Management and movement of building occupants in emergencies

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MANAGEMENT AND MOVEMENT OF BUILDING OCCUPANTS IN EMERGENCIES

by J.L. Pauls

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Sommaire

Il faut parfois faire évacuer les occupants d'un bâtiment en cas d'urgence dans le bâtiment même ou sur une plus grande échelle; toutefois, ce n'est que dernièrement que l'on a compris l'importance de prévoir des installations fonctionnelles et des méthodes de gestion adéquates facilitant de telles évacuations. On a effectué des recherches sur la circulation des gens dans les bâtiments et sur leur comportement dans les cas d'urgence, de façon à pouvoir prédire les réactions à ces situations et à assister les concepteurs, les gestionnaires et les préposés à la sécurité. De plus, l'article présente les découvertes importantes dans le domaine et les modèles de prédiction mis au point à la suite d'études effectuées au Canada sur l'évacuation des occupants dans les immeubles de grande hauteur et des grands bâtiments publics. On y indique aussi les domaines devant faire l'objet de recherches ainsi que les changements nécessaires dans le cas des mesures de prévention, y compris la conception des bâtiments.

PREFACE

The following is a reprint of a paper that first appeared in proceedings of the Second Conference on Designing to Survive Severe Hazards that was held in Chicago in November 1977 at the IIT Research Institute. Minor editorial revisions, including simplification of Figure 1, have been made in the reprint.

Excerpts from the section on evacuation of high-rise office buildings were published separately in May 1978 in *Canadian Architect* and in *Buildings*.

For detailed information on evacuation and related topics mentioned in the paper readers are referred to a forthcoming book on behaviour and fires, edited by David Canter and to be published by John Wiley and Sons.

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July 1978

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MANAGEMENT AND MOVEMENT OF BUILDING OCCUPANTS IN EMERGENCIES

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ABSTRACT

Evacuation of endangered occupants of buildings may be necessary in a variety of intra-building and larger-scale emergencies. The effectiveness of building facilities and management procedures needed for evacuation has not been well understood until recently. To predict emergency performance more accurately and to assist building designers, managers, and safety authorities, research has begun on the movement of people in buildings and their behavior in emergencies. In addition, examples are given of key findings and predictive models developed in Canadian studies of evacuation of tall buildings and large public assembly buildings. This paper suggests necessary areas of research and the need for change in a range of disaster mitigation measures, including building design.

INTRODUCTION

A pre-Mao Chinese proverb recommends that "Of the thirty-six ways to escape danger, running away is best" (1,2). A better reaction to danger might be to remove the hazard. This is the position of many participating in conferences such as this one, and much technological effort is devoted to mitigating hazards. The reaction recommended by the Chinese proverb, stressing escape, may be more conventional, but the conditions provoking the wish to escape may be real or they may be imagined threats. The place to which one tries to escape may actually be more hazardous and the act of escaping create other hazards.

Consider, for example, the experiences of someone in a well-engineered building during an earthquake. There may be a distinct feeling of discomfort, possibly even loss of balance (3). There may be perceived and perhaps real danger of injury from falling furnishings and building fixtures. There may be views of terrible destruction outside as other structures collapse. There may well be a strong feeling that the building may collapse, start burning, or that means of escape may be cut off. The individual may attempt immediate escape, unaware of attendant risks of elevator malfunction or of falls while rushing down stairs. If escape is successful the environment outside the building may be far more hazardous than that left behind. Finally, the escape route will almost certainly be shared by others who may not necessarily be travelling at the same speed or even in the same direction (people may be re-entering the building for a variety of reasons).

This introduction suggests the complex nature of the subject. Evacuation is both a design and a management problem. Controlling movement of people, facilitating safe, perhaps large-scale movement, and making building occupants aware of emergency conditions and procedures are problems for all, including engineers, architects, building owners and managers, public-safety authorities, and researchers, plus those in the behavioral and social disciplines.

How well have these tasks been carried out? What basic knowledge and technology is available regarding evacuation in particular or building safety measures in general? To what extent can the performance of exits even be predicted? What evacuation or refuge procedures are appropriate and are they within the competence of typical occupants of buildings or those with management responsibilities?

Although evacuation has been a major concern of building codes for over half a century, the scientific and technological basis for exits is poorly developed and often contains errors that have gone unrecognized. Recent research, much of it still not widely reported, has pointed out, for example, errors in current code rules governing the width of exit stairs and riser-tread geometry (4-7). The latter is often based on a simple design rule developed over three hundred years ago when body dimensions, stride length, and even the unit measurement were different from those used today - important differences that are not sufficiently recognized. (Exit stair treads, for example, designed according to such rules, are about 2 inches too shallow, a deficiency with greater consequences for descent than for ascent.) Some general reviews as well as detailed reports are available (1-22).

Directed toward eventual application to a range of design and management problems, this recent research is developing a very different and more realistic model of man than has been available to date for preparing and implementing safety measures in buildings.

This paper attempts to provide basic information about various forms of evacuation in buildings and to model some using empirically-derived relations. There will naturally be unanswered questions, including those about management roles, training, drills, cost-benefit, risk-acceptance. It reflects the author's main research interests in high-rise office buildings and large-scale public assembly buildings - considering fire, crowd-generated mishaps, and individual accidents as well as several aspects of normal occupancy. Several other hazards leading to evacuation and management problems are acknowledged, including earthquake, severe weather disturbances, bombings and bomb threats, and power failures.

One additional bias should be mentioned. This is the author's preference for simple, "people-based" solutions for many of the problems of evacuation and management. This occupant-reliant approach means that normal occupancy and emergency measures will be less affected by interruption of building systems such as power failure and breaches of security, and that those using buildings will be better able to cope in emergencies.

MOVEMENT OF PEOPLE IN BUILDINGS

Early studies bearing directly on movement aspects of evacuation were conducted first some sixty years ago, and frequently-mentioned, influential (to codes) reports from the United States and Britain are dated 1935 and 1952, respectively (23,24). Early work in other countries has been reported as well (25-31). In the English-speaking world, largely during the last decade, there have been a variety of studies (4,5,7,17-21,32-43). Many have dealt with capacity considerations for exit stairs, doors, and passageways; some have dealt with riser-tread details; a few have been particularly concerned with the difficulties disabled people experience in much of the built environment. Researchers aware of these studies note inadequacies in both quantity and quality. For designers of buildings, information sources are extremely limited, and to make matters worse the best book on design of pedestrian facilities appears to be unknown by most architects (20).

Canadian Studies

The author's research began in the late 1960's at the Division of Building Research of Canada's National Research Council. This was a time of growing concern about the problem of fire in high-rise buildings. Evacuation, particularly the time required to clear a tall office building, was one of several major concerns. Others included internal communications, smoke movement, fire department access, fire suppression, and internal communication (44-52).

