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TECHNICAL RECOMMENDATION

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METHOD FOR DETERMINING THE MINIMUM WIDTH OF EXITWAYS IN MEANS OF ESCAPE

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REFERENCE

Wade, C.A. 1992. Method for Determining the Minimum Width of Exitways in Means of Escape. Building Research Association of New Zealand Technical Recommendation No 11. Judgeford, New Zealand.

RELEVANCE

This design method is intended to be used as an alternative method for determining the minimum width of exitways in buildings. Currently, minimum width can be determined using the New Zealand Building Code (NZBC) Approved Document C2/AS1 (BIA, 1992 B). The method presented here will provide an equivalent level of safety to Approved Document C2/AS1 Paragraph 2.3.2, assuming that a common stair with a maximum pitch (slope) is used as permitted in Approved Document D1/AS1 (BIA, 1992 C). The method proposed here provides the additional flexibility to make allowances for the ease of use of stairs depending on their gradient. Stairs that are generously proportioned and comfortable for people to use will result in a faster flow of people and therefore faster evacuation can be achieved. In many cases the method will allow the exit width to be less than in Approved Document C2/AS1, for a given occupant load, but without any increase in evacuation time.

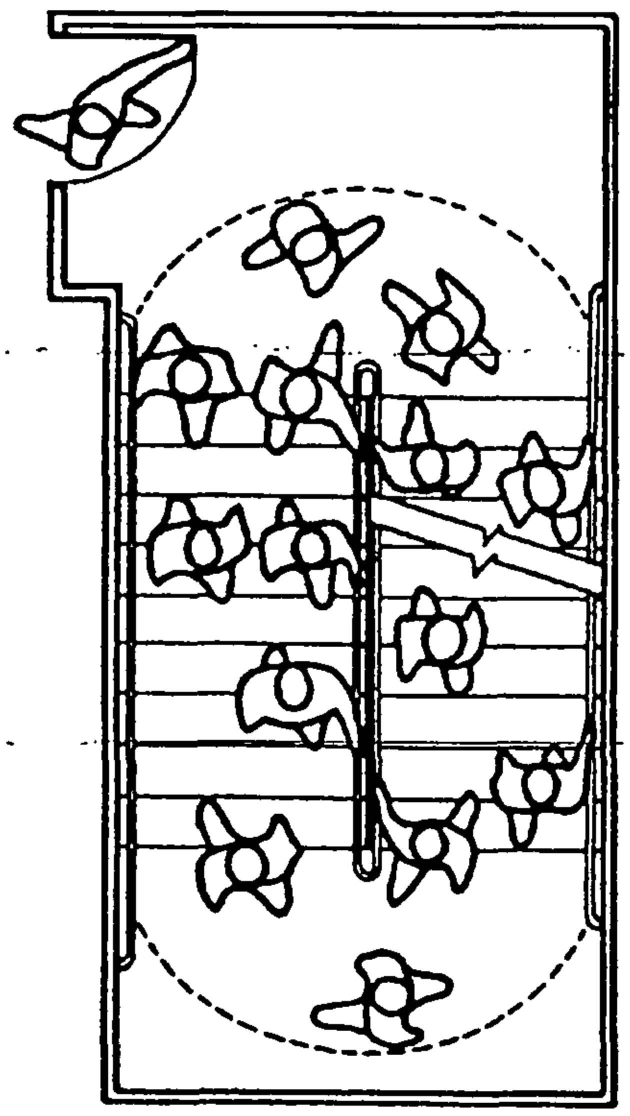

Figure 1 : Plan View of Stair in Use
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ACCEPTANCE

It is recommended that this design method be accepted as satisfying the requirements of the New Zealand Building Code Clause 2.3.3a (BIA, 1992 A) which states:

Escape routes shall be of adequate size for the number of occupants.

