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EMERGENCY ELEVATOR EVACUATION SYSTEMS

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ABSTRACT

Throughout most of the world, warning signs next to elevators indicate that they should not be used in fire situations. However, the idea of using elevators to speed up fire evacuation and to evacuate people with disabilities has gained considerable attention in recent years. The concept of an emergency elevator evacuation system (EEES) is developed. An EEES includes the elevator equipment, hoistway (elevator shaft), machine room, elevator lobby, as well as, protection from heat, flame, smoke, water, overheating of elevator machine room equipment, and loss of electrical power. While the primary objective of an EEES is fire evacuation of building occupants, these systems are also applicable for fire service mobilization before fire fighting and for non-fire emergency evacuation (due to bomb threats for example). In areas of high seismic activity, attention must be paid to earthquake design. Further, the development of an EEES needs to take into account human behavior so that building occupants will be willing and capable of operating the system in an emergency. The issues of communications, elevator control and out-of-service elevators are addressed. It is concluded that design of an EEES for a small number of people is feasible. An EEES for small numbers of people is much simpler than one for the large numbers of people in a general evacuation. Based on what is learned from an EEES for a small number of people, an application for many people could follow.

INTRODUCTION

In the 1960's concern about the danger of fire exposure of elevator passengers lead to the prohibition of elevator use for fire evacuation. Throughout most of the world, warning signs were placed next to elevators indicating they should not be used in fire situations. However, the idea of using elevators to speed up fire evacuation and to evacuate people with disabilities has gained considerable attention in recent years.

Bazjanac (1974, 1977) and Pauls (1977) studied the impact of elevator evacuation on evacuation time. On February 19 and 20 of 1991, the American Society of Mechanical Engineers (ASME) held a symposium in Baltimore entitled *Fire and Elevators*. Several of the papers at this symposium dealt with fire evacuation by elevators (Degenkolb 1991; Fox 1991; Gatfield 1991; Klote and Tamura 1991; Pauls et al. 1991). NIST hosted a workshop for elevator use during fires (Klote et al. 1992a). NIST has studied the feasibility of fire evacuation by elevator for office buildings (Klote et al. 1992b). This study used evacuation calculations to show that combined use of elevators and stairs could significantly reduce evacuation time for tall buildings.

Klote et al. (1994) studied the feasibility of elevator evacuation of FAA air traffic control towers and developed the concept of an emergency elevator evacuation system (EEES). This paper is a discussion of the EEES idea without restriction to occupancy type. An EEES includes the elevator equipment, hoistway (elevator shaft), machine room, elevator lobby, as well as, protection from heat, flame, smoke, water, overheating of elevator machine room equipment, and loss of electrical power. While the primary objective of an EEES is fire evacuation of building occupants, these systems are also applicable for fire service mobilization before fire fighting and for non-fire emergency evacuation (due to bomb threats for example). However, the focus of this paper is on fire evacuation aspect both with and without direct participation by the fire service.

POSITION AGAINST ELEVATOR EVACUATION

Problems with elevator fire evacuation were listed in some editions the NFPA Life Safety Code, but 1976 edition was the last to list these problems (NFPA 101 1976):

- Persons seeking to escape from a fire by means of an elevator may have to wait at the elevator door for some time, during which they may be exposed to fire, smoke or developing panic.

- Automatic elevators respond to the pressing of buttons in such a way that it would be quite possible for an elevator descending from floors above a fire to stop automatically at the floor involved in the fire and open automatically, exposing occupants to fire and smoke.

- Modern elevators cannot start until doors are fully closed. A large number of people seeking to crowd into an elevator in case of emergency might make it impossible to start.

- Any power failure, such as the burning out of electric supply cables during a fire, may render the elevators inoperative or might result in trapping persons in elevators stopped between floors. Under fire conditions there might not be time to permit rescue of trapped occupants through emergency escape hatches or doors.

There are other concerns. Fire or smoke might damage elevator equipment. Water from sprinklers or fire hoses could short out or cause other problems with electrical power and control wiring for the elevator. Overheating of elevator equipment could result in malfunction of elevators. Pressurization for smoke control could result in elevator doors jamming open, limiting movement of the car. Piston effect due to elevator car motion could pull smoke into the elevator lobby or the hoistway. However, it is possible to design EEESs with a high level of protection relative to these concerns.

EVACUATION SYSTEM CONCEPT

The EEES system includes the elevator equipment, hoistway, machine room, and other equipment and controls needed for safe operation of the elevator during the evacuation process (figure 1). Because people must be protected from fire and smoke while they wait for an elevator, the system must include protected elevator lobbies. Such protected elevator lobbies also help to prevent the fire from activating elevator buttons so that elevator cars are prevented from being called by the fire to the fire floor[1].

An EEES must have protection from heat, flame, smoke, water, overheating of elevator machine room equipment, and loss of electrical power. In addition, an EEES must have a control approach to assure protection of people traveling in the elevator. In areas of high seismic activity, attention must be paid to earthquake design. Further, the development of an EEES needs to take into account human behavior so that building occupants will be willing and capable to operate the system in an emergency. The following sections address these issues.

ISSUES OF ELEVATOR EVACUATION

This section presents some of the issues that have been raised concerning elevator evacuation.

1. **Myth of Panic:** There is a misconception that panic behavior would commonly result in people crowding into an elevator and blocking the elevator doors open so the car will not run. Keating (1982) states:

   > "Multiple deaths in fire tragedies are frequently headlined in the press by reports of panic behavior of the victims. Such conclusions by the press persist in spite of the insurmountable research evidence that concludes exactly the opposite."

   Keating discusses the human behavior studies of the survivors of many major fires and concludes that panic behavior is rare in fire situations. Bryan (1988) concurs that panic behavior is rare even among people aware of an ongoing fire, and he indicates that the most frequent mode of behavior during fire emergencies is deliberate and purposeful. Thus the probability of panic behavior in a lobby protected from heat and smoke is very low. However, education would be valuable to overcome misconceptions about panic.

