Evacuation drill held in the B.C. Hydro Building 26 June 1969

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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40000628
Building Research Note, 1971-09-01

CANADA

Building Research Note

EVACUATION DRILL HELD IN THE
B.C. HYDRO BUILDING
26 JUNE 1969

by

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DIVISION OF BUILDING RESEARCH · NATIONAL RESEARCH COUNCIL · OTTAWA · CANADA

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Over the last few years interest in emergency evacuation of buildings has grown considerably, as a result of fire incidents in tall buildings and intensive study of the movement and control of smoke (1, 2). As part of a total approach to life safety in buildings there exists a need for information describing the context, procedure, and efficacy of building evacuation. A few publications are available that summarize some pertinent operations research studies, examine existing regulatory practices in exit design, or even analyse some of the fragmentary records of evacuations of large buildings (3-9). These do not, however, meet the requirement for detailed descriptive and analytical information on evacuation as it may be conducted in the context of newer, higher buildings that may have sophisticated fire protection, air handling, and communications systems.

This Note reports a major evacuation exercise initiated and conducted by the British Columbia Hydro and Power Authority in Vancouver. At B.C. Hydro's request an independent observation committee (Appendix A) organized observations and assisted B.C. Hydro in evaluating the exercise. As a member of the committee, the author prepared an unpublished report that was distributed on a limited basis during 1970 by the Division of Building Research. Although DBR/NRC is publishing this Note (with the permission of the B.C. Hydro and Power Authority), no endorsement of a particular evacuation organization or procedure is intended.

BRIEF DESCRIPTION OF DRILL

On 26 June 1969 a pre-announced evacuation drill was conducted at the Head Office of the British Columbia Hydro and Power Authority in Vancouver. Over 1000 people were successfully evacuated from the 22-storey building within 14 min of the time the alarm was turned in.

During the first 2 min of the drill a prearranged procedure was followed to check the source of the alarm and organize key evacuation personnel. When total evacuation was ordered over the building's public address system, floor wardens supervised the clearing and checking of each floor before reporting to a central control centre, using an emergency telephone system. It took 12 min to clear the building once the evacuation was announced. Of a total of 945 people from floors above the mezzanine level 910 left by two 47-in. exit stairways and 35 used a supervised elevator.

DESCRIPTION OF THE BUILDING AND ITS OCCUPANCY

The air-conditioned office building was constructed in 1957. It has 21 floors above main and mezzanine, and two basement levels. The floor plan of floors 3 to 21 is illustrated in Figure 1. These floors form a reinforced concrete slab-type tower above a partial podium containing customer service, cafeteria, lounge, assembly, storage, workshop, computing, banking and trouble-service facilities. The last two are effectively separated from the other areas and were not evacuated during the drill.

A typical floor has a gross area of about 11,500 sq ft, of which about 6,800 sq ft is considered usable for offices and about 2,000 sq ft is taken up by main circulation routes. For floors 1 to 21 the total floor area served by the two exit stairways is about 188,000 sq ft. In this area 1365 work places were provided at the time of the drill, but only 945 persons were actually present. About 200 work places were provided in the two basements and on the main and mezzanine levels.

At the time of the drill the building was occupied solely by the staff of the British Columbia Hydro and Power Authority (except in the banking area). In addition to a wide range of ancillary activities in the podium areas of the building there were general and executive office activities carried out by a majority of Head Office staff. Staff members engaged in these activities were, with a few exceptions, capable of evacuating the building without assistance. During the drill 35 people, including arthritics and those having heart conditions, were evacuated by elevator, representing about 4 per cent of the total number on the upper floors. The remainder were probably fairly accustomed to using the stairways because of heavy interfloor traffic in this single-tenant occupancy, fairly slow elevator service, the placement of washrooms off the stairways (see Figure 1), and the generally high standard of finish and illumination in the stairways.

The geometry of the two exit stairways is shown in Figure 1. They have a width of 47 in. at shoulder height, and each stairway has an area of 155 sq ft per storey, of which about 140 sq ft is the effective area taken up by a 47-in.-wide stream of people. The length of the travel path per floor is 40 ft measured along the centreline of a 47-in. path down the stairs and landings.

EVACUATION PLANNING, ORGANIZATION, AND PROCEDURE

The planning for the evacuation drill and for future emergencies was extensive, and both planning and the procedures to be followed (as well as warning of an impending drill) were outlined in a bulletin given to B.C. Hydro Head Office staff a few days before the drill. In addition, detailed instructions (for total and partial evacuations) were issued to evacuation control personnel: evacuation control officers (five in the building), floor wardens, assistant floor wardens, and searchers, all under the direction of a Chief Evacuation Control Officer.