Largely through the cooperation of Canada's Dominion Fire Commissioner small teams from the Division of Building Research carried out observations of forty evacuation drills in office buildings ranging from 8 to 29 storeys in height. Various evacuation procedures were used, some interpreted by the evacuees as actual emergencies (from both fire and bombings). Quantity and quality of a wide variety of data surpassed any reported to that time, but to date only preliminary analyses of these data have been reported (4,5,53,54). Those that are available have dealt largely with density, speed, flow, time, and population characteristics of high-rise evacuations via stairs.

Flow on exit stairs. Major misconceptions have been discovered regarding the commonly used "unit exit width" basis for determining stair width. More realistic flow capacities for exit stairs have been proposed. Figure 1 shows the linear proportional relation between mean flow in total evacuations and effective stair width (the measured stair width minus 12 in., or 300 mm). This is compared with the unit exit width concept (the step function plotted in Figure 1), which is assumed in drawing up building codes following National Fire Protection Association standards (52,55).

The unit exit width concept is based on an over-simplified model of how crowds move along passageways, ramps, and stairs. On the assumption that people will walk two abreast down a 44-in. (1120 mm) exit stair, code writers have long adopted this width as a standard minimum. Although the rationale has recently been found faulty, this width is retained in the simulations described below because it is a common stair width in existing buildings and is thus familiar.

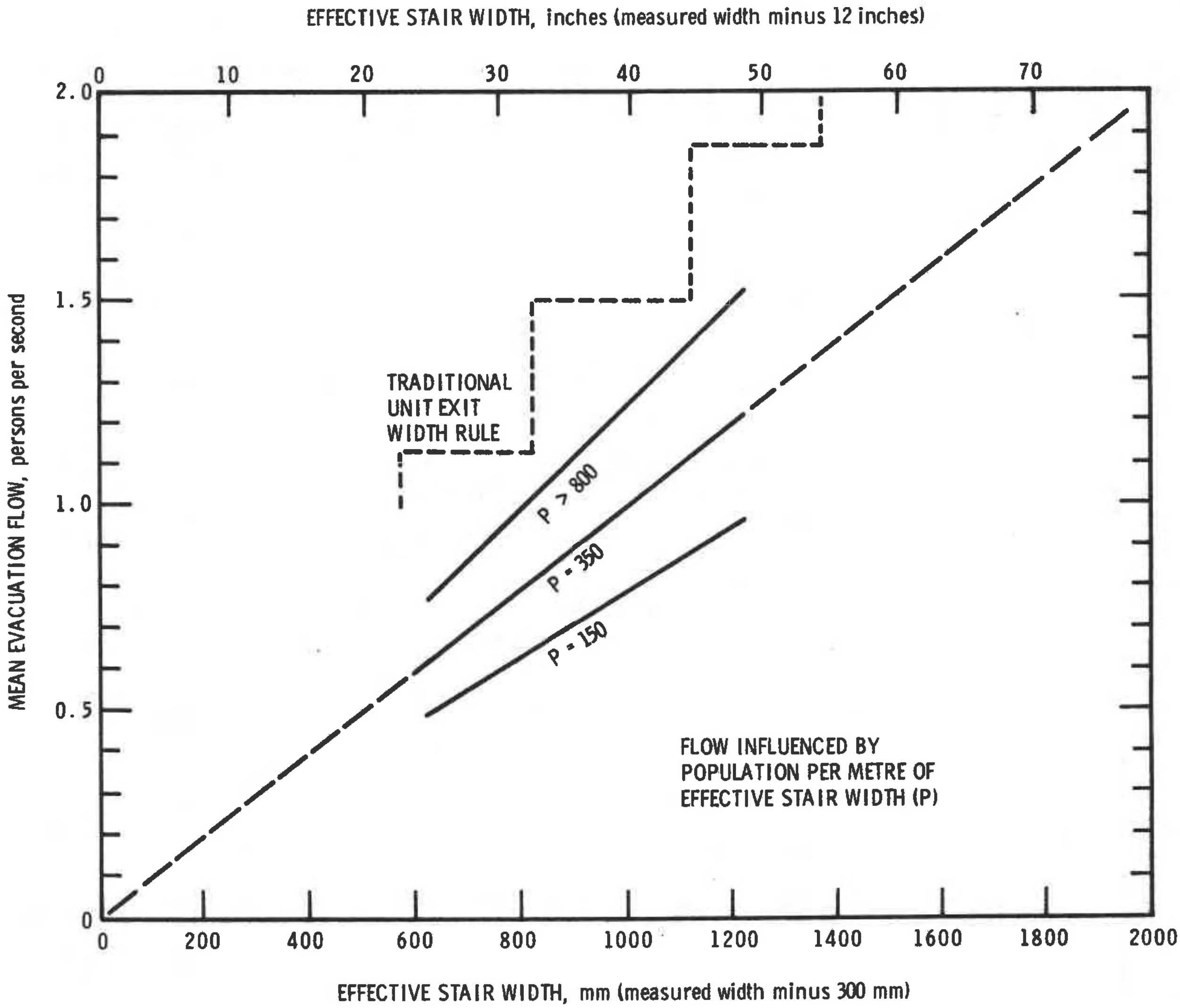

Figure 1

Effective stair width and mean flow in total evacuations of office buildings

Study findings relating stair width and crowd use illustrate their potential application to building codes and design manuals. Other examples of application are described in greater detail below (evacuation of tall office buildings), following a brief account of other studies of movement evolving from the drill observations.

Public assembly egress. Since 1972, in response to requests from designers and code officials for design information on crowd flow in multi-deck grandstands, the Division of Building Research has extended its interest in evacuation to include the normal access and egress of crowds in theaters, arenas, grandstands, and transit facilities. Extensive studies were carried out during 1974 and 1975 in newly constructed grandstands in Calgary and Ottawa.

Most notable among ensuing requests for information was one early in 1976 by the organizers of the Olympic Games in Montreal for assistance in preparing for the large-scale crowd conditions in the newly-constructed Olympic Park. In addition to providing assistance to those responsible for spectator facilities and crowd control, a ten-person research team (including two from the U.S.) documented varied aspects of spectator behavior and facility performance in Olympic Park and in the public transit facilities serving the Park. An unprecedented research record on video tape and film is one of the tangible results of several thousand man-hours of work connected with the Montreal study.

Grandstand and arena evacuation time. As was the case with the earlier study of office building evacuation, the study of crowd movement in assembly occupancies provided data and models for predicting building and management performance affecting crowd movement. Figure 2 shows the range of total evacuation times (either measured directly or calculated from observed flow data) for assembly-type buildings studied in Canada. One striking feature of this graph is the wide range of exit loadings and resulting clearing times for capacity crowds. A range of actual exit loadings and resulting clearing times for each building illustrates the observed effects of various imbalances in exit use that can occur, sometimes because of faulty distribution of means of egress and sometimes because of crowd-control procedures.