2. **Fires Inside an EEES:** For a fire in the hoistway, elevator lobbies or machine room; the EEES should be shut down. Fires in the hoistway or elevator lobbies can easily result in untenable conditions within the EEES. Fires in any part of an EEES would expose elevator components to smoke, elevated temperatures and possibly water from sprinklers. Elevator components currently being manufactured cannot be expected to operate in such

environments. While it is possible to develop elevator components that have some level of resistance to fire produced environments, the approach to EEESs taken in this paper is based on using currently available elevator components. Therefore, when there is a fire inside an EEES, the approach taken in this paper is to shut down the EEES.

3. **Protection of Waiting People:** People waiting for an elevator for fire evacuation need to have an elevator lobby that provides a high level of protection from heat, flame and smoke. The topics of protection from heat, flame and smoke are addressed later in this paper.

4. **Protection of Passengers:** One approach to protecting passengers from elevator doors opening automatically onto fire is to have elevator lobbies that provide protection from heat and smoke. Another approach is an elevator control mode that prevents elevators from stopping at lobbies where untenable conditions are detected. A system using both approaches would have a higher level of reliability because of redundancy.

5. **Protection from Heat and Flame:** Compartmentation is one of the oldest methods of fire protection and has been extensively used to limit the spread of fire. As discussed later in this paper, the methods of fire resistant construction are well established.

6. **Equipment Protection from Smoke:** Compartmentation, dilution and pressurization are techniques that can be used to protect an EEES from smoke infiltration. A joint US/Canadian research effort consisting of concept studies and full scale fire experiments lead to development of design data for elevator smoke control systems using pressurization. An overview of such smoke protection is presented later in this paper.

7. **Reliable Electric Power:** Existing technology can be used to assure highly reliable electric power so that elevators will be available when needed for fire evacuation. There is considerable experience in providing highly reliable power for numerous applications (computer facilities, hospital operating rooms, etc.). The topic of reliable electrical power is addressed in further detail.

8. **Water Protection and Fires Outside an EEES:** There is concern that water from sprinklers or fire hoses could short out or cause other problems with electrical power and control wiring for the elevator. For fires outside an EEES, water protection is needed, and such protection is addressed later.

9. **Protection from Equipment Overheating:** Loss of cooling has the potential to cause loss of elevator service due to overheating of elevator equipment. Approaches to prevent loss of machine room cooling are discussed later.

10. **Doors Jamming:** There is concern that pressurization for smoke control could result in elevator doors jamming open, limiting movement of the car. The friction force increases with the pressure difference from the hoistway to the lobby. In tall buildings, elevator doors frequently jam open during extremely cold weather. This is caused by stack effect induced pressure differences. Elevator mechanics commonly adjust the door closing forces to prevent door jamming. In field tests conducted of pressurized elevator systems by Klote (1984), no door jamming was encountered at pressure differences as high as 75 Pa (0.3 in H_2O). When door jamming was encountered in an elevator without smoke control, it was found that only a small additional force applied by the palms of the hands was sufficient to overcome jamming. Fire fighters and building occupants can be taught to overcome door jamming this way, and elevator doors could be fitted with grips or handles to aid in this effort.

11. **Piston Effect:** There is concern that piston effect due to elevator car motion could pull smoke into the elevator lobby or the hoistway. Analysis of the airflows and pressures produced by elevator car motion in a pressurized hoistway was developed by Klote (1988) based on the continuity equation for the contracting control volume in a hoistway above an ascending car. From this analysis, a simple approach to prevent pressurization failures due to piston effect was developed, and this approach is presented by Klote and Milke (1992).

HEAT AND FLAME PROTECTION

Compartmentation is one of the oldest methods of fire protection and has been extensively used to limit the spread of fire. Compartmentation is also one approach to smoke protection, and this is addressed in the next section. As a convenience to the reader the concepts of compartmentation are briefly described here, and for further information readers are referred to Barnett (1992), Boring et al. (1981), Bushev et al. (1978) and Campbell (1991).

Buildings are divided into compartments formed by fire barriers. These barriers are walls, partitions and floor-ceiling assemblies that have some level of fire resistance. The traditional approach to evaluate fire resistance is to subject a section of a barrier to a standard fire in a standard furnace. Each building fire is unique in duration and temperature, and it is not surprising that the performance of barriers in building fires differs to some extent from the performance in standard tests. Historically, the goal of fire resistant construction was property protection, but the primary goal of current codes is life safety. The codes require specific levels of fire resistance for specific applications with the goal of protecting life.

Throughout the United States, the fire resistance requirements vary. The requirements of the NFPA Life Safety Code (NFPA 101 1994) are discussed here, because they are representative. The Life Safety Code requires that fire barriers meet the requirements of NFPA 251 (1990) and have fire resistance ratings of 20 minute, ½ hour, ¾ hour, 1 hour, or 2 hour. Door openings and other types of openings in these barriers need to be protected. Fuel loads may be located next to walls and partitions, but generally they are not located against doors. Thus it is expected in many fires that doors would have less severe exposures than the barriers in which they are located. In general, NFPA requires: a 20 minute door in a 20 minute barrier, a 20 minute door in a ½ hour barrier, a 20 minute door in a ¾ hour barrier, a 1 hour door in a 1 hour barrier, and a 1½ hour door in a 2 hour barrier. However, there are some exceptions to these requirements depending on the building occupancy.

In general, stairs connecting three stories or less are required to be separated from the rest of the building by 1 hour fire barriers, and stairs connecting four or more stories are required to be separated by 2 hour fire barriers. The requirement for other shafts including hoistways in new construction is the same.

For an EEES to be equivalent to stairs with respect to compartmentation, the enclosures of the EEES need to be as good as that of a stairwell. The enclosures of the hoistway, elevator lobbies and machine room need to have the same level of fire resistive construction as stairwells. To be equivalent with NFPA 101 compartmentation requirements, an EEES four stories or taller would need 2 hour barriers separating the hoistway, elevator lobbies and machine room from the rest of the building.