Evacuation procedures for the B.C. Hydro Head Office building are designed to be simple to follow while permitting flexible control by key evacuation personnel. Total evacuation, for example, is initiated by means of a siren signal and an announcement, both transmitted over the building's public address system. (The building is not equipped with a general fire gong system.) Evacuation of each floor occurs under the direction of a floor warden or his alternate; people line up in the corridor area at the designated exit and proceed down the exit stairway as the warden directs. (During the drill lower floors were to precede upper floors.) The west stairway is the designated exit for even-numbered floors and the east stairway the exit for odd-numbered floors, although a warden can order evacuation via the alternate exit stairway if this is more appropriate. People who cannot walk down the stairways are evacuated by elevators taken out of automatic service by maintenance staff. Once outside the building, all personnel assemble in designated areas away from access routes to the building.

The effective functioning of the hierarchical organization of evacuation control personnel is dependent on the building's communications systems (although each floor warden can independently evacuate his floor if necessary). These systems include a public address network throughout the building, an emergency telephone system in each exit at every floor level, and intercoms in the elevators. These systems are all controlled from a service centre that normally acts as a trouble centre for B.C. Hydro's power distribution network and is thus constantly manned by trained staff.

With emergency procedures planned in great detail, the B. C. Hydro Head Office staff was probably better prepared for an evacuation than might normally be the case in high-rise office buildings. When a drill was held on 26 June it was not unexpected and there were few questions about procedure.

OUTLINE OF THE DRILL AS CARRIED OUT

The following log of events during the drill was derived from a tape recording of all conversations on the emergency telephone system and from notes made by a team of seventeen observers stationed throughout the building (Appendix A). Times are given in minutes and seconds, starting at 9:30 a.m. (assumed accuracy is within ± 15 sec).

0:00	Manual fire alarm station activated on seventh floor
0:45	Call over public address for Evacuation Control officers to report
0:50	Seventh floor asked to investigate alarm
1:15	Seventh floor reported that total evacuation required
1:45	Siren sounded for about 30 sec over public address system
2:15	Total evacuation announced over public address system
2:30	First Evacuation Control Officer arrives at service centre
2:35	First people out of east exit stairway (premature evacuation)
3:30	First people out of west exit stairway
4:00*	Firemen entered building and walked up stairways
6:30	Firemen arrived at seventh floor
10:35	Last floor reported clear (eighth floor).
11:10	Firemen on seventh floor reported everything "OK"
14:00	Last people out of exit stairways
14:30	Building officially reported clear
22:45	Re-entry of building approved.

* The Vancouver Fire Department responded to the alarm from a distance of several blocks and checked to see how easily firemen could ascend the stairways against the descending stream of evacuees. (In a real fire emergency the Fire Department would be notified by the B. C. District Telegraph Office, which acts as the central supervising station for fire alarms originating at B. C. Hydro.)

ANALYSIS OF MOVEMENT DURING THE DRILL

The charts and tables in Figures 2 and 3 provide, in highly condensed and abstract form, a description of movement during the drill. In Figure 2, for example, the movement characteristics of occupants from odd-numbered floors (all using the east exit) are described on a time-scale starting with the initial activation of the fire alarm station on the seventh floor. In the upper chart the sloping lines trace the movement of groups of occupants as these floor groups form and then follow each other down the exit stairways in nearly regular sequence. The information in the table immediately below the upper chart identifies the floor groups, the number of working places on the floors, and the actual number of evacuees from the floors. Positions of data for each floor group line up vertically with the lower end of the corresponding movement "trace" in the upper chart. In addition, the flow of evacuees from the stairways is plotted in the lower graph, directly below the corresponding population data in the table.

This analysis of the evacuation movement will be discussed in terms of the three key movement variables: speed, flow, and stairway area per person (the reciprocal of density).

The slopes of the traces in the upper charts of Figures 1 and 2 represent speed of movement down the stairs. In some cases data were available for calculating these speeds, which are indicated as ranging between 120 and 160 ft per min (equivalent to descending 3 to 4 storeys per min). Although this range is near or slightly above normal for movement down stairways (4, 5), the longer travel path length per storey (40 ft versus 30 ft or less for stairways having a more conventional geometry with less landing area) means that descent from upper floors takes longer. In addition, the frequent change of direction and stepping pattern from treads to landings may tend to reduce the density of a descending group of evacuees, thus reducing the flow down the stairways.

The discharge rate, or flow of people from the exit stairways (plotted on the lower graphs in Figures 2 and 3), was lower than might be predicted for stairways 47-in. wide. For example, the east exit stairway had a mean discharge rate of 43 persons per minute, with a maximum sustained rate of about 70 persons per minute for about a 2-min period. The literature on evacuation by stairs suggests a maximum flow of about 90 persons per minute in this width of stairway, i. e., 45 persons per minute for each 22-in. unit of exit width (3, 8, 9).