The set of arrows along the horizontal scale (for population per unit exit width - a standard code approach) marks Canadian code requirements for total exit width: 60 persons/unit for enclosed arenas, 100 persons/unit for elevated open grandstands, and 500 persons/unit for open grandstands giving immediate access to the ground. (Upcoming code revisions may state the rule for grandstands as 300 or 225 persons/unit; but this is a compromise rule that does not necessarily reflect recent research (56).) Although not strictly applicable to the total clearing times plotted, two arrows on the vertical time scale mark recent British requirements for clearing time for any one area of a grandstand, nominally 2½ minutes for low-quality grandstands susceptible to rapid fire spread and nominally 8 minutes for high-quality grandstands (57). Disparities between requirements and actual performance raise questions that may not be settled for some time.

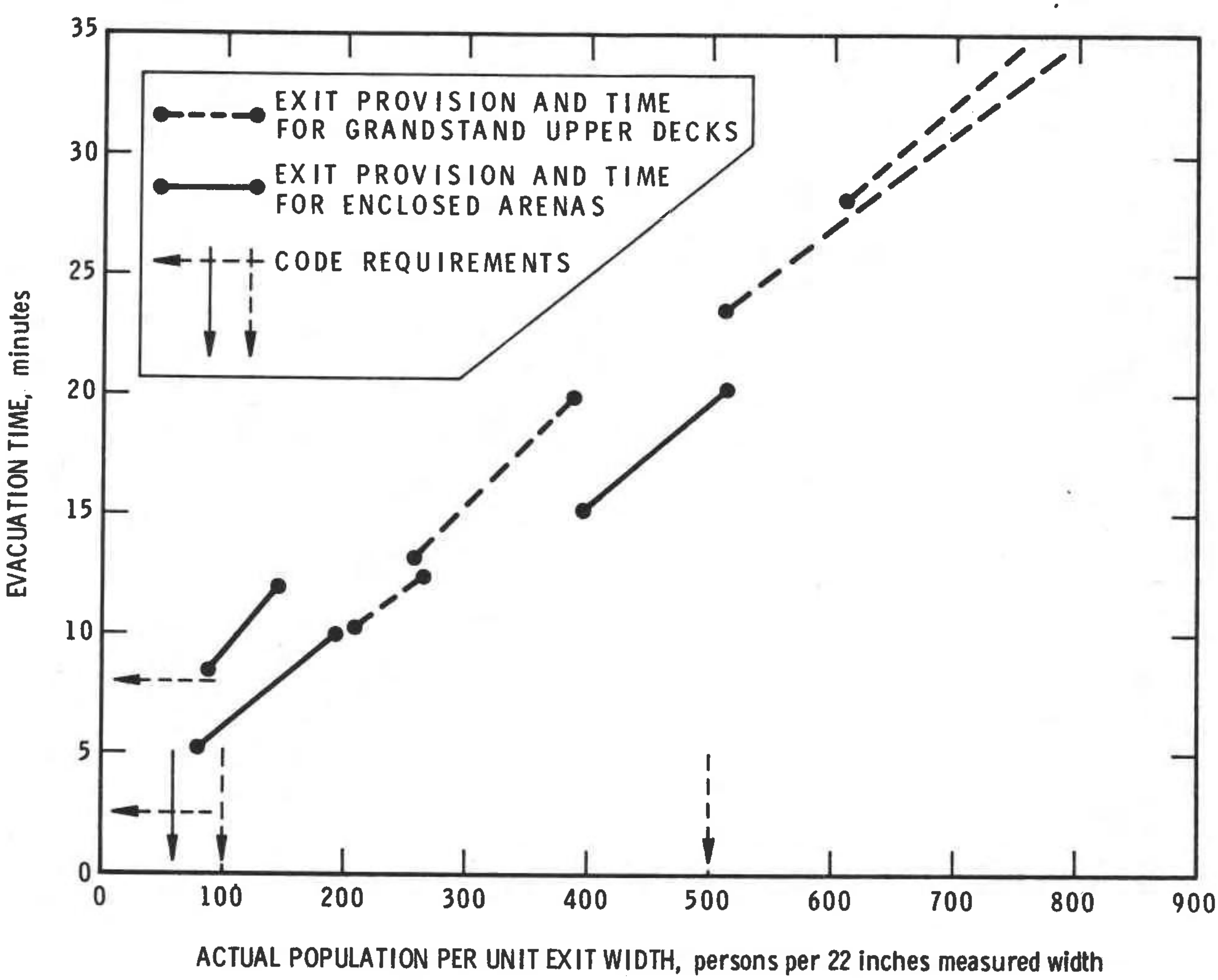

Figure 2

Evacuation time in relation to population using exits in some Canadian grandstands and arenas

Within the context of the present conference, relevant questions include what kind of hazards necessitate rapid clearing and what are the limiting times for various sizes and forms of buildings? For example, a sudden change in weather, bringing high winds, rain or hail, could prompt a rapid clearing of an open-air grandstand (an example of this, with resulting crowd crush fatal to some spectators was reported recently in Kingston, Jamaica). In other words, the type of grandstand assumed to be less susceptible to the hazards of fire, roof collapse, etc. (i.e., traditional code concerns) may prove to be one needing more exit facilities and not fewer, as is usually allowed in building codes.

Aside from hazards of earth, air, fire, and water, there are also crowd-generated hazards. After a total of 125 deaths and over 1000 injuries in eight crowd-related incidents during this century in Britain, regulations and standards have been introduced that set out stringent requirements applying to new and existing sports grounds (57,58). Such measures applied to physical as well as management features should help to rectify situations that verge on the deplorable in some sports grounds.

These comments are made to broaden the discussion of movement of people in buildings, a subject that technology has largely neglected. Ability to predict performance and to evaluate cost/benefit/risk is inadequate despite recent progress in research. Much of the information needed to assess exit performance is unpublished, still residing in files. To transmit some of that information to others the following section includes examples of evacuation systems in high-rise office buildings.

EVACUATION OF HIGH-RISE OFFICE BUILDINGS

Thanks mainly to technology (and to some extent, good fortune) the risk of death from a major fire in North American high-rise buildings remains low (46). Nevertheless, the potential for disaster exists. Hazards or perceived hazards other than fire may lead to evacuation of part or all of a high-rise building. For example, recently in New York some 100,000 people were cleared from office buildings as large as those in the World Trade Center owing to bombings or bomb threats. These evacuations were conducted by means of elevators, probably in a manner not too different from normal end-of-day egress (59).

Elevators may not be usable when disaster threatens, depending on a variety of factors including their design, the nature of the hazard, and operating decisions. The following modes of evacuation are based largely on exit stair use, but include the possibility of elevator use in large buildings.