SMOKE PROTECTION

The mechanisms that can be used to provide smoke protection are air flow, buoyancy, compartmentation, dilution and pressurization. Detailed information about these mechanisms is presented by Klote and Milke (1992). Because of the concern about supplying oxygen to the fire, Klote and Milke recommend against using airflow for smoke control, except when the fire is suppressed or in the rare cases when fuel is restricted with confidence. Further, airflow has been primarily used to manage smoke from fires in subway, railroad and highway tunnels. For the EEES concept of this paper with extensive barriers (walls, floors and ceilings) and automatic closing lobby doors, smoke control by airflow has limited applicability. Buoyancy is primarily used to manage smoke in large spaces such as atria and shopping malls. Systems that rely on buoyancy are inappropriate for smoke protection of EEESs. For the EEES concepts of this paper, the mechanisms of compartmentation, dilution and pressurization are discussed below.

Compartmentation

Systems using only compartmentation have a long history of providing protection against fire spread. In such fire compartmentation, the walls, partitions, floors, doors, and other barriers provide some level of smoke protection to spaces remote from the fire. Smoke leakage into spaces protected by compartmentation depends on the leakage of barriers and pressure differences due both to natural building flows and fire induced flows. Analysis of smoke protection by compartmentation is possible and requires analysis of smoke leakage, toxicity and evacuation. Bukowski et al. (1991) provide computer routines for such evaluations.

While such methods can be used to design these systems, no testing technique has been developed that can assure that these systems will work as intended. However, an approach similar to smokeproof enclosures for stairs by natural ventilation is possible as discussed later.

Dilution

Dilution of smoke is sometimes referred to as smoke purging, smoke removal, smoke exhaust, or smoke extraction. Dilution consists of supplying air to and exhausting air from a compartmented space. For a compartment remote from the fire, dilution can be used to maintain tenable conditions when there is some smoke infiltration from an adjacent space. As with compartmentation, analysis of smoke protection by dilution is possible and requires analysis of smoke leakage, toxicity and evacuation. Also the computer routines of Bukowski et al. (1991, 1994) can be used for such evaluations. As with compartmentation, no testing technique has been developed that can assure that these systems will work as intended.

Pressurization

Systems relying on compartmentation with pressurization are designed on the basis of no smoke leakage into protected spaces. Accordingly, analysis of such pressurization systems is less complex than that of systems using compartmentation alone or compartmentation with dilution. Acceptance testing and routine testing of pressurization systems is done by measurement of the pressure difference produced when the system is operating.

A joint U.S./Canadian project was undertaken to evaluate the feasibility of using pressurization for smoke protection of elevators used for fire evacuation. Full-scale fire experiments were conducted in a ten-story fire research tower near Ottawa (Tamura and Klote 1988, 1987a, 1987b). These experiments verified that pressurization can provide smoke protection for an EEES. Design information for these systems is presented by Klote and Milke (1992), and this information has been extended to include the effects of wind (Klote 1995).

WATER PROTECTION

During a fire, water from sprinklers and fire hoses can damage electronic, electrical, and mechanical components of an EEES. For fires outside the EEES, the two major locations of concern about water damage are the machine room and the hoistway. Two potential approaches to minimize water damage are:

1. use of elevator components that can function in a wet environment, and
2. prevention of water from entering the hoistway or machine room.

The following sections discuss these approaches including the extent of the water exposure that elevator emergency evacuation systems might face.

Water Exposure

The purpose of this section is provide information about the quantities of water that can be released in a building due to fire suppression or firefighting. For a commonly manufactured sprinkler head with a 12.7 mm (0.50 in) diameter orifice, the flow rate at 69 kPa (10 psi) with a discharge coefficient of 0.75 is 67 L/ min (17.7 gpm). These conditions are typical of the kind of minimum requirements for the remote heads in a sprinkler system. However, heads closer to the source of water would be subject to higher pressures and have higher flows. For example, a pressure away from a the remote head of 600 kPa (87 psi), the flow would be about 200 L/min (53 gpm).

The extent of water exposure from fire hoses is usually different for interior and exterior attacks. For interior attacks, the fire service usually uses manually held hoses with either solid-stream nozzles or spray nozzles. Solid-steam nozzles of diameter from 6 to 29 mm (0.25 to 1.125 in) are considered for hand held hoses. A 29 mm (1.125 in) solid-steam nozzle produces the *standard* stream of 950 L/min (250 gpm) at 310 kPa (45 psi) nozzle pressure.

Spray nozzles (also called fog nozzles) from 19 to 64 mm (0.75 to 2.25 in) are also manually held and used for interior attacks. A Manually held hose with solid-stream or spray nozzles has flow rates from approximately 40 to 1150 L/min (11 to 300 gpm). Often for exterior attacks, the fire service uses mechanically restrained hoses referred to as *master flow devices* that have flow rates from 1900 to 7500 L/min (500 to 2000 gpm). The flows discussed above are summarized in table 1.

Water Resistive Elevator Components

Currently no elevators have been developed with water resistant components for operation during fire evacuations. However, many elevators operate outdoors on exterior walls of buildings with many of the system components exposed to rain, wind and extremes of temperature. These outdoor conditions are believed to be much more severe than those associated with water flow inside a hoistway due to a building fire. While it is technically feasible to build elevators with water protected components which will operate during a fire, testing and maintenance of such water resistive components is a concern.

Without routine testing for water resistance, components that degrade from years of use or are accidentally damaged would go undetected and unrepaired. To assure that the water resistive features operate properly, routine inspection, testing and repair efforts would be needed. The most positive approach to testing would involve use of a water spray or a water stream inside the hoistway and possibly inside the machine room. For machine rooms located at the bottom of the hoistway, the water problem is more of a concern. These water tests have the potential for water leakage to other building spaces and resulting damage to building finishes and other objects. Because little is known about water flow in hoistways, the extent to which water protection is needed and routine tests are needed is unknown.

Further research may result in improved understanding of hoistway water flow, methods of developing water resistant elevator components and appropriate tests. Until such water resistance technology is developed for elevator evacuation, the only practical approaches are (1) prevention of water from entering the hoistway, (2) the use of exterior elevators, and (3) the use elevators with exterior lobbies. Theses alternatives are discussed below.

Prevention of Water Entry

Building construction can be used with the intent of preventing water from entering the hoistway and machine room. The following sections discuss the use of sloping floors, floor drains and doors with seals to keep water out of the hoistway, and a possible approach combining these elements is discussed.