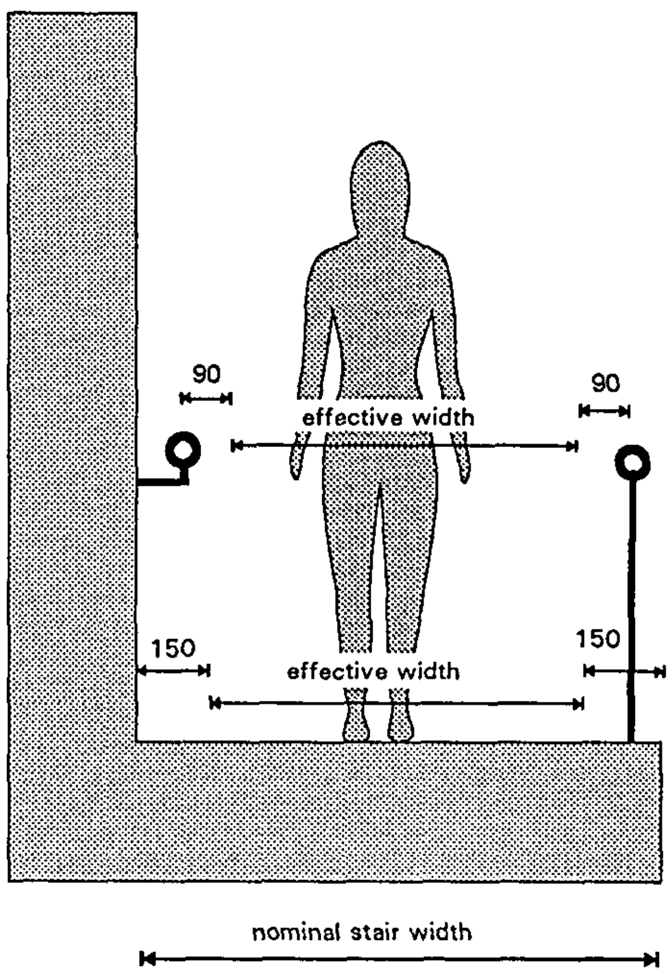
SCOPE OF APPLICATION

The method described here is applicable to all types of occupancy or purpose group, except open grandstands and similar types of open-air stadia. In these cases the method could still be applied in principle, but the calculations would be different.

BACKGROUND

This design method is primarily based on the "effective width model" developed by Pauls (1988) and as used in the method described in NFPA 101 M (1988).

The effective width model describes the following observed phenomena - there is an edge effect at the sides of a moving mass of people, i.e., most people in a crowd tend to keep a small clearance from side boundaries of an escape route. Furthermore, because of lateral body sway (the natural side-to-side swaying of people to maintain balance when walking slowly) people in a crowd do not walk shoulder to shoulder in regimented lanes, but rather walk in a staggered arrangement that makes more efficient use of the available space and permits each person to see several steps ahead (see Figure 1). The average flow of people past any point is directly proportional to the effective stair width (see Figure 2), which is measured:



(a) 150 mm from a wall (possibly more or less depending on surface roughness and cleanliness). The effective width is therefore the nominal or usually credited stair width minus approximately 300 mm; or

(b) 90 mm from the centreline of a handrail (the centre of the handrail is the preferred reference point for determining effective width). Where there are two handrails, the effective width is the handrail centreline spacing minus approximately 180 mm; or

(c) between the edges of projecting seats into an aisle.

Where two or more of (a), (b) or (c) apply, the least value determined becomes the effective width.

Figure 2 : Measurement of effective stair width in relation to walls and handrails (all dimensions in mm)

Horizontal Exitways

Level passageways forming horizontal means of escape can be assumed to provide a maximum flow of 1.3 persons per second per metre of effective width (Nelson and MacLennan, 1988).

$$\text{flow} = \frac{\text{no. of people}}{\text{flow time} \times \text{effective width}} = 1.3 \frac{\text{persons}}{\text{sec. m}_{\text{eff}}}$$

$$\Rightarrow \text{flow time} = \frac{\text{no. of people}}{\text{flow} \times \text{effective width}}$$

The longest flow time derived from requirements given in Approved Document C2/AS1 for horizontal exits is 157 seconds. This is based on a minimum width of 1000 mm (effective width = 700 mm) with 7 mm/person required. This width will accommodate up to 143 people (=1000/7).

$$\text{flow time} = \frac{143 \text{ people}}{1.3 \dfrac{\text{people}}{\text{sec. m}} \times (1.0 - 0.3) \text{ m}} = 157 \text{ seconds}$$

For a flow time of 157 seconds, the maximum flow amounts to 204 persons per metre of effective width or 4.9 mm of effective width per person.

