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TIME OF EVACUATION BY STAIRS IN HIGH BUILDNGS

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F. R. Note 8

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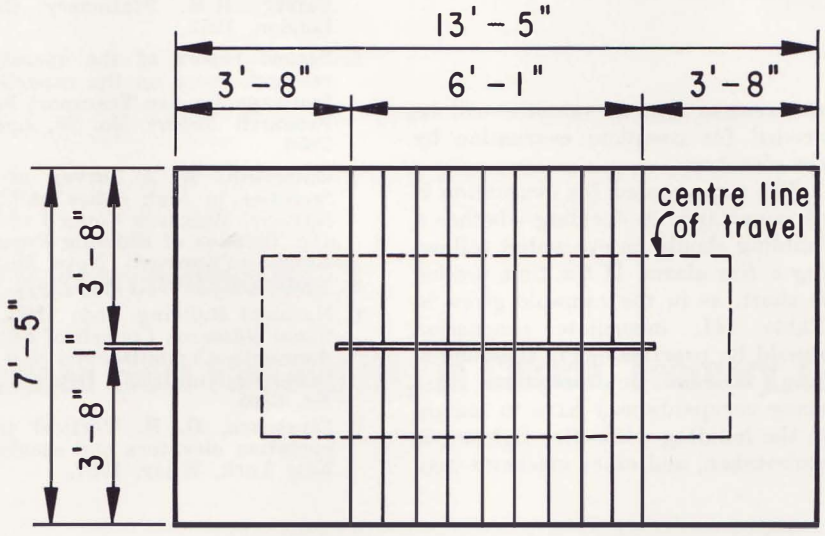
Time of evacuation by stairs in high buildings



13.4 X 7.4 = 99 sq ft

Average length of exit travel path = 27 ft

FIGURE 1
MINIMUM STAIR; 2 UNITS EXIT WIDTH (44 INCHES)

Although there is no record of large loss of life in fires in high buildings, the increasing number being erected makes it desirable that the provisions for safety to life be reconsidered. It is now becoming evident that in the event of fire in a lower storey of a high building, all vertical shafts will probably become filled with smoke, due to the buoyancy effect that induces vertical movement of air and smoke. This has been discussed in recent papers from the Division of Building Research (1, 2, and 3). Complete reliance can no longer be placed on immediate evacuation, or upon the concept of stairways as a place of safety in high buildings. Other factors in the building design will increasingly have to

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be brought into play to increase the degree of safety of the occupants.

When considering the various measures that can influence safety it is always desirable as a first step to predict the time that is needed to evacuate a building. This forms the subject of this paper.

The design of exit stairs and doorways for use in emergency was studied (4) by the National Bureau of Standards and the National Fire Protection Association jointly in 1935. Surveys were made of exit facilities in a number of buildings throughout the United States, and measurements were made of rate of travel on stairs and passages in railroad stations.

It was observed that persons can move freely in lanes that have an effective width of about 22 in. measured at shoulder height. The term "unit exit width" was used to denote this 22-in. lane width. The National Bureau of Standards suggested that the effective rate of travel was about 45 persons per minute on stairs and 60 persons per minute through doors, per unit exit width. It was recognized however that this concept of flow could not properly be applied to high buildings where many floors feed into the same stairway width. It was therefore suggested that in high office buildings there should be sufficient space in the stairways for the occupants of half the floors above the first to stand during an emergency assuming that persons can stand there at 1½ sq ft per person. The figures suggested to meet this recommendation have become the basis of requirements for exits in most North American building codes.

In 1956 the London Transport Board (5) started an extensive series of experiments on the movement of people in horizontal passages and on stairs. Although the objective was the improvement of the design of these facilities in underground stations the results are interesting and relevant to problems of evacuation. It was again demonstrated that there is a relationship between rate of travel and concentration of people. It was found that if the space per person in the passageway is 2 square feet or less all forward movement stops. This points to the danger recognized in most building regulations that any reduction in the exit width may obstruct forward movement and result in panic.

In an experiment designed to examine the effect of lane widths, it was found that a 6-ft-wide stair could pass 130 persons per minute. If, however, the 6-ft-wide stair was divided by a central handrail, (i.e. two 3-ft-wide stairs) this was reduced to 105 persons per minute. A 3-ft-wide stair is therefore not very efficient as it can handle little more than one exit lane.