The area of stairway available per person (the reciprocal of density) during the evacuation movement can be calculated once the speed and flow are known(see Appendix B). For example, at a flow of about 70 persons per minute the speed of descent in the east exit stairway could be assumed to be about 120 ft per min. This suggests that each person moving from the stairway at this point had about 6 sq ft of area available while still in the stairway. An over-all estimate of the average area available per person just before leaving the exit is 11 sq ft (assuming average speeds of 130 ft per min and discharge rates of 42 persons per minute). Observers reported that there were gaps in the flow from the exits so that this estimate of 11 sq ft average area per person should be reduced to perhaps 9 or 10 sq ft to represent a typical condition in the descending groups of occupants. These figures and the subjective evaluations of observers suggest that the stairways were not overcrowded. Observers and evacuation personnel also reported that movement was predominantly two-abreast or in a staggered file (as opposed to single file), as would be expected with 47-in. stairway width. This suggests that, on the average, a spacing of five stair treads existed between one person and the next immediately ahead in the stairway.

Under these conditions, few difficulties were experienced by those using the stairs. Only one minor mishap was observed when a woman from the ninth floor slipped and fell at about the seventh floor. She was assisted out of the exit at the sixth floor and was taken down to ground level by elevator. Apparently, there was little difficulty when several firemen walked up each stairway, against the downward flow of evacuees, to reach the seventh floor (the "fire floor").

According to observers and evacuation personnel, interruptions of uniform downward movement were largely the result of lower floor groups entering the stairs and thus stopping those from floors above (this prior evacuation of lower floors being part of the planned procedure for the drill). This is shown, in the top charts of Figures 2 and 3, as progressively longer periods of halted movement at the upper storeys. It should be noted that the eighth-floor group was seriously delayed in entering the stairway because upper floor groups were permitted to precede it. If there had been an actual fire on the seventh floor, the eighth should have been one of the first to be evacuated.

In comparing this evacuation exercise with other evacuation exercises it is important to keep in mind that the B. C. Hydro procedure called for group evacuation by floor, starting with the lower floors. In addition, the group from each floor only left that floor when all the occupants had gathered in the vicinity of the one exit designated for that floor. This procedure permits a great deal of control to be exercised by evacuation personnel (at the cost of increased evacuation time).

Other evacuation procedures employ such control in varying degrees. They include the traditional type of unorganized egress of individuals without specific directions (other than an alarm signal) and a phased, partial evacuation where complete floors in the vicinity of a fire are evacuated before upper floors (starting at the top of the building and carrying on down to the fire area). Furthermore, evacuation may not be from the building to the outside but from a fire compartment and other threatened compartments to relatively safe areas in the same building.

EVACUATION TIME

Evacuation time, for total evacuation by stairways, is an aggregate of the times taken for occupants to perceive the signal to evacuate, decide on appropriate behavior, move to the exit stairway, and walk down the stairways to the exterior at ground level. The time taken for all the people to move down the stairs can be considered as a function of the speed of movement of the first person from the lowest occupied floor to the exit discharge and also the discharge rate (itself a function of speed and density) for the stream of evacuees who follow.

If a prediction were to be made for the fastest possible evacuation of 910 persons by two stairways from floors 1 to 21 of the B.C. Hydro building, the evacuation time would include about $\frac{1}{2}$ min for the first persons to reach the stairways, $\frac{1}{2}$ min for travel by them from the first floor to the ground level (at a speed of about 100 ft per min) and about 5 min for the remaining occupants to flow out behind these first persons in a steady stream (at an average flow of 90 people per minute). This totals about 6 min. Keeping in mind that the prediction is for uncontrolled evacuation, this time may be compared with the 12-min period that ensued after occupants in the B.C. Hydro building heard the evacuation announcement over the public address system and evacuated in a controlled manner.

It should be noted that the two most important factors influencing evacuation time in the exercise were the organization for evacuation before the stairways were entered and the actual rate of discharge from the exits. This rate only averaged about 42 persons per minute (with a sustained peak of about 70 persons per minute) instead of about 90 persons per minute as the prediction assumed. The longer actual time apparently resulted because a large measure of control was exercised in the evacuation procedure and the evacuees desired comfort rather than maximum speed and density in the stairways.

If another, similar, evacuation were attempted, with a comparable degree of procedural control and occupant comfort, it would be possible to reduce evacuation time to about 10 min. This would require a more efficient use of the time spent organizing occupants on each floor and the avoidance of gaps in the flow of evacuees, especially between floor groups.

Another improvement in procedure might be to modify or delete the reporting by wardens to the service centre, by emergency telephone, of clearance of each floor. These reports were delayed by as much as 6 min (with a mean delay of 2 min 40 sec) when the telephone system became jammed. Although these delayed reports may have tended to give evacuation control officers at the service centre a poor picture of the course of the evacuation, they were apparently not a factor in extending the evacuation time since the longest reporting delays were experienced by the wardens from the lower floors, which were the first to be cleared.