Total Evacuation via Stairs: Example

Figures 3, 4, and 5 show in graphical form three procedures that might be used in evacuating some or all occupants from a high-rise office building or of moving endangered people to areas of refuge. In these charts the vertical scale is the vertical spatial dimension of a building, with each floor indicated. The horizontal scale is time, measured from the initiation of the alarm. Each line is a movement trace indicating where (in height) a

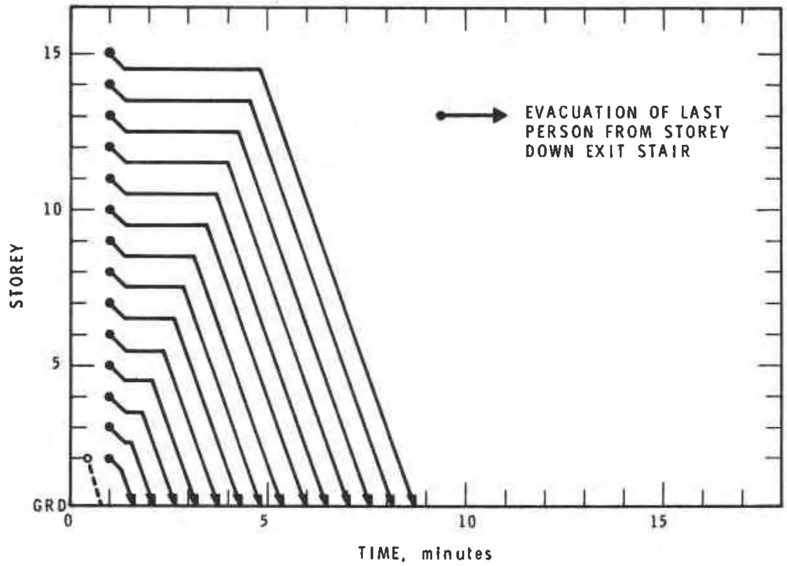

Figure 3

Total evacuation via exit stairs in 15-storey building

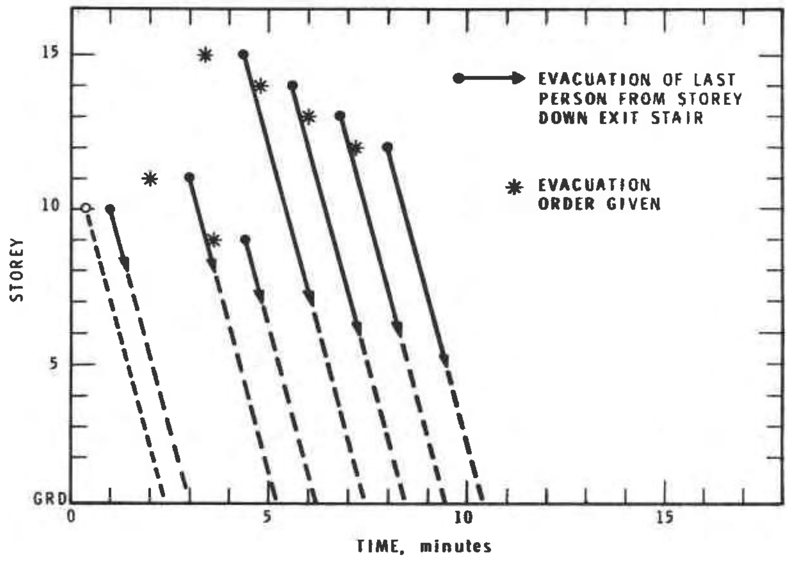

Figure 4

Selective evacuation via stairs in 15-storey building particular evacuee is at any particular time. In presenting data from observed evacuations, such traces usually record, as well, the observers' movements down the stairs with the evacuees. In the present charts the traces represent the movement of the last individuals leaving each floor.

The slopes of the lines indicate speeds of movement (3.6 floors per minute in Figure 3). The vertical separations between the lines indicate the relative amounts of space available to the occupants of one floor as they queue or move through the exits (in Figure 3, 2.5 sq ft (0.23 m^2) per evacuee queuing on the stairs and nearly twice as much walking down the stairs). The horizontal separations of lines indicate flow (in Figure 3, 60 persons per minute down each standard 44-in. (1120 mm) exit stair). Assumed speeds, densities, and flows are based on the observed performance of nearly 15,000 persons in nearly thirty total evacuation drills (4,5). The chosen values reflect an optimistic judgement that would be justified with experienced occupants and high standards of exit facilities. Thus the predicted evacuation times should be considered lower limits. Upper limits could be 2 minutes longer (even more for evacuations held in cold weather when there may be delays in entering stairs and lower flows of descent because evacuees may retrieve and wear or carry bulkier outdoor clothing.

Figure 3 displays movement traces characteristic of total evacuation, the conventional procedure where all occupants attempt to leave the building at the same time. Illustrated is the total evacuation of a 15-storey office building with two 44-in. (1120 mm) wide exit stairs. Each floor is assumed to contain 70 able-bodied persons when evacuation begins. This is a realistic expectation of the average number of occupants actually present for each 15,000 sq ft (1400 m^2) of gross rentable area per storey (4,5,60) - assuming about 200 sq ft (19 m^2) per actual occupant, in contrast with the 100 sq ft figure usually suggested in building codes. Applying somewhat optimistic evacuation-initiation and flow assumptions it can be predicted that such a building will be cleared of 980 occupants by means of stairs in just under 9 minutes.

A brief comment on the term "able-bodied persons" may be appropriate. If the office workers observed in Canadian office buildings are representative, as they appear to be, it is estimated that about 3 per cent of those usually present in high-rise office buildings cannot or should not attempt to evacuate by means of crowded exit stairs. In addition to those with obvious physical disabilities, this minority includes people with heart disorders and convalescents from recent illness, surgery or accident. Movement of these individuals to a place of safety will require additional planning and assistance from other occupants. It could include their descending stairs behind able-bodied persons (who would already be moving at a fairly slow speed characteristic of high-density crowds); being carried; or having elevators operated by authorized personnel to take them to safety.

A building such as that depicted in Figure 3 could be expected to have approximately 25 persons who might descend the stairs behind the main crowd of evacuees and approximately five best evacuated by elevator, assuming one is available. Evacuation of the disabled is thus, in part, a problem of management, of first determining the abilities of persons in the building, planning for assistance and evacuation facilities, and finally making sure the appropriate procedures are carried out.

Although it has the virtue of simplicity, total evacuation has drawbacks. When everyone is evacuated indiscriminately, it entails considerable movement, totalling over 7,000 person-storeys in Figure 3. (A person-storey is a unit of measurement derived from multiplying the number of persons by the distance each moves on the stairs.) Evacuation times increase in a nearly-proportional relation with the number of people evacuated (Figure 6) and can quickly become too long. People on floors where danger may be greatest do not necessarily receive priority in using exit stairs. Priority in uncontrolled total evacuations was observed (in the drills studied) to go generally to those entering the exits rather than to those queuing in them.

Selective Evacuation via Stairs: Example

In selective or phased evacuations (Figure 4), exit stairs are generally reserved during initial stages of evacuation for people on the fire floor and adjacent floors (assuming for the moment that fire is the hazard). Ten phased-evacuation drills observed in Ottawa included sequential evacuation of occupants on some or all other floors, starting from the top. Upper floors can become untenable before most of the lower floors because of smoke movement due to chimney effect during cold weather (48-52). In buildings having zoned air-handling systems for groups of floors the priority with which floors are to be cleared could differ.

