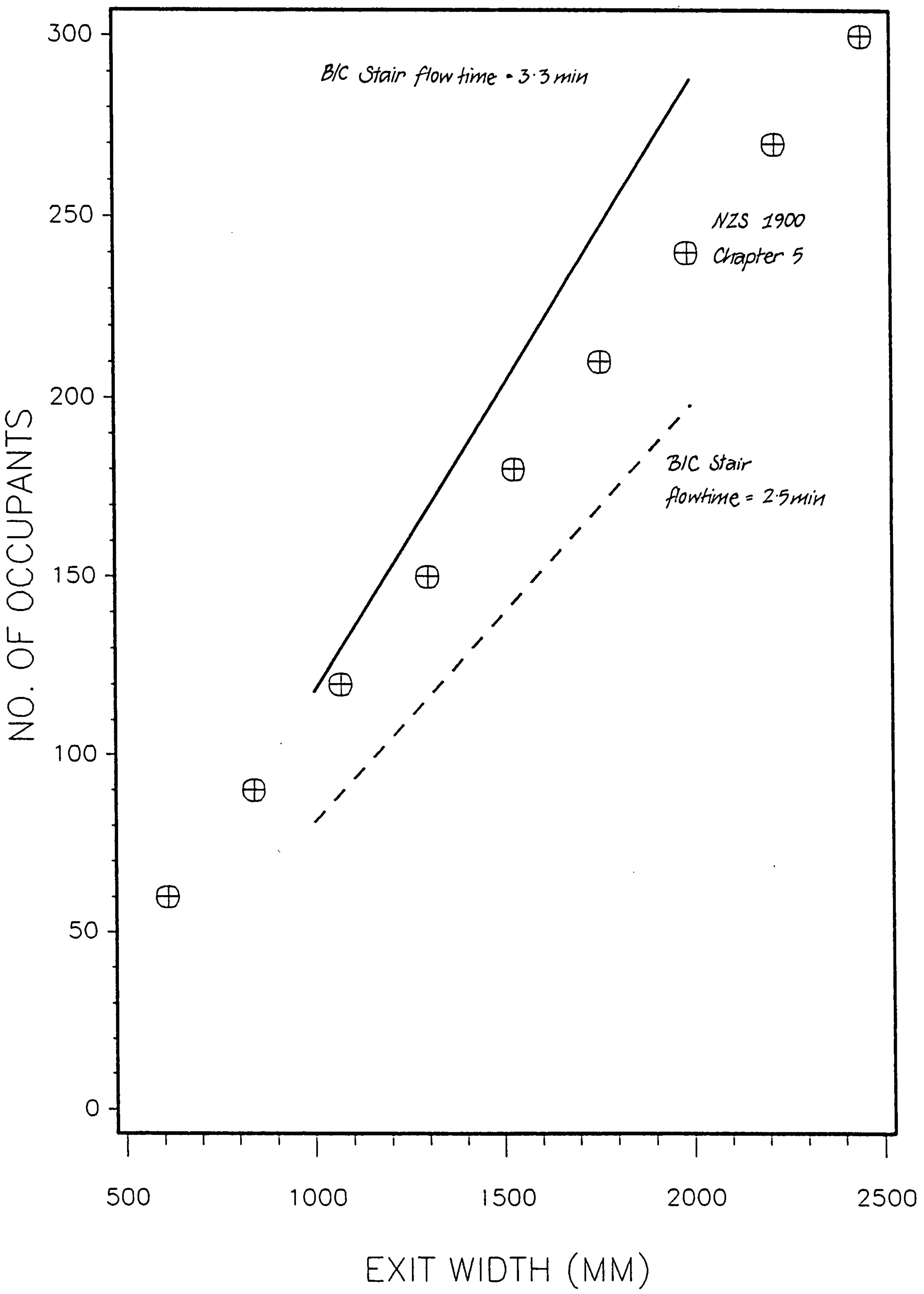


Figure 5 : Comparison of number of occupants versus stair width where one exitway is available and no intermediate handrails provided

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