ENVIRONMENTAL CONDITIONS IN THE STAIRWELLS

It has already been noted that evacuees had adequate room to walk comfortably down the exit stairways. In addition, several other environmental conditions were noted to assist in establishing the context for evacuation movement:

The two exit stairways were well lighted. No measurements were made during the drill, but maintenance staff reported illumination at about 20 footcandles (20 lumens per ft). This was provided by an unusual system of unshielded continuous-tube fluorescent luminaires at the soffit. Wall surfaces were plaster and stair treads were terrazzo, producing various degrees of spread and regular reflection. Emergency lighting was installed but not used during the drill.

In terms of these visual features, the exits should function better than many found in office buildings (which often have inadequate or poorly distributed exit illumination). Except for a possible claustrophobic response to the spiraling enclosure geometry of the stairway, occupants appear to find the stairs "attractive" and suitable for frequent use.

Sound levels were measured in the west stairwell with an octave band noise analyser installed on the fourth floor landing. The noise analysis is given in Figure 4. Sound levels in the stairwell before and during the evacuation fall under N. C. 45 and N. C. 70, respectively, with most of the noise produced by speech and the impact of footsteps on the terrazzo floor.

Initially, there was some question of whether noise and excessive reverberation would make the exit seem more crowded or interfere with the use of the emergency telephone in the exits. In the tape recording of emergency telephone conversations there seemed to be little difficulty with speech interference. The results of a questionnaire given to evacuation staff after the drill indicate that only a small number of people found the noise annoying including a dozen who indicated that it made the use of the emergency telephone more difficult. (This may represent a majority of those who had to use the telephone.) Conversations inside the stairwell were clearly heard over several feet, permitting people walking side by side to talk easily. In general, it appears that reverberation, which was severe when the stairwell was unoccupied, was minor when people were present owing to increased absorption.

There was some question, initially, about stuffiness and over-heating in the stairwells. Although the questionnaire did not cover this point specifically, there were several comments that the lower levels of the stairwells were too warm and stuffy, even in the east stairwell where doors on the ground, first and twenty-first levels were left open. In the west stairwell only the ground- and tenth-floor doors were propped open. No measurements were taken of thermal conditions.

COMMENTS FROM EVACUATION PERSONNEL AND OBSERVERS

With a few exceptions, the siren and the initial announcement, both transmitted over the public address system, were clearly heard everywhere in the floor areas. With no speakers in the exit stairways, however, there was some confusion when some of the wardens stationed at the emergency telephones did not hear subsequent announcements. (Provision of speakers in the exits could alleviate this difficulty and provide a convenient means of communicating with evacuees in the exits should some change in the evacuation procedure become necessary.)

In terms of their initial interpretation of the public address announcements, all the evacuation personnel, and presumably most of the other occupants, were sure it was an exercise rather than a real emergency.

When asked to comment on the effects of fatigue in descending the stairway only a few of those questioned thought this worth mentioning. (A short questionnaire was given to 63 evacuation personnel and 17 observers to help in assessing the exercise.) There were two reports of slight dizziness during descent from upper floors and it is probable that many people's legs were a bit unsteady after the unaccustomed long descent. An observer moving with the group from the sixteenth floor reported the speed as "exceedingly fast." In Figure 3 this particular speed is estimated to be 160 ft per min.

Employee reaction to the exercise appeared to be favourable, and, in some cases, enthusiastic. There were some reports of staff members who arranged to be absent at the time of the expected drill, but the number of people actually participating probably represented a typical building population. The prevailing favourable attitude of the B. C. Hydro staff to the exercise was due in large part to the approach taken by B. C. Hydro management in explaining, endorsing, participating in, and expressing appreciation for the successful exercise. In addition, the exercise was well reported by news media in Vancouver so that B. C. Hydro personnel knew they had participated in an important exercise having implications beyond their own safety.

SUMMARY

It is not the purpose of this Note to present detailed conclusions or to suggest a comprehensive list of improvements to the organization, procedures, and communications systems tested in the B. C. Hydro exercise. The exercise is significant in that it was attempted, completed, and reported. The results answer some questions and pose others; for example, office workers are, on the whole, capable of descending 22 flights of stairs in a very short time, but it is questionable whether they are willing to sacrifice their "body buffer zone" (space between themselves and other people or environmental features) in order to use the stairways more efficiently.

The answering of questions such as these and proposing of optimum solutions to the evacuation problem, as one aspect of a total approach to life safety, depends on a series of studies ranging from descriptive reporting through highly disciplined hypothesis formation and testing activities. This report forms a small part of tne necessary first step.