Figure 4 shows movement traces characteristic of selective or phased partial evacuation in which both the need to evacuate and the priority of such evacuations are determined, partly in advance, by trained building staff and by fire department personnel. They use communications systems to determine emergency conditions, make decisions on appropriate action, and give directions regarding evacuation. (It should be noted that the sharing of responsibilities and actions may differ from one city to another, particularly if people are directed not to evacuate but rather to stay in the building.)

The 15-storey building, similar in exit features and population to that depicted in Figure 3, is assumed to have a fire on the tenth floor. Only the top half of the building is to be evacuated (in a special sequence) and people from upper floors may seek refuge on certain lower floors or may evacuate to the exterior at ground level. In any event, because of the time required to control evacuation and because of reduced density and flow conditions, nearly 9 minutes are required merely to move half the building occupants to below the fire area (5). This would entail some 2,600 person-storeys of stair use by 490 persons.

From simulations (utilizing realistic input data) it can be seen that 15 storeys occupied by 1,000 persons could be taken as perhaps representing a limiting condition below which total evacuation might be used in preference to controlled selective evacuation, assuming that people facing the most immediate threat somehow get into the exits first. It must be stressed that selective evacuation entails functioning equipment for communications and personnel proficient in its operation - conditions that are not easily achieved (5,54,61).

Staged Evacuation via Stairs and Elevators: Example

A limiting condition for evacuation may be reached as height and population increase. Evacuation procedures entailing limited movement by stairs to refuge or muster floors, followed perhaps by further complete evacuation by protected elevators, may then be worth considering. One such procedure is depicted in Figure 5. It was partly inspired by first-hand knowledge of the efficiency of the relatively simple total evacuation movement by stairs. It is a further development of the idea, promoted recently, that elevators should be put to greater use for evacuation (62-64). Perhaps most important, it is an attempt to solve, or at least to avoid, problems experienced already with elevators exposed to fire, earthquakes, or even sabotage (52, 65-68). (Because of such problems, codes do not include elevators as exits (52,55,56).)

The hypothetical building modelled in Figure 5 has 40 office floors, two 44-in. (1120 mm) wide exit stairs, and four groups of four elevators serving the ground floor and floors 2 to 12, 12 to 22, 22 to 32, 32 to 41. Elevator cars are 3,500-lb (1600 kg) size (large enough to carry standard stretchers), with speeds ranging from 800 to 1200 ft/min (244 to 366 m/min), those with higher speeds serving upper zones. Assumed building populations served by the four groups of elevators are (starting with floors 2 to 11) 1200, 1200, 1100, and 1000 persons or 4500 persons in total. Such a building might have 20,000 to 25,000 sq ft (1860 to 2326 m^2) of gross rentable area per office floor.

The building would have no special fire protection or communication systems installed other than on the elevator transfer floors, 12, 22, and 32, which were originally constructed or retrofitted with fire suppression, smoke control, compartmentation, and communication systems permitting them to be used as refuge floors in the event of fire. The elevator systems and shafts have no unusual safety features; they can be readily switched to independent or emergency service. (Measures providing greater safety in elevators used by fire department personnel and possibly for evacuation are described more completely in the literature (49,52,56,65).)

Before describing the emergency conditions under which stairs and elevators are used sequentially to evacuate such a building totally, brief mention should be made of one alternative, that of uncontrolled total evacuation via exit stairs (similar in form to that described for a smaller building in Figure 3). Assuming that 4500 able-bodied occupants actually start to leave when notification is given, the total evacuation via 44-in. (1120 mm) stairs would take almost 40 minutes. The movement trace for the last person from the forty-first floor is indicated by the dashed line in Figure 5. Note that this entails a wait of nearly 27 minutes, either on the office floor or in the exit stair before the last evacuee starts to descend. With all 4500 in the exits simultaneously, there would only be about 1.8 sq ft (0.17 m^2) of stair area, or half of one tread, per evacuee.

The evacuation procedure detailed in Figure 5 entails uncontrolled evacuation down the stairs to refuge or muster floors (the elevator transfer floors), a process initiated by the simple sounding of a general alarm clearly understood by the occupants as a directive to evacuate. (This assumption raises