Rate of movement was measured for different concentrations of people on stairs and in passages. Table I has been derived from the values for movement up stairs. It was noted that movement down was slightly faster, but the report did not deal with this point in detail. It was shown that at 5.5 sq ft per person, speed in the up direction was 129 ft/min and down 132 ft/min. The difference is therefore not great. In Table I the effective discharge in persons per unit exit width per minute is also shown derived from the figures for speed and concentration. It can be seen that for concentrations of 3.0 to 5.5 sq ft per person the effective discharge in persons per minute does not change.

A British Post War Building Study (6) issued in 1952 described a method of design to ensure that all the occupants of a building could enter the stairs in 2½ minutes. The basis of the calculations is the number of people discharged per unit width per minute. Two intervals are calculated by this method, which has become the basis of the British Standard Code of Practice:

(a) the time required to fill the stairs with people, and

(b) the time during which additional people can enter the stairs from the upper floors. This becomes possible as a corresponding number leave at the ground floor. If we do not regard the stair as a safe area of refuge we should add a third interval, (c), the time required for all the people remaining in the stairs to move out.

The following formula, adapted from the method described in Ref. 6, is suggested as a simple basis for calculating the time for complete evacuation, i.e. the sum of the intervals (a), (b) and (c) above.

$$T = \frac{N + n}{r \times u}$$

TABLE I

Relationship Between Concentration Of People on Stairs and Forward Movement

Concentration of People on Stairs, sq ft per person	Forward Movement, ft per min	Resultant Discharge From Stairs, persons per unit exit width* per min
2	0	0
2.5	53	39
3.0	75	45
3.5	82	43
4.0	94	43
4.5	106	43
5.0	117	43
5.5	129	43
6.0	139	43
6.5	143	40
7.0	147	39
7.5	150	37
8.0	152	35
8.5	154	33
9.0	156	31
9.5	157	30
10.0	158	29
11.0	158	26
12.0	158	24
13.0	158	22
14.0	158	21
15.0	158	19

*unit exit width = 22 in

where T = the time, in minutes, required for complete evacuation by stairs.

N = the number of people in the building above the first floor. It is assumed that the occupants of the first floor will leave by other doors at grade

n = the number of people who can stand on the stairs at 3 sq ft/person or the number of people on the floor, whichever is less

r = the rate of discharge of the stairs in people per unit exit width per minute. If the number of persons on the floor is equal to or greater than n at 3 sq ft/person, r = 45. If the number of people on the floor is less than this, an appropriate value for r is selected from Table I depending on the effective concentration expressed in square feet per person in the stair. Concentration of people in stairs is determined by dividing the horizontal area of stairs and landings between each floor and the one immediately below by the number of people on the floor.

u = the number of units of exit width in the stair, i.e. the number of 22-in. increments.

This calculation gives the time required for movement of people through the stairs. It may also be necessary in some instances to consider additional features that may extend the time of evacuation. The British Study has shown that the practical maximum movement of people in horizontal passages is 200 ft. per min. The National Building Code places a limit of 100 or 150 ft on the distance of travel to an exit, depending on whether the building is sprinklered or not. One may assume, that the occupants will be uniformly distributed over the floor area and so the time required for the first persons to enter the stairs will be negligible. If, however, all the occupants were 100 ft from the stair there would be a ½ minute addition to the evacuation time.

Some exit stairs discharge directly to the exterior; others discharge into corridors or vestibules. In the latter case the travel distance across the space from the foot of the stairs to the exterior may also have to be taken into account. There is also a delay in responding to the alarm. This may be assumed to be relatively short in office buildings where all the occupants are awake and alert. In residential buildings, however, if all the occupants are asleep one would expect a considerable delay in responding to an alarm.

A survey was made recently of 10 high office buildings (7) to study the relationship between time of evacuation in practice drills, number of occupants, and area of stairs. Table II shows the evacuation times recorded compared with the periods calculated by the above formula. On the average the calculated times are less by close to two minutes than those achieved in practice drills. The greater differences appear to be associated with buildings that have long corridor systems and those having a low population density.