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ACKNOWLEDGEMENTS

The assistance given by the British Columbia Hydro and Power Authority in the task of planning and conducting observations is gratefully acknowledged. The assistance given by Mr. C. Sutton, B. C. Hydro's Chief Fire Prevention Officer, is especially appreciated. In addition, the author wishes to thank members of the observation team for their assistance in collecting information and preparing this Note.

APPENDIX A

MEMBERS OF OBSERVATION COMMITTEE

L. Auvache, Chief, Burnaby Fire Dept.

W.H. Ball, DBR/NRC

G. Birnie, Chief, Vancouver Fire Warden

R. Chandler, Chief, West Vancouver Fire Dept.

J. Flanagan, B.C. Hydro

H. Jenns, Deputy Provincial Fire Marshal

B. McLure, B.C. Telephone Co.

J. L. Pauls, DBR/NRC

C. W. Sutton, Chief Fire Prevention Officer, B.C. Hydro

D. Watts, MacMillan Bloedel Ltd.

LIST OF OBSERVERS AND LOCATIONS DURING DRILL

P. Anhorn, DBR/NRC, (West exit, ground floor)

G. Birnie, Chief, Vancouver Fire Warden, (6th floor, with radio)

T.N. Blackall, DBR/NRC, (Basement exit)

A.W. Bridge, Burnaby Fire Dept., (West exit, 14th floor to ground)

H. Chapman, Burnaby Fire Dept., (West exit, 20th floor to ground)

R.W. Davies, MacMillan Bloedel, (East exit, 7th floor to ground)

H. Hogan, Burnaby Fire Department, (West exit, 8th floor to ground)

H. Jenns, Deputy Provincial Fire Marshal, (6th floor, with radio)

G.A. Laurie, MacMillan Bloedel, (East exit, 15th floor to ground)

D. McCluskie, Vancouver Fire Dept., (East exit, ground floor)

H.J. McColm, Vancouver Fire Dept., (Service centre)

R. Montador, City of Vancouver, (West exit, 16th floor to ground)

J. L. Pauls, DBR/NRC, (West exit, 4th floor, noise measurement)

M. Rangeley, Vancouver Fire Dept., (West exit, ground floor)

J. Robinson, City of Vancouver, (East exit, 5th floor to ground)

P. A. Schaerer, DBR/NRC, (East exit, ground floor)

D. Watts, MacMillan Bloedel, (East exit, 21st floor to ground).

APPENDIX B

RELATION BETWEEN SPEED, FLOW, AND DENSITY OF MOVEMENT DOWN STAIRWAYS

Flow is directly proportional to both speed and density for movement down stairways

$$F \propto S \cdot D$$

The constant of proportionality for this relation is determined by the geometry of the stairway

$$F = \frac{a}{l} \cdot S \cdot D$$

where

- F is the flow in persons/min
- S is the speed in ft/min
- D is the density of persons on the stairway in persons/sq ft
- a is the horizontal area of stairs and landings in sq ft/storey
- l is the travel path length in ft/storey.

The area of stairway available per person (represented by A in the equation below) is simply the reciprocal of the density (D). The concept of area per person is somewhat easier to visualize and for this reason is used in discussing stairway movement characteristics.

$$F = \frac{a}{l} \cdot \frac{S}{A}$$

or

$$A = \frac{a}{l} \cdot \frac{S}{F}$$

where A is expressed in sq ft/person.

It should be noted that as a refinement to this equation the area a is considered to be the effective horizontal area that would be used by a descending stream of people and l the centreline distance of this stream taken along the slope of the stairs. As a result, the area a used in this Note is less than the area of the stairshaft (i. e. 140 sq ft rather than 155 sq ft). This refinement simply recognizes that a moving stream of people does not fill angular corners of the stairshaft. (The effective area for movement is shown as a shaded ring, 47 in. wide, in the exit stairway detail in Figure 1.)