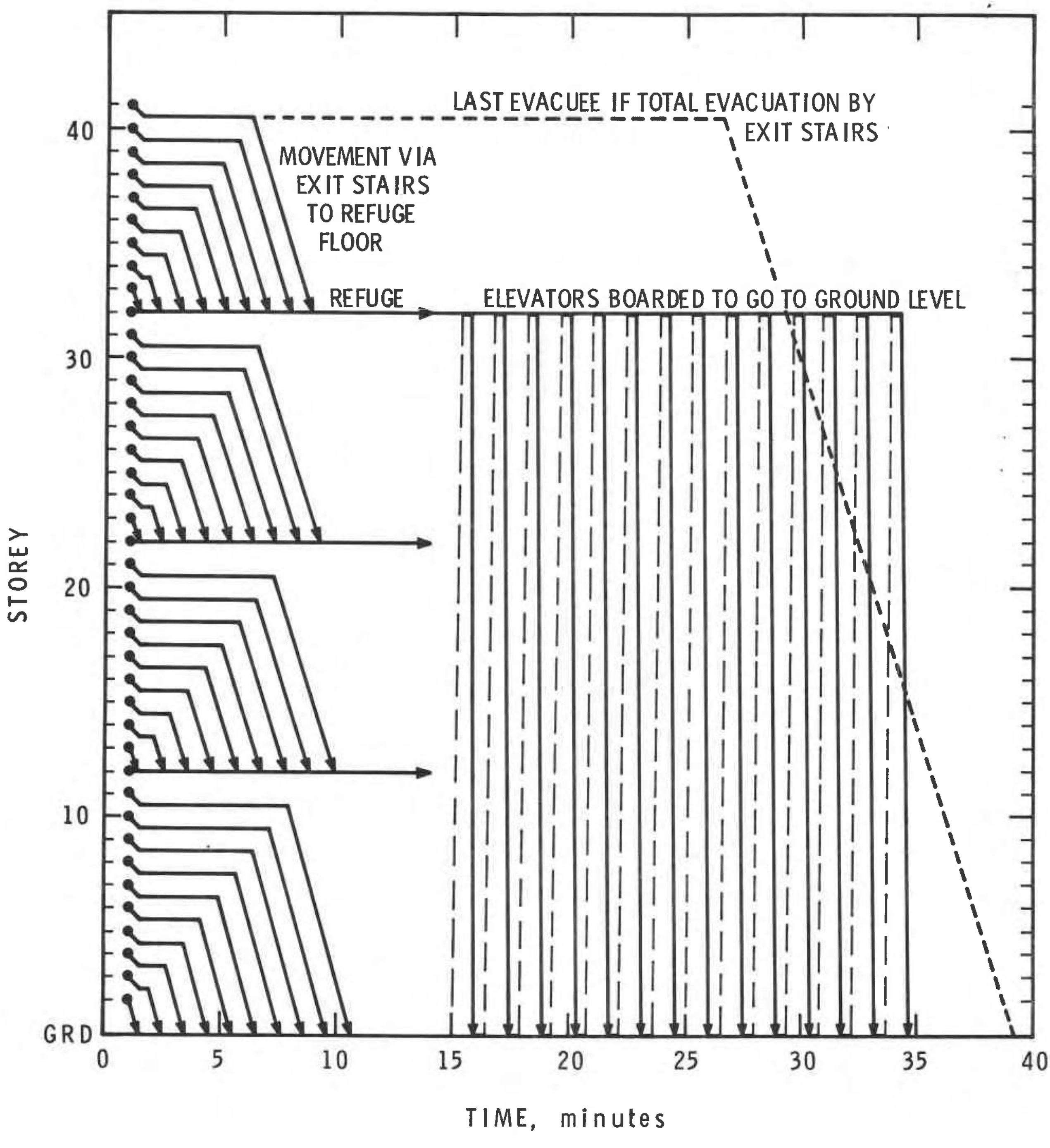

Figure 5

Staged evacuation via stairs and elevators in 41-storey building questions in the light of reported, but not well documented, ignoring of fire alarms, particularly in occupancies where false alarms are frequent and evacuation drills not held.

Similarities between high-rise buildings and large ships at sea have been made previously in pointing out that both must cope with emergencies by means of self-contained resources. It is useful to extend this analogy to note that, just as in ships, evacuation in this high-rise building is a two-stage process. On a ship, passengers and crew are mustered on life-boat decks where optimum use is made of management resources while decisions are made regarding further action; finally, and if necessary, life boats are used as effectively as possible. The procedure in a building is similar, with muster floors and elevators.

Each person would have up to 20 sq ft (1.9 m^2) of floor area on these refuge floors, which can be reached by all occupants (except the 1200 from floors 2 to 11 proceeding directly by stair to the ground floor) within a 10-minute period. During this time and for 5 minutes thereafter, all elevators would be returned to the ground floor and switched to emergency or independent service, the system would be checked, and (if functioning adequately and approved by the commanding fire officer, if the emergency were fire, for example) put to use transporting disabled persons from the office floors to the ground floor. A period of 15 minutes has been assumed for completion of this critical phase entailing "elevator capture," checking, approval, and dedicated use for disabled.

If no further evacuation of those on refuge floors were warranted and a return to normal occupancy desirable, the occupants could readily move back to their floors of origin by elevators and stairs within another 15 minutes. On the other hand, if the hazard required complete evacuation, the elevators could be used in their most efficient mode of operation to transport organized groups from refuge floors to the ground floor. Only the operation of the top group of elevators is shown in Figure 5. Fourteen trips per elevator would be needed during a 20-minute period to clear 1000 people from their temporary refuge on the thirty-second floor. The other two refuge floors could be cleared in a somewhat shorter time. (Elevator performance data for this simulation are as given by Strakosch (69).)

If stairs are to be used concurrently with elevators to move people from the three refuge floors to ground level, this stage of the evacuation could be shortened from 20 to about 14 minutes, assuming that one-third of the people on each of the three refuge floors use the stairs. The total time for the staged evacuation could thus be under 30 minutes, of which 5 minutes would be marked by no mass movement.

This extended description of the procedure is intended to illustrate problems as well as possibilities. Several favorable features have already been mentioned. All elevator trips from the refuge floors are made through sections of the hoistways that do not have floor stops and therefore lack doors, thereby providing a measure of protection against fire. This feature could be discarded if for some reason one of the groups of elevators proved to be inoperable or was needed for fire department operations. In this case all four groups of elevators would be used, including those serving lower floors (the earlier procedure leaves the lowest group of elevators unused); evacuees would board the elevators usually serving floors below the transfer (refuge) floor rather than those serving floors above. Another feature of the evacuation depicted in Figure 5 is the emphasis that can be placed on quality rather than quantity of communication channels and supervisory personnel, there being only three refuge floors to deal with.

An additional feature should be mentioned, for it mitigates a common difficulty. The sudden discharge of 4500 building occupants would not take place until some 15 minutes into the emergency, permitting traffic control procedures to be set up at street level. A very real problem in evacuations (or in any normal end-of-the-day egress) is the provision and management of adequate pedestrian facilities for large groups of people at street level (20,21,70,71).

Finally, it must be stressed that no general recommendation for use of elevators in emergencies is implied. In view of the problems that have occurred with elevators in building fires their use requires careful consideration and approval by authorities. This hypothetical example is given only to illustrate some of the problems and some of the potential solutions.

General Evacuation Time Prediction

A more comprehensive graph showing evacuation time as a function of actual evacuation population is given in Figure 6. Here is plotted the generally-useful relation between time of evacuation by stairs and actual evacuation population in office buildings. Also plotted are time requirements for completion of both the first and second stages of the stair/elevator procedure depicted in Figure 5. This permits prediction for a range of population and building heights. The effect of one procedural change is shown, entailing mass evacuation by elevator from the refuge floors after 5 rather than 15 minutes. Although not recommended such a procedure could be attempted.

Similarly, a relatively uncontrolled procedure using only elevators operating in normal down-peak, automatic mode is problematic. In view of the number of things that can go wrong with such elevator use in emergencies it is not possible here to predict related evacuation times (assuming evacuation can be successfully completed). At best the evacuation times might be similar to those predicted by line C_2 in Figure 6, at worst in excess of those predicted by line C_1 .

SAFETY OF ELEVATOR AND STAIR USE

One final comment, albeit a tentative one, should be made regarding the relative merits of elevator use and stair use. This pertains to risk. One source, using elevator company statistics, notes that fewer than 1000 accidents were reported in 1973 for an estimated use of 350,000 elevators totalling 40 billion rides in the U.S. (72). By comparison, annual stair use roughly estimated to total some 2,000 billion person-flights in the U.S. results in accidents requiring hospital treatment for 465,000 persons (for a rate of