Sloping Floors: Sloping floors can control water flow, provided that the water velocity is relatively low as when the flow is due to a distant spill [order of 0.1 m/s (20 fpm)]. Analysis of Klote, Levin and Groner (1994) showed that a slopping floor cannot control relatively high velocity flow, such as those from hose streams.

Floor Drains: A 50 mm (2 in) diameter floor drain has a maximum capacity of about 115 L/min (30 gpm), and a 75 mm (3 in) diameter floor drain has a maximum capacity of about 190 L/min (50 gpm). These capacities are for floor drains that are clean and have a slope of about 2% of the length. However, drains are sometime installed with less slope and they often become clogged.

By comparison with the water flows of sprinklers and fire hoses (table 1), it is apparent that a clean and properly installed floor drain of 75 mm (3 in) diameter may be able to carry away the water from sprinklers, but it does not have the capacity to deal with fire hose flows. A clogged drain or one without the proper slope my not be able to carry away the water from sprinklers.

Floor drains may be a significant part of a design to prevent water from entering a hoistway or machine room. However, it is not appropriate to rely totally on floor drains for water protection.

Door Seals: Seals have been historically been used on exterior doors for comfort and energy conservation and on interior doors for control of odors, sound and light. Seals on the doors between the elevator lobby and the building have the potential to significantly reduce water flow into the elevator lobby. However, seals can be installed improperly or be damaged over a lifetime of normal operation.

Klote, Levin and Groner (1994) presented an analysis that illustrate how much water can flow through an undercut and why seals are important. For a door that is sealed [bottom gap thickness of about 2 mm (0.08 in)], this analysis results in a maximum flow under the door of about 30 L/min (8 gpm). For an undercut of 12 mm (0.47 in), the maximum flow would be about 190 L/min (50 gpm). While door seals cannot prevent all water leakage into an elevator lobby, they can significantly reduce such flow.

As with floor drains, door seals may be a significant part of a design to prevent water from entering a hoistway or machine room. However, it is not appropriate to rely totally on door seals for water protection.

Possible Approach: The combined use of sloping floors, floor drains and doors with seals to prevent water flow into the hoistway is illustrated in figure 2. The lobby door with seals reduces the extent that water can get inside the lobby. The floor drain is located on the inside of the lobby, which reduces the amount of water that can reach the drain. If the drain were outside the lobby, the water flow could exceed the capacity of the drain. The lobby door must be opened when people enter the lobby. The floor drain and the sloped floor are intended to deal with the small quantities of water that may enter the lobby when the door is opened. If small streams of water flow past the floor drain, the sloping floor reduces the chance of water reaching the hoistway. A trench drain (figure 3) can help minimize flow past the drain. In the idealized arrangement of figure 2, the elevator doors are at a right angle to the lobby door reducing the potential that water spray into the lobby through an open doorway will reach the hoistway.

The above discussion addressed preventing water flow through the elevator lobby, but water can also flow directly into the hoistway. Efforts should be made to prevent water flow directly into the hoistway. Cracks and gaps on the inside surface of the hoistway should be filled and sealed, and a water resistant coating on the surface may be appropriate.

Exterior Elevators

The discussion so far was restricted to elevators located inside a building. However, there are advantages to locating elevators on the outside of the building. As already stated, many elevators operate outdoors on exterior walls of buildings with many of the system components exposed to rain, wind and extremes of temperature. Such exterior elevators could be used as EEESs. Exterior elevators are subjected to severe rain and winds. However, it is possible that the water flow through an elevator door into the hoistway would be significantly different from flow due to rain, and elevator components that work during rain might fail due to water exposure during a fire. At present, it is recommended that exterior elevators not be used as part of an EEES without protecting the elevator lobby from water entry. Further research might provide information concerning the need for protecting the lobbies of exterior elevators from water entry.

Elevators With Exterior Lobbies

Some elevators are located in their own towers and are separated from the building by a section of exterior walkway or an exterior elevator lobby. This approach is used in many motels in warm climates, and it is illustrated in figure 4(a). Such elevators are another alternative for EEESs.

The water flow due to sprinklers and fire hoses in the building that was not stopped by closed doors with seals would flow into the elevator lobby. This lobby is outside and is designed for water to flow away from the elevator doors. The approach that protects the elevator from rain can be expected to protect it from water during a fire.

Further, such elevator lobbies being open to the outside are similar to an approach for stairs described in the NFPA Life Safety Code as smokeproof enclosures by natural ventilation. To qualify as naturally ventilated, the code requires that a stair vestibule have a minimum net area of 1.5 m^2 (16 ft^2) of opening in an exterior wall facing an exterior court, yard, or public space at least 6.1 m (20 ft) in width. The idea of this opening is to provide a path for smoke flow from the building to flow outside without going into the stairs. This same approach can be used with elevators. Further, an exterior elevator that is separated from the building as shown in figure 4(b) would also have a similar level of water and smoke protection.

OVERHEATING OF ELEVATOR MACHINE ROOM EQUIPMENT

Loss of cooling can result in loss of elevator service due to overheating of elevator equipment, and precautions need to be taken to minimize the likelihood of such overheating. The elevator controllers located in the machine room are of particular concern because of the high heat generation rates of their solid state components. Most elevator manufacturers specify a maximum machine room temperature in which their controllers can operate. This temperature is usually in the range of 30 to 35 °C (86 to 95 °F). This is the reason machine rooms are air conditioned in most modern buildings. Temperatures in excess of those specified by the manufacturers can reduce elevator reliability or result in elevator malfunction. These malfunctions include cars traveling with open doors and cars going to floors that were not called. The ASME A17 Committee is developing requirements to prevent elevator operation with overheated controllers. For further information about the operation of elevators at high temperatures readers are referred to Ribiberio (1991), Marchitto (1991) and Madison (1991).

Elevators intended to be used for emergency evacuation must have a reliable means of cooling machine room equipment during fires outside the EEES (machine room, hoistway and elevator lobby). Approaches to provide this cooling are:

1. air conditioning equipment dedicated to cooling the machine room,

2. air conditioning equipment for cooling the machine room and other building spaces,

3. equipment specifically developed for cooling the elevator controller, and

4. thermal storage for keeping the elevator controller cool during the fire.