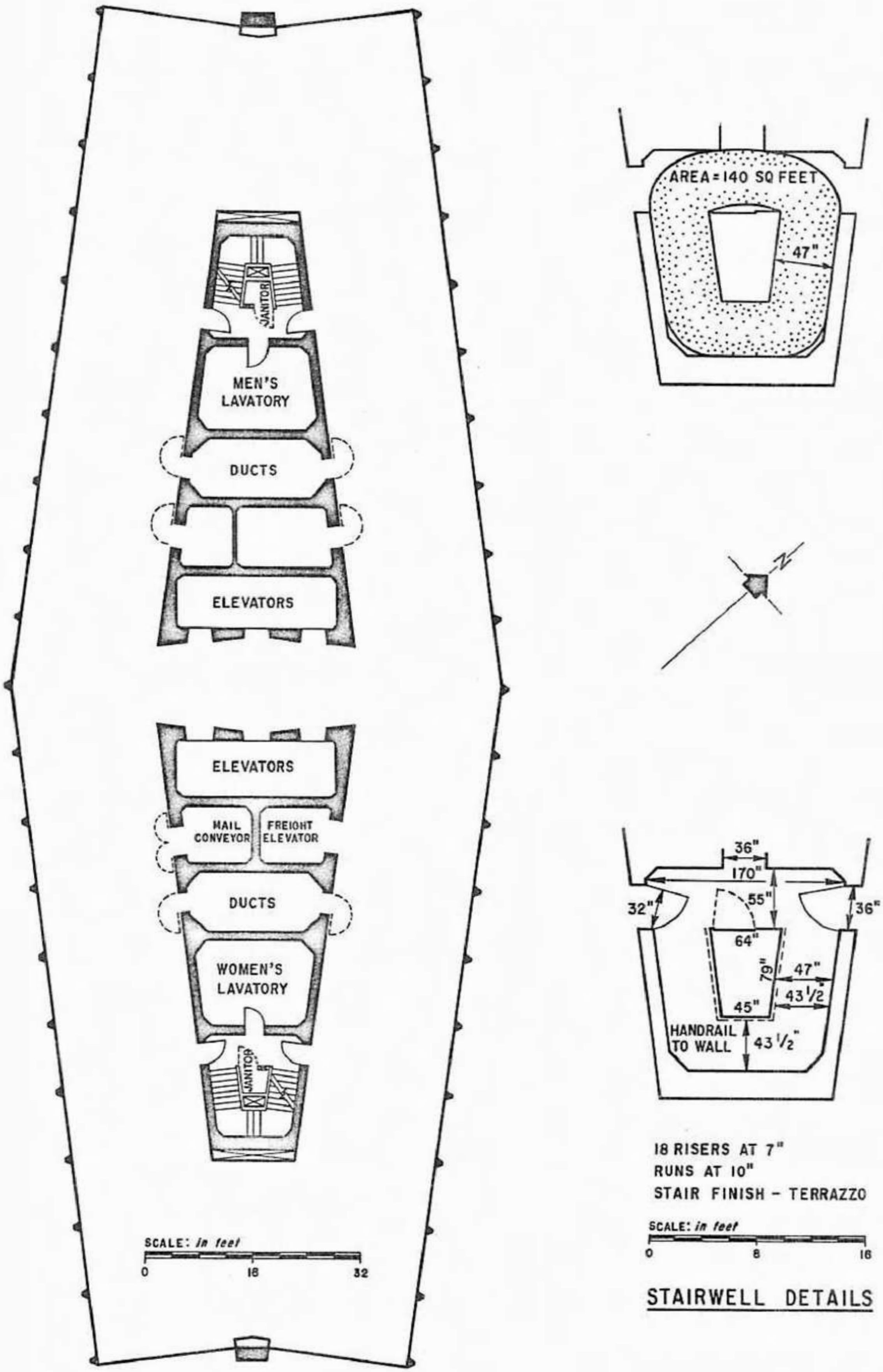
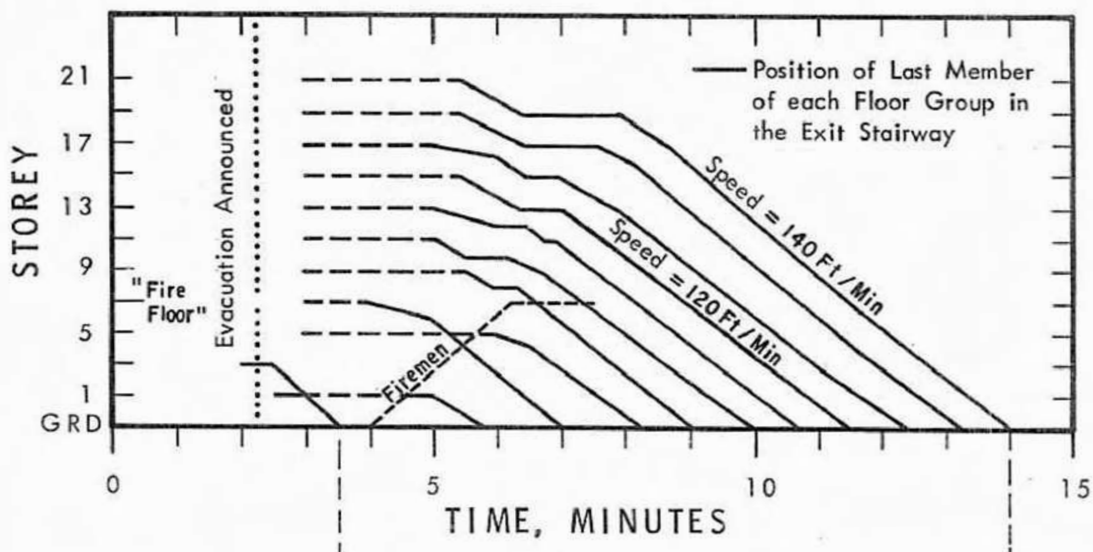