Vertical Exitways

The effective width model empirically relates the usable (or effective) width of a standardised stair of defined pitch (180 mm risers and 280 mm treads) to its flow capacity (the number of persons passing a given point in a unit of time) assuming there is a simultaneous demand on the exitway by a crowd of people in the following manner:

$$W_e = \frac{8040P}{t^{1.37}} \text{ where:} \qquad [1]$$

W_e = effective width (mm)

t = flow time (sec) < 600

P = no. of people served by the exitway

Rearranging the equation, the required effective width per person, can be given by:

$$\frac{W_e}{P} = \frac{8040}{t^{1.37}} \qquad [2]$$

The longest flow time derived from requirements given in Approved Document C2 (minimum nominal width = 1000 mm requiring 9 mm of width per person will accomodate 111 people (=1000/9)), and the steepest common stair permitted by Approved Document D1 (tread = 280 mm (min) and riser = 190 mm (max)) is 188 seconds. This is derived as follows:

$$\frac{W_e}{P} = \frac{1000-300}{111} = 6.3 \text{ mm effective width per person}$$

Since the stair being considered is steeper than the standard stair to which equation [1] and [2] apply, an adjustment is made to determine the effective width per person which is applicable to a standard stair. In accordance with the adjustments described in the following paragraphs, the standard stair is more efficient by 2% than the "common" stair used and the flow time calculated as:

$$\frac{W_e}{P} = \frac{8040}{t^{1.37}} \times 1.02$$

$$\Rightarrow t^{1.37} = \frac{8040}{6.3} \times 1.02 = 1302$$

$$\Rightarrow \ln t = \frac{1}{1.37}\ln(1302) = 5.23$$

$$\Rightarrow t = e^{5.23} = 188 \text{ seconds}$$

Therefore, by substituting 188 into equation [2], the minimum effective width per person for the standard stair can be calculated as 6.2 mm. For stairs which have riser or tread dimensions different from the standard stair their comfort and efficiency will be increased or reduced as the case may be. This will result in a shorter or longer time for people to traverse the stair, and requires an adjustment to the effective width per person according to the actual riser and tread dimensions.

Efficiency Factors

This design method uses an Efficiency Factor to take into account the increases or decreases in W_e/P discussed in (a) to (f) below. The efficiency factor indicates whether the performance of the exitway is better (+x%) or worse (-y%) than for an assumed standard case, and is required for vertical exitways for entry into Table 1.

The following is suggested as a guide in cases where a stair is used in the descending direction by a crowd.

(a) subtract one percent from W_e / P for every 5 mm that the tread exceeds 280 mm, up to a maximum of 10 percent.

(b) add one percent to W_e / P for every 5 mm that the tread is less than 280 mm.

(c) subtract one percent from W_e / P for every 5 mm that the riser is less than 180 mm up to a maximum of 5 percent.

(d) add one percent to W_e / P for every 5 mm that the riser exceeds 180 mm.

For ease of calculation, (a) to (d) are represented in graphical form in Figure 3. Several other adjustments to W_e/P may also be made to credit properly the performance differences due to other factors of stair design, construction and use (see Figure 4).

(e) add 10 percent to W_e/P for stairs where occupants must ascend.

(f) assume that a stair or horizontal exit used by a crowd containing a significant number of people who are elderly, very young, or unfamiliar with the exitway and its surroundings will perform up to 20% less efficiently than otherwise calculated. (Add 20 percent to W_e/P.)

Minimum Widths

Irrespective of the minimum width determined on the basis of the number of occupants there will be a minimum width necessary. A minimum width of between approximately 800 and 900 mm will comfortably accommodate a flow of occupants in single file, but passing with ease would not be possible.

The BIA (1992 B) recommends in Approved Document C2/AS1, Table 2, minimum widths of 850 mm and 1000 mm for horizontal and vertical exitways respectively. This applies to all occupancies (or purpose groups) except open grandstands (or similar) or places where people are sleeping and under detention (SD purpose group) or where they require care (SC purpose group). Exits from these latter spaces (SD, SC) are required to be at least 1200 mm and 1500 mm wide for horizontal and vertical exits respectively. Where the occupant load is less than 20, the minimum widths of 850 mm and 1000 mm may be reduced to 700 mm and 850 mm respectively.

For passageways or corridors that are required to accommodate the movement of beds the minimum width should be 2400 mm.

Approved Document C2/AS1 (BIA, 1992 B) permits obstructions such as door frames to impinge within the minimum exit width by no more than 100 mm.