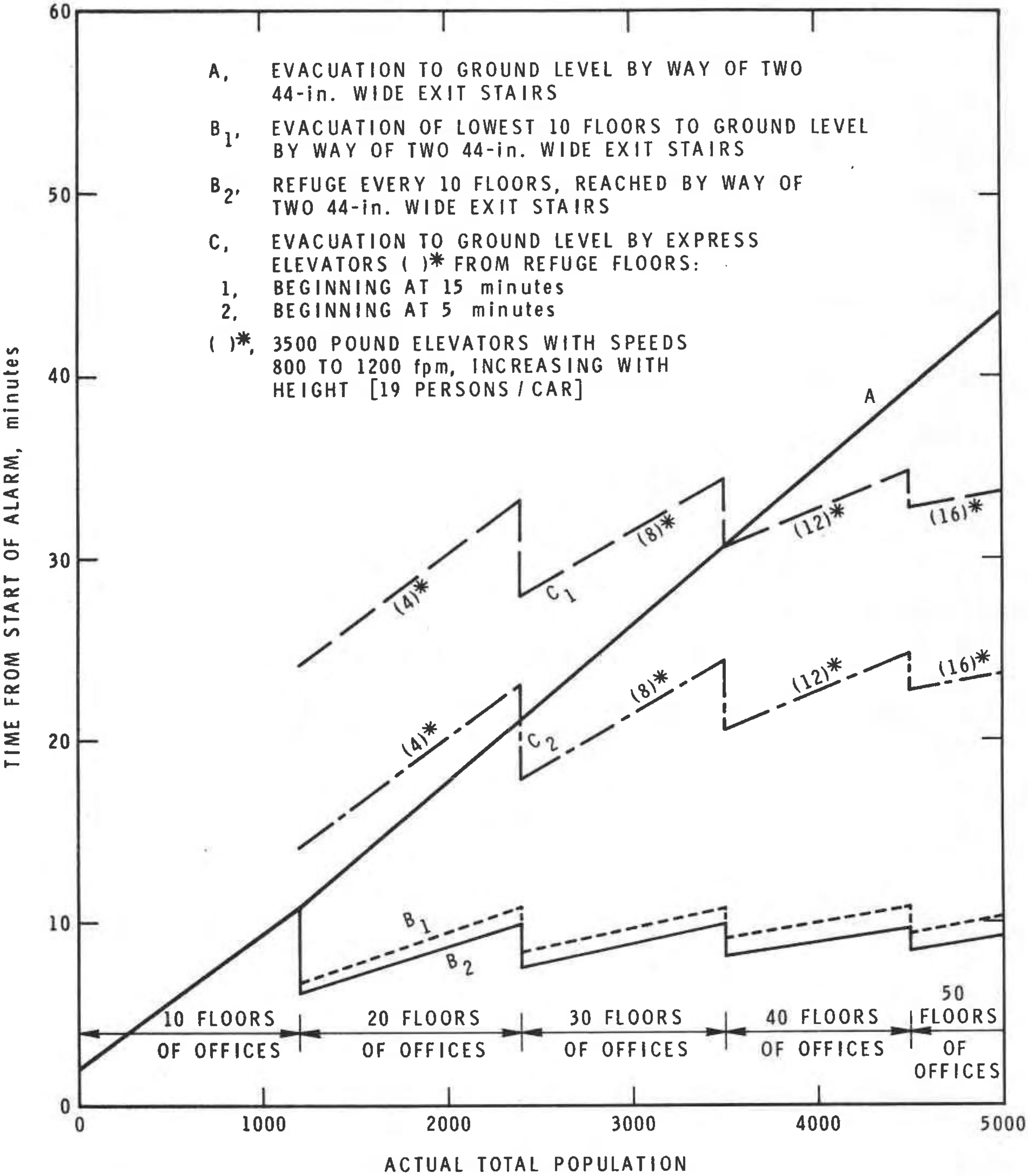

Figure 6

Times needed for various refuge and evacuation procedures using stairs and elevators in tall office buildings

1/4,200,000) (19). These figures are for normal use and, for stairs, cover a considerable range in quality of facilities.

With regard to possible risk of injury due to falls experienced in evacuation situations, preliminary Canadian studies of office building evacuation and normal crowd egress in public assembly occupancies suggest that one injury requiring hospital treatment may occur for stair use (during evacuation) ranging from one million to ten million person-flights. Total-evacuation drills studied in Ottawa entailed about 200,000 or more person-flights and no injuries were reported.

Such figures are preliminary and unofficial. What can be reported, based on first-hand observation, is that dense crowd movement (inherently slow) may present lower risk of falling than is the case for individuals moving alone or in small groups.

Based on the study directed by Canada's Division of Building Research at the 1976 Olympic Games in Montreal, and from a reading of recent reports on stair design and safety, there is considerable evidence that faulty stair design, construction, and maintenance (sometimes still in compliance with existing building codes) is a major factor in stair accidents (7,19,21,22). At one of the stadiums recently studied in Canada, a serious defect of riser-tread dimensional irregularity noted on one particular stair was linked to an incident rate some fifty times larger than the incident rate observed on the same stair after dimensional irregularities were corrected. (The rate of the simplest observable incident or noticeable misstep is linked to the rate of injury estimated for stair use, there being about a thousand noticeable missteps for each injury requiring hospital treatment (19).)

The subject of stair safety, particularly in evacuation situations, is one requiring further research, both statistical and etiological. This being the case, it is impossible to suggest in any comprehensive manner what design and retrofitting requirements are justified. Research to date has, however, provided an improved technical basis for safety regulations and design rules for stairs (5,6,7,19,21,22,34,35,40).

Benefits of Normal Use of Exit Stairs

Perhaps a problem of policy and practice is the deliberate de-emphasis of normal use of exit facilities arising out of a concern for security. In high-rise buildings occupants dissuaded, either subtly or openly, from using exit stairs for some of their normal circulation may become too dependent on elevators, even to the point of not knowing where the exit stairs are located and what the experience of using them is like. This is unfortunate in view of the overwhelming evidence that lack of familiarity with more than one means of access and egress has led to unnecessary deaths in building fires. It further complicates the management of evacuations where stairs must be used.

Although these are reason enough for reversing the trend towards cutting off access to exit stairs for ordinary use, there are other benefits to be gained from normal use of exit stairs. During power failures, elevators are totally or severely disabled and such stairs must be used. Again, familiarity would be an advantage. Greater normal use of exit stairs also reduces the demand on elevators for a variety of intra-building and inter-building trips. Although this may be a minor factor in some buildings, depending on tenancy, in others it could be exploited and could result in savings in capital and operating expenses.

In one 21-storey office building studied recently in Ottawa each occupant used the building's exit stairs for an average of three trips each day. Although average stair-trip lengths were shorter than average elevator-trip lengths the estimated cost of stair use compared with cost of elevator use is worth considering. The cost of stairs is estimated to be less than one cent per use; that of elevators can be at least three times as much per trip, assuming six trips per day by elevator. These costs do not include cost of employee time for the trip. In addition to documenting use of stairs and elevators by an accurately-determined building population, this study utilized questionnaires to gauge office workers' attitudes and reasons for stair or elevator use. This pointed out further justification for choosing stairs rather than elevators: less delay in getting from one place to another, and the prospect of healthful benefits from the mild physical exertion in using stairs (40).

To make this digression directly relevant to the subject of designing for emergency, the normal use of exit facilities should encourage more conscientious design and maintenance. Such improvements can only increase their effectiveness when their use is crucial to life-safety.

EMERGENCY PROCEDURES IN OTHER OCCUPANCIES

The foregoing description of evacuation considerations has been based on studies largely carried out in office and public assembly occupancies. The examples have been for office building evacuation and refuge procedures, but these are not the only, nor even the most pressing, concerns in the field of life safety from fire and other hazards. They are merely the ones that have been accessible to the author over the last decade and lend themselves to relatively simple modelling.