FIGURE I

PLAN OF TYPICAL FLOOR IN THE B.C. HYDRO HEAD OFFICE BUILDING



Discharging Floor Group	3	1	7	5	8	11	13	15	17	19	21
Available Work Places on Floor	40	145	98	66	79	67	50	64	54	45	18
Actual Number of Evacuees in Group	19	61	72	58	62	49	55	35	31	27	15
Total Number of Evacuees Using Exit	19	80	152	210	272	321	376	411	442	469	484

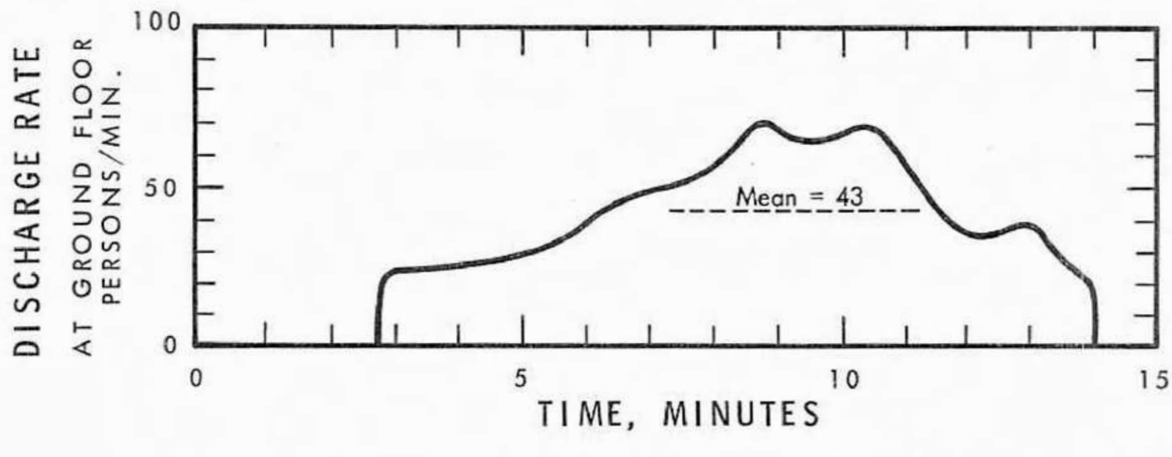
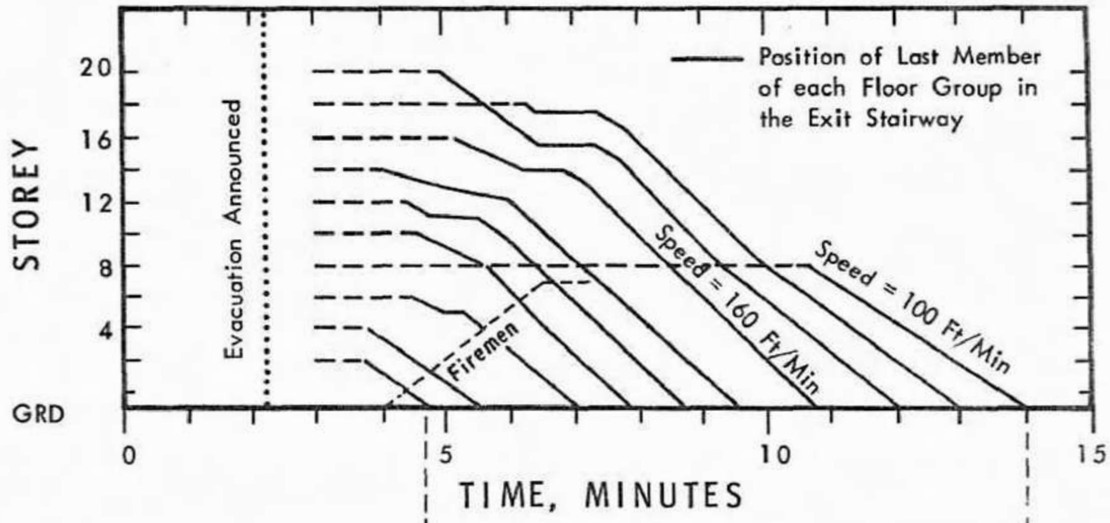


FIGURE 2

GRAPHS AND TABLE DESCRIBING THE EVACUATION OF PERSONS ON ODD-NUMBERED FLOORS USING THE EAST STAIRWELL



Discharging Floor Group	2	4	6	10	12	14	16	20	18	8
Available Work Places on Floor	99	51	64	63	70	72	49	44	48	81
Actual Number of Evacuees in Group	54	?	?	37	?	?	?	?	25 ?	99 ?
Total Number of Evacuees Using Exit	54		105 ?	142		251 ?		301 ?	326 ?	425