Summary

Finally, it should be noted that there are other use factors that may have significant positive or negative effects on evacuation performance. For example, a stair that may be marginally too narrow (relative to some requirement) may perform acceptably in evacuations if there is sufficient preparedness and familiarity on the part of management and users. Conversely, an otherwise acceptable stair may have its advantages negated by factors such as normal prohibition of use because of security concerns. Generally the design and approval of egress facilities require good judgement that goes beyond strict adherence to quantitative formulae.

DESIGN PROCEDURE

1. Determine the maximum occupant load to be served by the exit from the appropriate occupant density tables, eg., Table A2 from Approved Document C4 Fire Safety Annex Appendix A (BIA, 1992 D). Occupant density tables give the number of occupants per square metre of floor space for different activities and spaces.

The number of occupants to be accommodated by any particular exit, will also depend on the total number of exits. Readers are referred to Approved Document C2/AS1 Table 1 (number of exits required) and Paragraph 2.3.2b which requires the total exitway width from a space to still be available if any one exit is blocked by fire.

For Horizontal Exitways

2. Using Table 1, take the far right column labelled horizontal exits and move vertically down until the maximum number of occupants the exitway is required to serve is found (previously calculated). Move horizontally to the left and read off the minimum nominal exit width and minimum distance between handrail centrelines (if applicable).

3. If the horizontal exit is to be used by a crowd containing a significant number of people who are elderly or very young increase the above widths by 20%.

4. If the number of occupants to be served by the exit exceeds 306, the widths can be calculated as follows:

effective width (mm) = 4.9 × number of occupants
nominal total width (mm) = 4.9 × number of occupants + 300
width between handrail centrelines (mm) = 4.9 × number of occupants + 180

Linear interpolation between the number of occupants may be used if desired in conjunction with Table 1.

For Vertical Exitways

5. Given that the dimensions of the stair risers and treads are known, determine the Stair Efficiency Factor from Figure 3.

6. Determine other Efficiency Factors covered by the items discussed in (e) and (f) above and summarised in Figure 4.

7. Sum all the Efficiency Factors to determine the Total Stair Efficiency Factor.

8. Refer to the appropriate column in Table 1 for the Total Stair Efficiency Factor. Move vertically down until the maximum number of occupants for which the stair is required to serve is found (previously calculated in Step 1 above). Move horizontally to the left and read off the minimum nominal stair width and minimum distance between handrail centrelines (if applicable).

Linear interpolation between the number of occupants and the efficiency factors may be used if desired in conjunction with Table 1.