Currently, machine room cooling is either supplied by dedicated air conditioning equipment or by equipment that also conditions other spaces. Thus approaches 1 and 2 have the advantage of using existing methods and equipment. The challenges with these approaches are to provide protection against fire damage and loss of electrical power. Reliability of electrical power is addressed in the next section, but the dedicated equipment of approach 1 uses less electricity than non-dedicated equipment of approach 2. This is an advantage from the viewpoint of reliable power.

Dedicated cooling equipment located in the machine room or outside the building eliminates the possibility of damage to this equipment from fire outside the machine room to the extent that the fire resistive construction withstands the fire. Examples of such cooling equipment include: inexpensive through-the-wall units, and roof mounted condenser units with fan and evaporator coils located in the machine room. Thus approach 1 eliminates the possibility of damage to the machine room air conditioning equipment from fire outside the machine room to the extent that the fire resistive construction withstands the fire.

Approach 3 has been informally discussed by some people interested in the use of elevators during fires. The electronic industry has considerable experience with cooling electronic equipment using a variety of heat transfer fluids including air and water. However, this approach would require manufacturers to develop new controllers incorporating cooling capabilities. Approaches 1 and 2 have the advantage that they use components that are currently on the market.

Approach 4 consists of providing thermal storage for keeping the elevator controller cool during a fire elevator operation. The thermal storage could be in the form of a water reservoir or of a metallic heat sink. As with approach 3, the use of thermal storage would require manufacturers to develop new controllers.

In conclusion, approach 1 which is dedicated air conditioning equipment located in the machine room or outside of the building has the following advantages:

1. it eliminates the possibility of damage to the machine room air conditioning equipment from fire outside the machine room to the extent that the fire resistive construction withstands the fire.

2. it uses less electricity than approach 2 which is an advantage from the viewpoint of reliable power.

3. it has the advantage of using components that are currently on the market.

RELIABILITY OF ELECTRICAL POWER

Reliability of electric power consists of:

a. assuring a source of power and
b. assuring continued distribution of power to where it is needed.

Considerable experience exists in assuring the supply of electrical power for critical functions in hospitals, communication facilities, computer facilities and the like. However, elevator evacuation is a unique application, and the approach to assure reliability of electric power must be appropriate to the application. While it is beyond the scope of this paper to determine what components are needed to assure reliable power for elevator evacuation, the following discussion should be helpful for those making such determinations.

Some components that can be used to ensure reliability of power are fire protected distribution, redundant feeds, power from multiple substations outside the building, and emergency generator sets. Because elevator evacuation can tolerate short duration power loss, uninterruptable power supplies are not necessary. Any consideration of reliability of electric power should consider potential causes of power failure and the consequences of that failure.

Concern about interruption of power supplied by the local utility is not as important for elevator evacuation as it is for many other applications. Applications such as hospitals and many communication facilities operate most or all of the time, and they need highly reliable power for all the time that they operate. Emergency evacuation by elevators is different in that this mode of elevator operation is only needed during a building fire. At most, the EEES would be expected to operate during a fire situation for a few hours over the life of the building [2]. The likelihood of simultaneously having a fire and having the utility company power interrupted is relatively small, provided that the fire and power failure do not have the same cause (for example an earthquake). However, the probability of having a power distribution failure during a fire is relatively high. This is because fire frequently damages electrical distribution within buildings.

The location of electrical components has an impact on reliability of electrical power as is illustrated by the following discussion of feeders in hoistways and emergency generator sets. Electrical feeders located inside a hoistway are protected by the fire endurance of the hoistway. Further, loss of these feeders due to fire exposure in the hoistway has no impact on evacuation, because fire in the hoistway would have already rendered the EEES unusable. Thus, feeders inside the hoistway do not need any special fire protection. If an emergency generator set is at a location remote from the elevator mechanical room, the power feeders from the generator will need fire protection. However, if the generator set is inside the mechanical room, the power feeders will not need any special fire protection for the same reason as the feeders inside a hoistway.

The level of reliability needed and the appropriate components needed to achieve that reliability depend on the particular evacuation system and on the total level of fire protection in the building. Some buildings may only need fire protection for the power distribution system, and other buildings may need emergency generator sets.

EARTHQUAKE PROTECTION

The probability of a fire starting during an earthquake or in the time of emergency following an earthquake may be little different than at other times. Earthquakes often damage utilities including water distribution systems, and earthquakes often place a high demand on the fire departments for rescue and medical aid. It is not surprising that the fires that do start during these times often become large and result in considerable property damage. For the convenience of the readers, a brief description of the current approach to seismic protection is provided. However, this section is in no way intended to be a substitute for the codes, and designers should use applicable codes directly. Part XXIV of the ASME A17.1 Elevator Code (ASME 1993) addresses safety requirements for seismic zones 2 and greater. Seismic zones are defined by the model building codes (BOCA 1993; SBCCI 1988; UBC 1988 and 1993) based on professional judgement. There are some differences between these definitions. The Uniform Building Code (UBC) definition is shown in figure 5 to give the readers an idea of these zones. The UBC zones were selected because they were used in the earlier FAA study (Klote et al. 1994).

In zone 2, strengthening of rails and other structural elements is required. In seismic zones 3 or greater, a major concern is a collision between the elevator car and the counterweight[3] that has been dislodged from its rails. The rails and other structural elements are strengthened to withstand a horizontal acceleration of ½ *g* or greater[4]. Additionally, if a seismic switch senses such an acceleration, elevators are put into the emergency mode described below. For moving cars, the emergency mode consists of an emergency stop, followed by motion away from the counterweight at low speed to the nearest available floor, open doors and shut down. Cars not moving, when an earthquake is sensed, remain inactive. Further, this emergency mode is also activated if a displacement switch indicates that the counterweight has been derailed.