Limited Utility of the "Hydraulic Model"

Models such as that illustrated in Figure 3 and those that have long been assumed in drafting code requirements for means of egress have been described by the term "Hydraulic Model" (19). In simple form the model treats a building like a reservoir of water (or ball-bearings). Exit routes are pipes with valves controlling drainage through the bottom. Performance, or rate of discharge, is related to readily-measured orifice dimensions.

Treated with caution, such a model has much utility. Proof of this is the resulting ability to predict with reasonable accuracy the time required for total evacuation of able-bodied persons from office buildings, sports buildings and schools. The danger lies in inappropriate generalization to include other occupancies or even to more realistic, complex situations in the occupancies studied. For example, the importance of realistic evacuation-initiation assumptions in offices has already been pointed out. Failure to model this initial stage of evacuation properly has been partly responsible for overly-optimistic predictions of total evacuation times reported in the literature.

Widespread acceptance of the model in code requirements has perhaps drawn attention away from what happens at the "threat end" of the evacuation process as opposed to the "safe end" (the size of the exit orifices) (19). It is at the threat end that so many of the unsolved problems of life safety lie, for it is here that the vast majority of people die, for example, in fires.

Fortunately, in recent years research attention has begun to concentrate more fully on the problems occurring at the threat end and mitigating measures are beginning to appear: obvious ones are detection units and systems, emergency communications systems, and fire suppression systems. No less significant, but unfortunately not subject to the same commercial incentives for research and development, is the concern for normal occupancy activities, management capabilities, and emergency procedures in buildings.

Health-care Facilities

Concern about emergency procedures in health-care facilities is at the heart of recent major research programs in the U.S., Britain, and Canada. With funding largely from national health agencies this research is being conducted within national institutes for building and fire research as well as under contract to university and private research personnel (19, 73-77).

Empirical and theoretical studies within these research programs have included findings similar to that reported above regarding long delays in evacuation-initiation when controlled procedures are attempted in office evacuations. For example, the staff organization in a hospital requires time to asses the situation prior to a mass movement of patients. Even within the confines of a hospital ward threatened by fire, considerable time may be required simply for staff to shift furniture and prepare patients to be moved. These tasks alone add significantly to the time required for evacuation. In a recent British test evacuation of one ward of less than thirty patients, complete removal to the ground level two floors below took 23 to 30 minutes, of which as much as a third was taken up by preparation for movement (74). There is a great need for the development of workable, efficient emergency methods of moving patients and for making these methods familiar to staff in health-care facilities (78).

In addition to the normally recognized institutions such as hospitals and nursing homes there are also new occupancies such as large residential buildings occupied mainly by self-reliant elderly people. Aside from physiological disabilities that may affect perception and decision-making, there are special social and psychological characteristics that must be taken into account in planning facilities and procedures, perhaps entailing evacuation, for use in emergency situations (79).

EMERGENCY PLANS

Responsibility is divided for making best use of emergency facilities and human resources among various authorities, emergency services, building management personnel, and ultimately everyone using buildings. It is not surprising, therefore, that there is confusion regarding fire safety measures. This does not mean that people cannot cope with emergencies. Contrary to what is often believed, they generally cope well with unexpected, life-threatening situations, whether fire or natural disaster. Panic is rare (1,2,11,12,18,80). There is, however, some evidence and a growing body of scientific documentation in support of the effectiveness of safety education, drills, and other activities affecting awareness, as well as adequately prepared management resources. In short, coping ability is surprisingly good, but it can be made better.

Noteworthy Developments

A few examples of fire safety may illustrate the state of the art. In view of the Canadian context in which this paper is prepared, mention should be made of the requirements, standards, and training programs of the Dominion Fire Commissioner. These apply to buildings occupied by Canadian federal employees (61,81). Significant attention to fire safety is also evident in the efforts of the U.S. General Services Administration, particularly during the early 1970's (45, 82-84). There has also been activity at state and local levels where authority often lies for the safety of the general public. The high-rise fire-safety requirements of New York City's Local Law 5, 1973, have drawn wide interest and some local opposition, the latter recently leading to a court ruling that some requirements (e.g., for retrofitting) are void and unenforceable (85,86). In the context of this paper it is worth noting that the New York City requirements for fire safety planning, including occupant education and building-management fire-safety responsibility, were upheld by the Court.

Not necessarily in response to legal requirements, associations and individual building administrations also are becoming increasingly aware of fire safety. In many cases, however, the recommendations for fire-safety planning appear to be given only lip-service, particularly outside of institutional or government occupancies (87). Knowledgeable individuals and associations such as the National Fire Protection Association and the National Safety Council have prepared guidelines and standards to assist managers and others in setting up emergency plans (52,55, 88-90).

In making available such action-oriented literature there are dangers, on the one hand, of being superficial and not providing sufficient detailed guidance, on the other, of going into excessive detail, thus limiting application to a variety of building and occupancy conditions. In either case, much of the literature is partly based on misconceptions about human behavior of the type mentioned above with reference to panic or is excessively modelled on military-type organizations and procedures.
A quotation from an article titled "Disasters bring out the best in people," (although taken somewhat out of context) gives two generally-useful suggestions (80):

1. Don't overplan. "You can't think through every contingency," says Quarantelli, "and a massive disaster plan is no plan at all if no one knows what it says. The plan must state guidelines and principles rather than specifics."

2. Plans should be tried out. The plan must be practiced to uncover minor but crucial flaws, says Dynes. "... such as stretchers in a hospital not fitting through the emergency exit stairway." Exercising the plan is more important than drawing it up, he emphasizes. Unless it is practiced people will do things in their own normal way.

To these recommendations might be added two others based on observations of office building evacuation drills. In holding drills distinguish between the goal of training and education and the goal of evaluation. For example, to make high-rise building occupants more aware of what happens and why, take the time in the course of pre-announced drills to communicate, over public address systems if available, general explanations in addition to specific directives. Other types of drills, given without advance notice (and only after sufficient information-giving drills), can be held to evaluate occupant preparedness, determine evacuation times, etc. The second suggestion is that systematic observation, evaluation, and reporting should be done on the drills that are held. In such studies there is much to be learned that may alter the current conception of and approach to building safety measures. This will provide a better idea of how well safety dollars are being spent, and will improve awareness of the relative effectiveness of building design, equipment systems, and operating or management measures.

CONCLUDING REMARKS

In the absence of measures for mitigating the physical impact of severe hazards, and perhaps even with such measures, evacuation may still be needed to preserve life safety. Properly understood, it can serve us well; misunderstood, it may serve us badly.

Ideally, people using a building should be aware not only of its emergency features and appropriate procedures but also of the conditions they will face in carrying out such procedures; for example, the delays they may experience as other people are given the necessary priority in exit use. Unfortunately, as has been suggested here, this goal is several steps away. To achieve the goal, designers and managers need detailed knowledge of the appropriate procedures and resulting conditions. Researchers have only recently begun to assemble data and to build models, including models of human behavior related to emergencies in buildings. Only the first steps have been taken towards increased ability to predict, and eventually to control, emergency conditions.

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