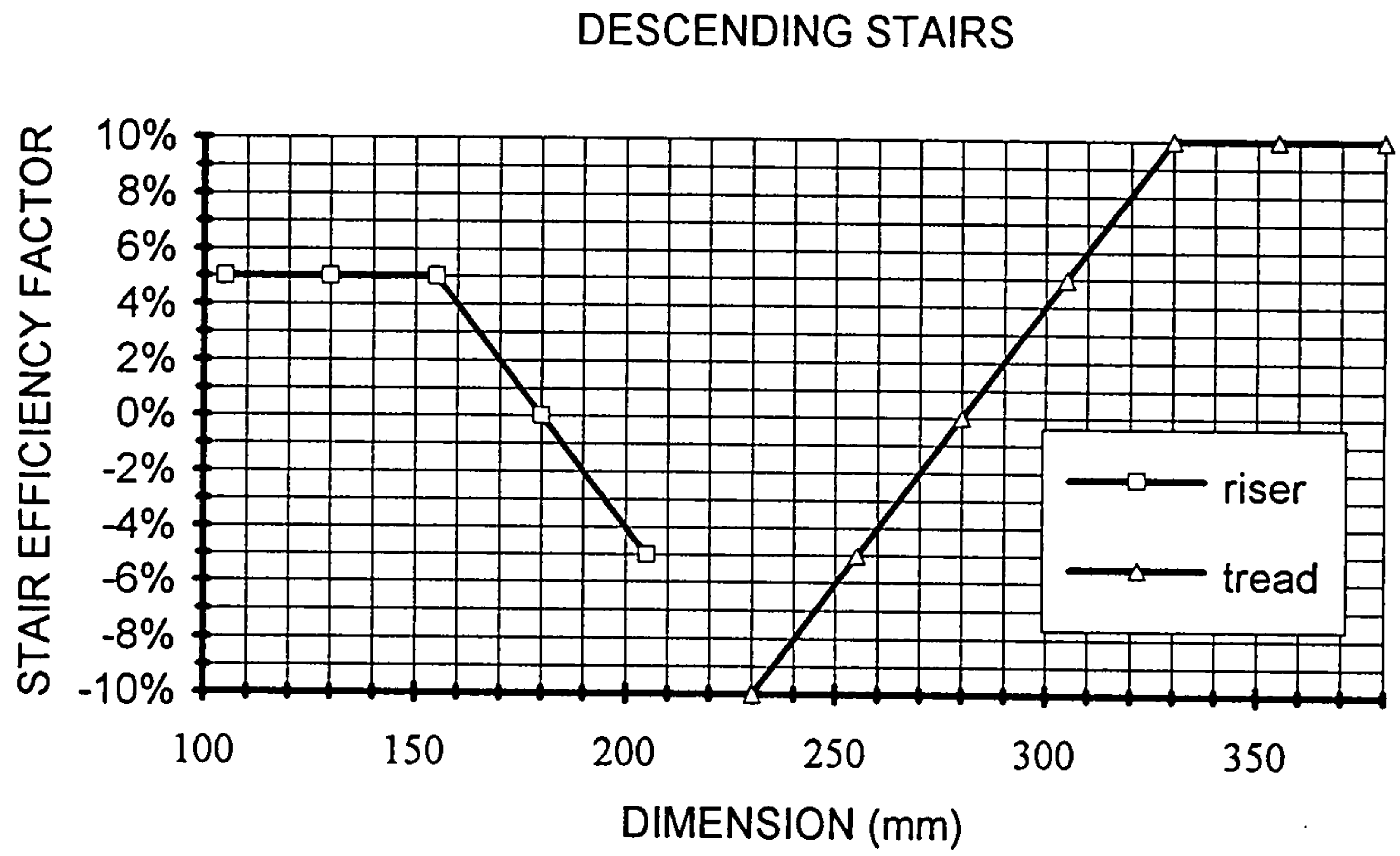


Figure 3: Efficiency Factor for Different Riser and Tread Dimensions

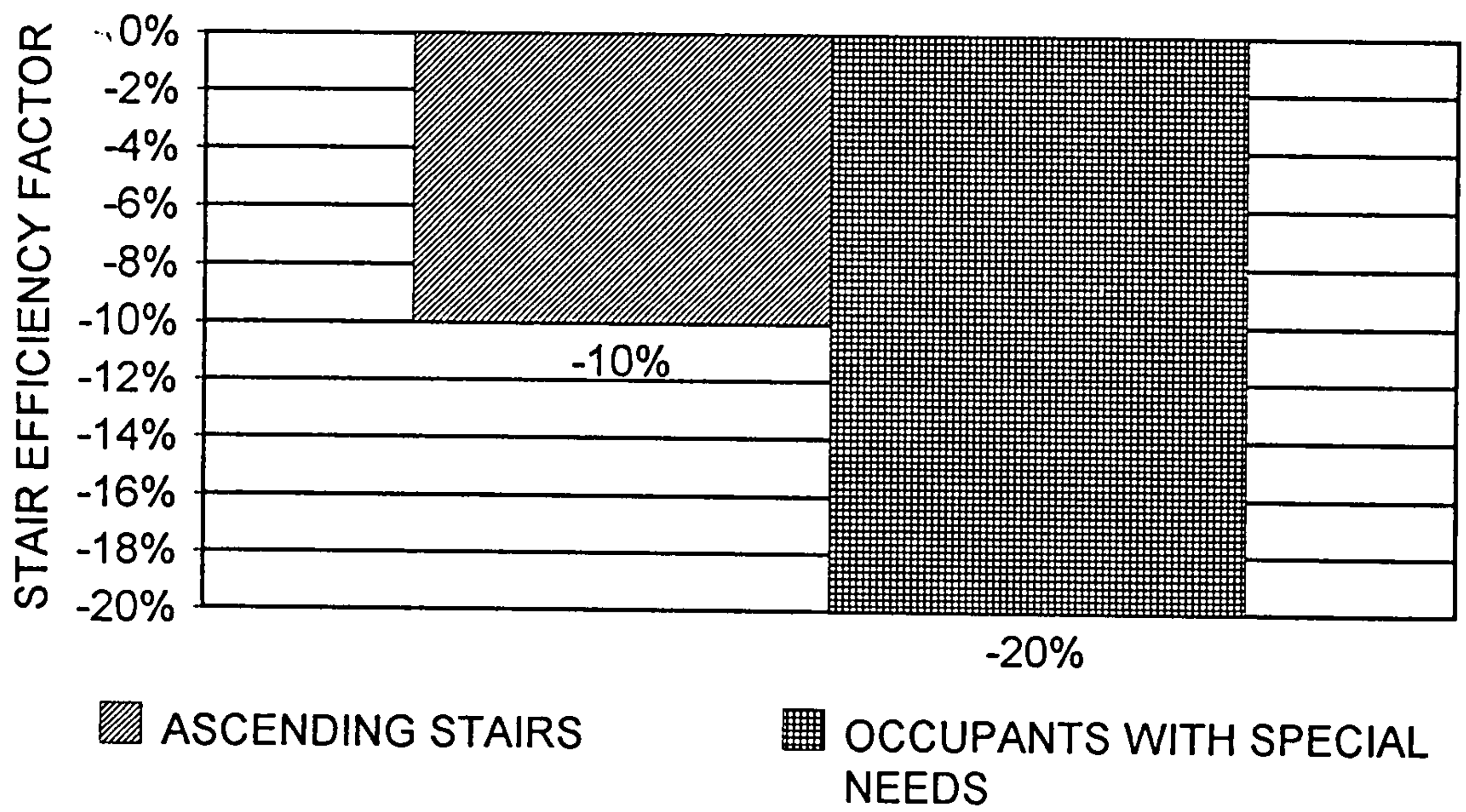


Figure 4: Efficiency Factors for Construction and Use

Nominal Width, mm	Handrail Centres, mm	Effective Width, mm	Maximum number of people able to be served by stair with Total Stair Efficiency Factor:										Hori-zontal Exit
			-45%	-35%	-25%	-15%	-10%	-5%	+0%	+5%	+10%	+15%	
700	580	400	36	42	49	55	58	62	65	68	71	75	82
750	630	450	40	47	55	62	66	69	73	77	80	84	92
800	680	500	45	53	61	69	73	77	81	85	89	93	102
850	730	550	49	58	67	76	80	85	89	94	98	103	112
900	780	600	54	63	73	83	88	93	97	102	107	112	122
950	830	650	58	69	79	90	95	100	106	111	116	121	133
1000	880	700	62	74	85	97	102	108	114	119	125	131	143
1050	930	750	67	79	91	103	110	116	122	128	134	140	153
1100	980	800	71	84	97	110	117	123	130	136	143	149	163
1150	1030	850	76	90	103	117	124	131	138	145	152	159	173
1200	1080	900	80	95	110	124	131	139	146	153	161	168	184
1250	1130	950	85	100	116	131	139	146	154	162	170	177	194
1300	1180	1000	89	106	122	138	146	154	162	170	179	187	204
1350	1230	1050	94	111	128	145	153	162	170	179	187	196	214
1400	1280	1100	98	116	134	152	161	170	179	187	196	205	225
1450	1330	1150	103	121	140	159	168	177	187	196	205	215	235
1500	1380	1200	107	127	146	166	175	185	195	205	214	224	245
1550	1430	1250	112	132	152	172	183	193	203	213	223	233	255