As an example of the accelerations that can occur during earthquakes, figure 6 shows maximum horizontal accelerations at ground during the Northridge earthquake (EQE 1994). There were many locations during this earthquake that had accelerations at ground level lower than ½ *g*. The acceleration that activates a seismic switch is that at the seismic switch, not that at ground. Typically, flexible structures (for example steel structures) will encounter lower accelerations than those at ground. A seismic switch in a flexible structure would be expected to encounter lower accelerations than those at ground. Thus during an earthquake, there are many locations where accelerations are less than ½ *g*, and the elevators will continue to operate.

The approach described above requires that elevators be able to operate under accelerations up to ½ *g* and takes the elevators out of service in an orderly manner when higher accelerations are detected. While it is theoretically possible to develop elevators that could operate through much higher accelerations, development of such elevators would be a large effort, and there is no assurance that such elevators would be affordable. Further research is needed in this area. The earthquake requirements of ASME A17.1 only apply to new buildings. It is recommended that this approach to seismic protection be used for EEESs in seismic zones 3 and greater.

AVAILABILITY OF ELEVATORS

When an elevator in an EEES is out of service for scheduled or unscheduled maintenance, it cannot be used for evacuation. If there are many elevators in a building, the number of elevators used for evacuation can be selected to allow for a percentage that may be out of service.

In buildings with only one elevator, the above redundancy approach to assuring availability is not possible. Two other approaches to maximize availability are off hours maintenance and short turn around repairs. Scheduled maintenance can be done during off hours when the building is shut down or in a low state of activity. Maintenance contracts can put a premium on fast repair for unscheduled maintenance. When an elevator is out of service, a sign should clearly indicate this so that valuable evacuation time is not wasted waiting for an elevator that can not come.

ELEVATOR CONTROL

In additional to normal elevator operation, there are two other modes of operation: elevator recall and firefighters operation. Upon alarm of a smoke detector in an elevator lobby, the elevator goes into a recall mode in which the car is moved to the exit landing and removed from service. In the event of a fire on the exit floor, the elevator goes to an alternate floor and is taken out of service. ASME A17.1 refers to this recall as *Phase I*. The landing to which the car is moved is the exit floor or an alternate floor if smoke was detected on the exit floor. After recall, firefighters can operate the elevator, and such operation is under the control of the firefighter inside the elevator. ASME A17.1 calls firefighters operation *Phase II*.

Some approaches that might be used to control elevators during an elevator emergency evacuation are:

1. normal use (with less sensitive detectors),
2. Phase II, and
3. an evacuation mode.

Normal Use

In an EEES, the elevator (including the elevator lobbies, hoistway and machine room) is protected from the fire effects as discussed above. Thus the elevator is operating in an environment without fire. There is no physical reason why an elevator so protected cannot continue to operate normally provided that the smoke detector in the elevator lobby does not go into alarm. As stated earlier, an alarm from this smoke detector will result in Phase I elevator recall. Typical smoke detectors are very sensitive, and they can be put into alarm by a quantity of smoke so small that a person might not notice. Such small amounts of smoke may enter the lobby when lobby doors are opened for evacuation. Such low levels of smoke are not a tenability concern. To avoid unwanted elevator recall, the smoke detectors in the elevator lobbies that initiate Phase I operation can be replaced with less sensitive detectors such as heat detectors.

Using normal operation during evacuation is not appropriate for evacuation of large numbers of people, where a full elevator car might stop at every floor on its way to the exit floor. However, normal mode would be appropriate for evacuation of small numbers of people, such as a few people with disabilities in an office building or the small number of workers in an FAA air traffic control tower. The computer program for elevator evacuation (ELVAC) by Klote, Alvord, Levin, and Groner (1992) can be used to estimate time for elevator evacuation.

Phase II

The fire service, using Phase II operation, could also use elevators for evacuation of small numbers of people. Further, it is possible that building personnel could operate the elevators under Phase II for evacuation before the fire service arrives. Use of Phase II by non-fire service people would require that the elevator operators be trained and that the general approach not adversely affect fire service operations. Phase II service must only be provided by people who are aware of the location and extent of the fire and of its potential for endangering people using elevators.

Evacuation Mode

Development of an elevator control mode for evacuation of the general population would require development of a specific control concept, a study of people movement during such fire evacuations, and modification of ASME A17.1 to accept this new control mode.

Some of the features that could be considered for this fire evacuation mode are:

1. ability to import signals from other building systems (fire alarm, HVAC, electric power distribution, etc.),

2. ability to predict fire growth and smoke spread by computer simulation, and

3. ability to adapt evacuation strategy to the fire situation using data from features 1 and 2.

The capabilities of feature 3 could include the ability to prioritize floors for evacuation and the ability to cancel calls from a floor with untenable conditions in the elevator lobby. This evacuation mode has the potential to be a significant part of people movement in building in fire emergencies.

Development of an elevator control mode for evacuation would require understanding of people movement during a fire. Such movement is much more complicated than that during a fire drill. The fire service is entering the building as the occupants are leaving, and some occupants travel against the flow of traffic to rescue others or the get belongings. Paths that are blocked by fire or smoke cannot be used. To some extent, figure 7 shows this complexity of people movement during fire.

One significant means of passenger protection is to minimize the number of ways in which the elevator equipment can be shut down or taken out of service during emergency periods. Elevator control systems generally incorporate logic which causes elevator stoppage when any number of malfunctions occur. In normal service, this is a valuable means of reducing passenger risk or discomfort. In a fire emergency, a shutdown may present more of a hazard to building occupants than continued operation of a fire elevator system at reduced performance levels.

To reduce this source of hazard, elevator operation may be altered in emergencies even beyond today's Firefighters Service levels. The definition of changes to make will require an analysis of the risks and benefits associated with each change. Certain safety interlocks might be disabled. For example, if a hoistway door interlock shows open above the car when the car is heading toward the lobby or recall floor, it might make sense to continue operation, rather than to shut down and leave the passengers stranded. Clearly, stopping a distant elevator will not protect someone at the open door, while it would put the elevator occupants at increased risk. Similar evaluations would have to be considered for other safety chain components such as the buffer switch or gate switches.