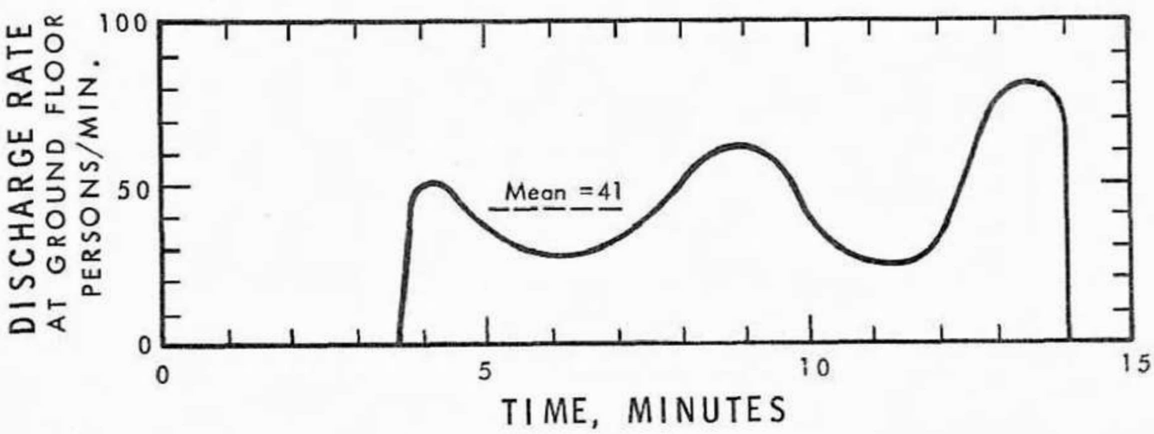
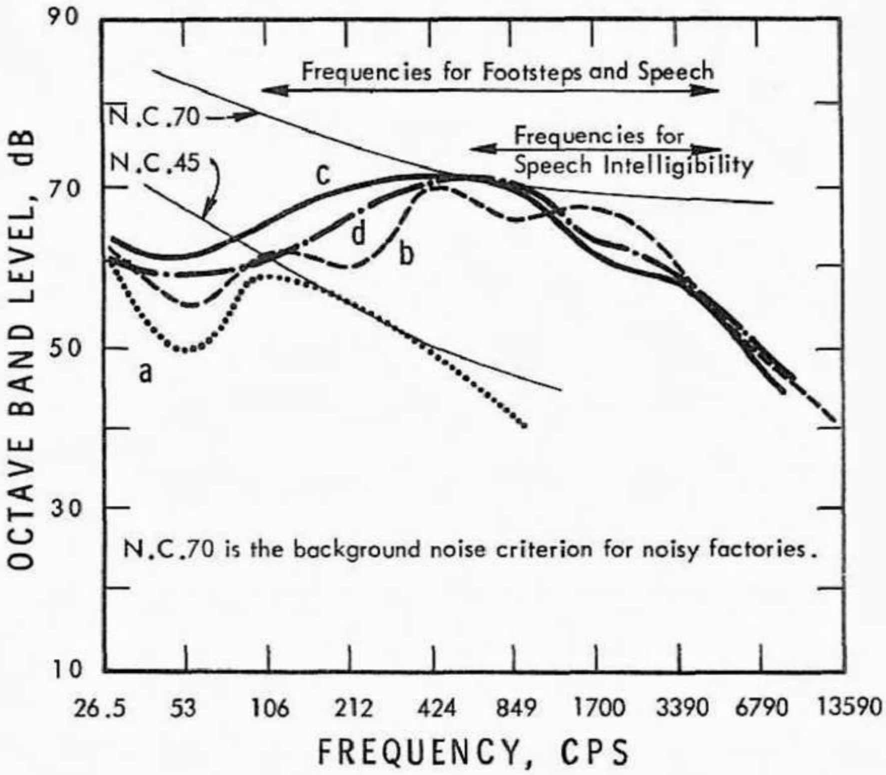


FIGURE 3

GRAPHS AND TABLE DESCRIBING THE EVACUATION OF PERSONS ON EVEN-NUMBERED FLOORS USING THE WEST STAIRWELL.



TEST	TIME, MINUTES	NOISE ANALYSER RESPONSE SETTING
a	− 5 (Before Drill)	Slow
b	+ 4 (During Drill)	Slow
c	+ 6 (During Drill)	Fast
d	+10 (During Drill)	Slow

FIGURE 4

STAIRWELL NOISE ANALYSIS

NOISE MEASURED IN THE WEST STAIRWELL, FOURTH FLOOR, WITH A GENERAL RADIO CO. TYPE 1558-A OCTAVE BAND NOISE ANALYSER WITH 1560 PET MICROPHONE ASSEMBLY 3FT ABOVE FLOOR LEVEL

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