1600	1480	1300	116	137	158	179	190	200	211	222	232	243	265
1650	1530	1350	121	142	164	186	197	208	219	230	241	252	276
1700	1580	1400	125	148	170	193	205	216	227	239	250	261	286
1750	1630	1450	129	153	177	200	212	224	235	247	259	271	296
1800	1680	1500	134	158	183	207	219	231	243	256	268	280	306
intermediate handrail required													
1850	865	1370	122	145	167	189	200	211	222	233	245	256	
1900	890	1420	127	150	173	196	207	219	230	242	254	265	
1950	915	1470	131	155	179	203	215	227	239	251	262	274	
2000	940	1520	136	160	185	210	222	234	247	259	271	284	
2050	965	1570	140	166	191	217	229	242	255	268	280	293	
2100	990	1620	145	171	197	223	237	250	263	276	289	302	
2150	1015	1670	149	176	203	230	244	258	271	285	298	312	
2200	1040	1720	154	181	209	237	251	265	279	293	307	321	
2250	1065	1770	158	187	215	244	259	273	287	302	316	330	
2300	1090	1820	162	192	222	251	266	281	295	310	325	340	
2350	1115	1870	167	197	228	258	273	288	304	319	334	349	
2400	1140	1920	171	203	234	265	280	296	312	327	343	358	
2450	1165	1970	176	208	240	272	288	304	320	336	352	368	
2500	1190	2020	180	213	246	279	295	311	328	344	361	377	
2600	1240	2120	189	224	258	292	310	327	344	361	379	396	
2700	1290	2220	198	234	270	306	324	342	360	378	396	414	
2800	1340	2320	207	245	282	320	339	358	377	395	414	433	
2900	1390	2420	216	255	295	334	354	373	393	412	432	452	
3000	1440	2520	225	266	307	348	368	389	409	429	450	470	