COMMUNICATIONS

The development of a fire elevator system needs to take into account human behavior so that building occupants will be willing and capable to operate the system in an emergency. Human consideration studies concerning elevator evacuation indicate that occupants waiting for elevator will need communications to let the people or system controlling the elevator know that they are waiting and to be informed of the status of evacuation elevators (Groner and Levin 1992; Levin and Groner 1994).

The categories of communications that may be needed are:

1. human to human,
2. human to machine,
3. machine to human, and
4. machine to machine.

Communications are already in place for systems used by the fire service. Communications for systems intended for evacuation do not exist, and the development of such communications would need to take into account people movement during a fire.

CONCLUSIONS

1. It is feasible to design an emergency evacuation elevator system for evacuation of a small number of people (e.g. a few people with disabilities in an office building, air traffic controllers in a control tower, and occupants of luxury apartment building). Such an application would require protection of elevator equipment such that it would be operating in an environment without fire.

2. An emergency evacuation elevator system must include building construction protection for elevator passengers, people waiting for elevators, as well as, for elevator equipment. This protection consists of protection from heat, flame, smoke, water, overheating of elevator machine room equipment, and loss of electrical power.

3. It does not appear that an emergency evacuation elevator system for evacuation of a large numbers of people is practical at this time. Such a system would have a high level of complexity including sensors, evaluation of fire conditions, elevator control algorithms, and complex and unpredictable patterns of people movement. The application of elevator evacuation for small numbers of people is much simpler than elevator evacuation of large numbers of people. Thus a system for a small number of people is the next logical step. Based on what is learned in this step, a more complete system might follow.

NOTES

1. Even buttons that are not heat sensitive can short out when subjected to the elevated temperatures of a fire.

2. An EEES may also operate during fire drills and testing.

3. A counterweight is a mass that is moved up and down in the opposite direction from the elevator car to conserve energy.

4. g is the acceleration of gravity, which is about 9.8 m/s^2 (32 ft/s^2).

Table 1. Water flows of some suppression & firefighting devices

Device	L/min	gpm
12.7 mm (0.50 in) Sprinkler Head	67-200	17.7-53
29 mm (1.125 in) Solid-Stream Hose Nozzle	950	250
Manually Held Hose with Spray Nozzle	40-1150	11-300
Master Flow Devices	1900-7500	500-2000

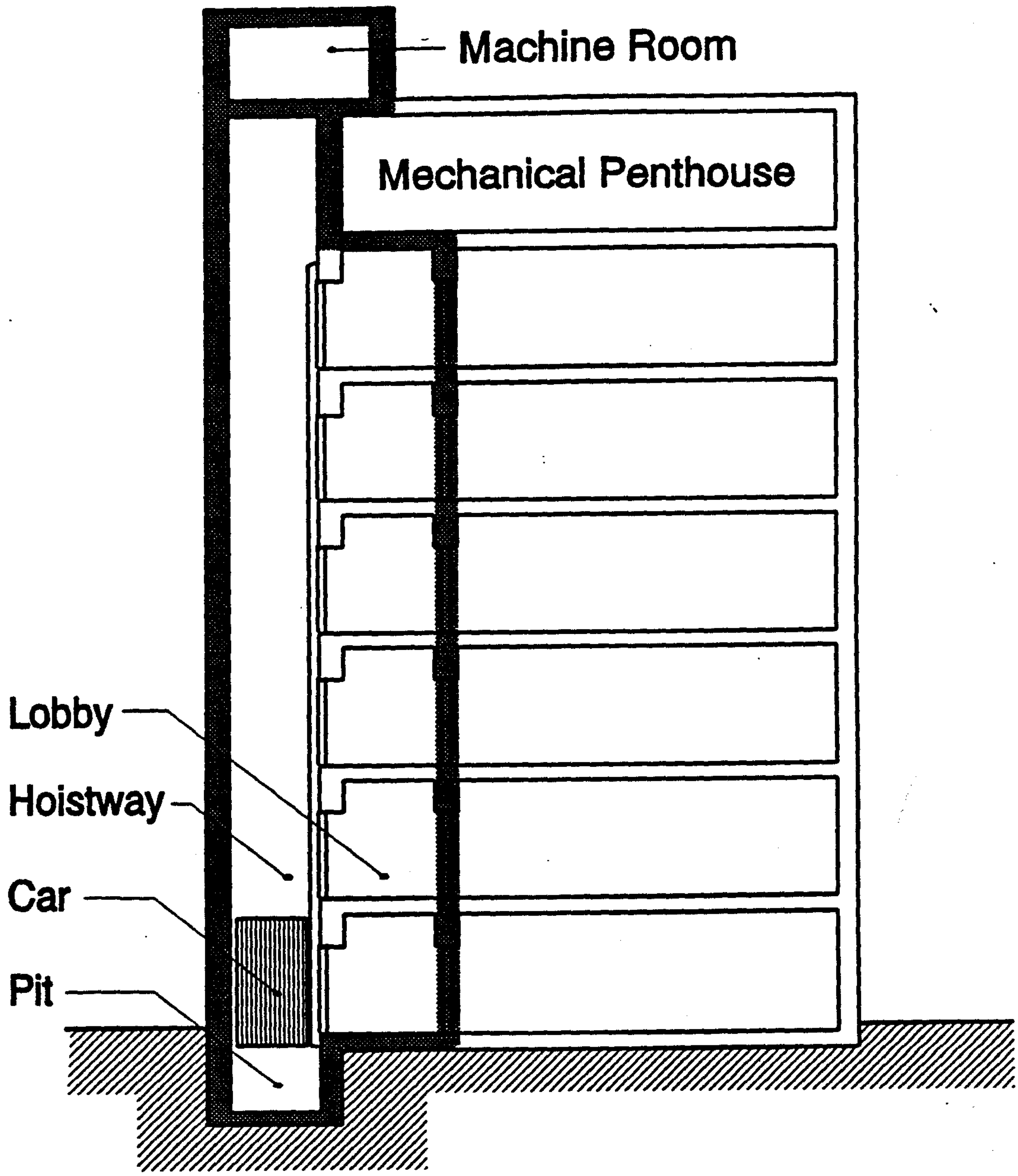


Figure 1 Elevator system including elevator equipment, machine room, hoistway and elevator lobby