Table III has been prepared to show the relationship between height of building, number of occupants, and time of evacuation by one typical stair. The stair selected has a clear width of 44 in. above the handrail and has a horizontal floor area of 99 sq ft between each floor and the one next below.

The National Building Code 1965 (8) would permit up to 120 persons per floor for each stair of this size in office buildings and 60 persons per floor in residential buildings. It can be seen that a 6-storey building having 128 persons per floor should be able to be evacuated by the stairs in 7½ minutes. A 20-storey building can also be evacuated in 7½ minutes provided there are not more than 34 persons per floor per stair.

The method of calculation described gives the practical minimum time for evacuating a building depending on the population, height of the building, and area and width of

TABLE II

Time of Evacuation For Certain Existing Office Buildings

Building No.	Height in Storeys	Area of Exit Stairs per Floor, sq ft	Width of Exit Stairs, unit exit width	Average Number of Occupants per Floor at Time of Survey	Evacuation Time Calculated By Formula, min	Evacuation Time in Practice Drill, min	Maximum No. of Occupants per Floor By NBC Provisions
1	7	857	10	61	2.1	4 1/2	600
2	7	636	8	108	2.1	5	480
3	9	692	8	133	3.6	4 1/2	480
4	9	408	4	111	6.0	5 1/2	300
5	11	346	4	110	6.7	6 1/2	240
6	11	150	4	100	5.8	7 /12	240
7	12	314	4	67	4.3	9	240
8	13	319	6	38	1.8	4	360
9	18	260	4	50	5.2	7 1/2	240
10	22	160	2	80	20.0	imcomplete	180

TABLE III

Number of Occupants Related to Time of Evacuation by One Stair

Area of Stair = 99* sq ft
Width of Stair = 44 in. (two units of exit width)

Height of Building in Storeys	Maximum Number of Occupants per Floor per Stair to Permit Evacuation in		
	10 min	7 1/2 min	5 min
20	45	34	22
15	62	46	30
10	96	71	48
9	108	84	56
8	128	96	64
7	145	109	75
6	173	128	83
5	217	160	104
4	289	214	139
3	433	321	208

*Plan of stair is shown in Fig. 1.
The National Building Code, 1965 would permit 120 persons per floor in office buildings and 60 persons per floor in residential buildings based on this stair.

stairs. It can be seen that if too many people enter the stairs at one point, or if any obstruction occurs on the floor, the concentration may approach that at which all forward movement will stop. This must be prevented in order to avoid the possibility of panic.

Table IV shows the evacuation times for buildings 15 to 50 storeys in height, having 240, 120 or 60 persons per floor based on the 44-in. stair discussed above. The calculations show that a 30-storey building with 240 persons per floor would require 1 hr and 18 min and a 50-storey building 2 hr and 11 min to evacuate this number of people. These figures are quoted only to demonstrate that the time needed for evacuation is long. One can imagine that many of the occupants would be unwilling or unable to walk down 50 flights of stairs.

An alternative may be to use the elevators for evacuation if it can be guaranteed that they will continue to function smoke-free for the required time. It is normal practice for elevator systems to be designed to bring down to the ground floor 20 per cent of the population in the peak 5 minutes (9). This normally occurs at the end of the working day. If this rate can be maintained one can assume that 25 minutes will be needed for complete evacuation by the elevators.

The time needed for evacuation is of importance in deciding whether a building should be evacuated following a fire alarm. If the time needed is short, as in the example given in Table III, immediate evacuation should be practicable. If the time is long, it must be recognized that many occupants may have to remain in the building while fire fighting is undertaken, and other measures may have to be taken to improve the safety features of the building. The other factors relating to fire safety in high buildings are being studied by the Division of Building Research and future articles will deal with those including movement of smoke and provision of areas of refuge.

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TABLE IV

Time of Evacuation by One Stair

Area of Star = 99 sq ft
Width of Stair = 44 in. (two units exit width)

Height of Building Storeys	Time Required For Evacuation		
	of 240 persons per floor	of 120 persons per floor	of 60 persons per floor
50	2 hr 11 min	1 hr 6 min	33 min
40	1 hr 45 min	52 min	26 min
30	1 hr 18 min	39 min	20 min
20	51 min	25 min	13 min
15	38 min	19 min	9 min