Table 1: Maximum Number of Occupants to be Accommodated by an Exitway

WORKED EXAMPLES

(a) A single flight of stairs descending 2130 mm is to be used by 310 persons in an airport complex. What is the minimum required stair width if a riser - tread geometry based on 180 mm risers and 305 mm treads is provided?

> From Figure 3, the efficiency factors for the riser and tread are 0% and +5% respectively, giving a total of +5%.
>
> Use the column in Table 1 with a total stair efficiency factor of +5%, and move vertically down until 310 occupants is reached. Move left along the row to find a minimum nominal stair width of 2300 mm and requiring handrails at minimum centres of 1090 mm. *(BIA (1992 B) would require a minimum nominal width of 2790 mm with an intermediate handrail provided.)*

(b) A horizontal exit in a cinema is required to accommodate 200 people. What is the minimum width required?

> Refer to the far right column in Table 1. For up to 204 people the minimum nominal width required is 1300 mm. *(BIA (1992 B) would require a minimum nominal width of 1400 mm.)*

(c) A stair in a day-care centre is required to accommodate 65 people. The stair has risers and treads measuring 175 mm and 310 mm respectively. What are the minimum nominal width and distance required between handrail centrelines?

> From Figure 3, the efficiency factors for the riser and tread are +1% and +6% respectively, giving a total of +7%.
>
> From Figure 4, the efficiency factor for people with special needs such as young children is -20%. The total stair efficiency factor is therefore +7-20 = -13%.
>
> Use the column in Table 1 with a total stair efficiency factor of -15% (the closest to -13%; alternatively linear interpolation could be used), and move vertically down. It is seen that for up to 69 people the minimum nominal width required is 800 mm. The minimum distance between handrail centrelines is 680 mm. However there is a an overall minimum width requirement of 1000 mm (BIA C2/AS1 Table 2, 1992) which will govern in this case. *(BIA (1992 B) would also require a minimum nominal width of 1000 mm.)*

(d) A stair in the basement of a multi-storey office building is required to accommodate 200 people. It has risers of 195 mm and treads of 270 mm. What is the minimum nominal width required for the stair?

> From Figure 3, the efficiency factors for the riser and tread are -3% and -2% respectively, giving a total of -5%.
>
> From Figure 4, the efficiency factor for an ascending stair is -10%. The total stair efficiency factor is -5%-10% = -15%.

Use the column in Table 1 with a total stair efficiency factor of -15%, and move vertically down. It is seen that for up to 203 people the minimum nominal width required is 1950 mm with an intermediate handrail required. The minimum distance between handrail centrelines is 915 mm. *(Approved Document C2 (BIA, 1992 B) would require a minimum nominal width of 1800 mm without a requirement for an intermediate handrail. If the building height is more than 30 m then the maximum width permitted would be 1500 mm (Paragraph 2.3.4) requiring additional exitways to be provided as necessary.)*

REFERENCES

Building Industry Authority (BIA). 1992 A. Building Regulations. Wellington.

Building Industry Authority (BIA). 1992 B. Approved Document C2/AS1 Means of Escape. Wellington.

Building Industry Authority (BIA). 1992 C. Approved Document D1/AS1 Access Routes. Wellington.

Building Industry Authority (BIA). 1992 D. Approved Document C4 Fire Safety Annex Appendix A. Wellington.

National Fire Protection Association (NFPA). 1988. 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.

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.

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