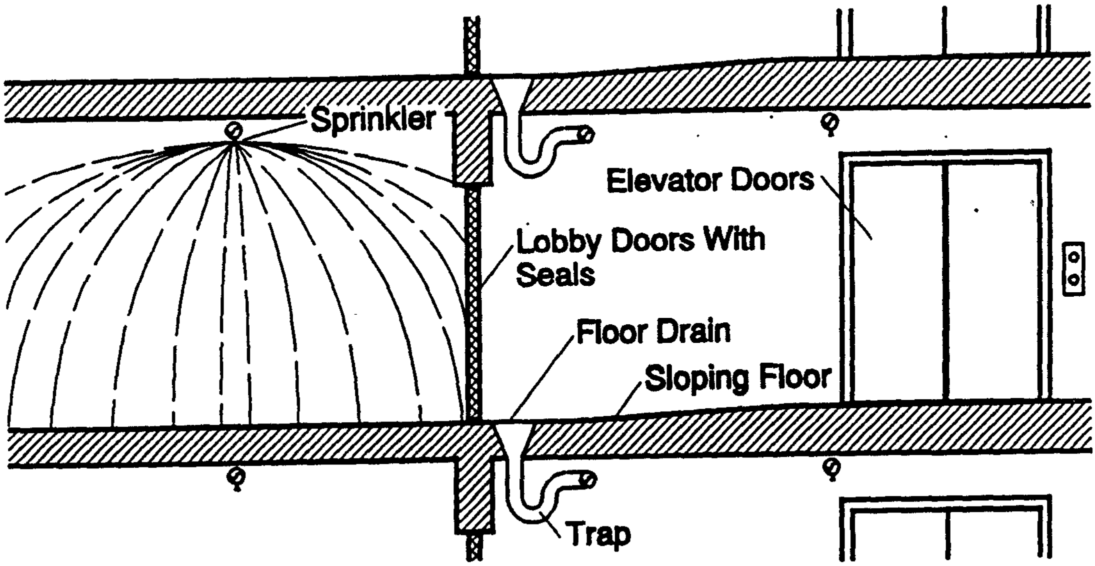


Figure 2 Conceptual use of sloping floors, floor drains and doors with seals in an effort to prevent water flow into hoistway

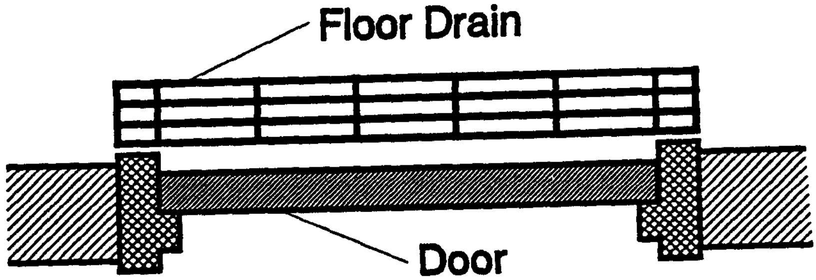


Figure 3 Use of trench floor drain to minimize water flow past drain

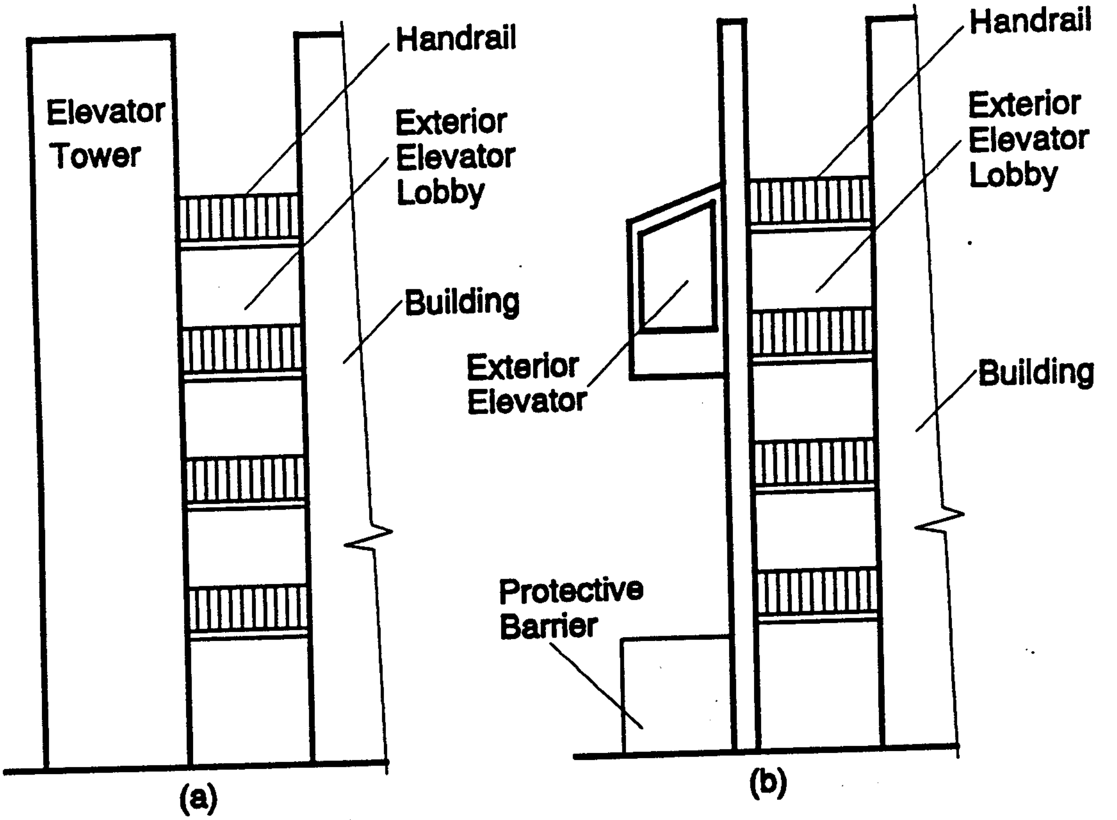
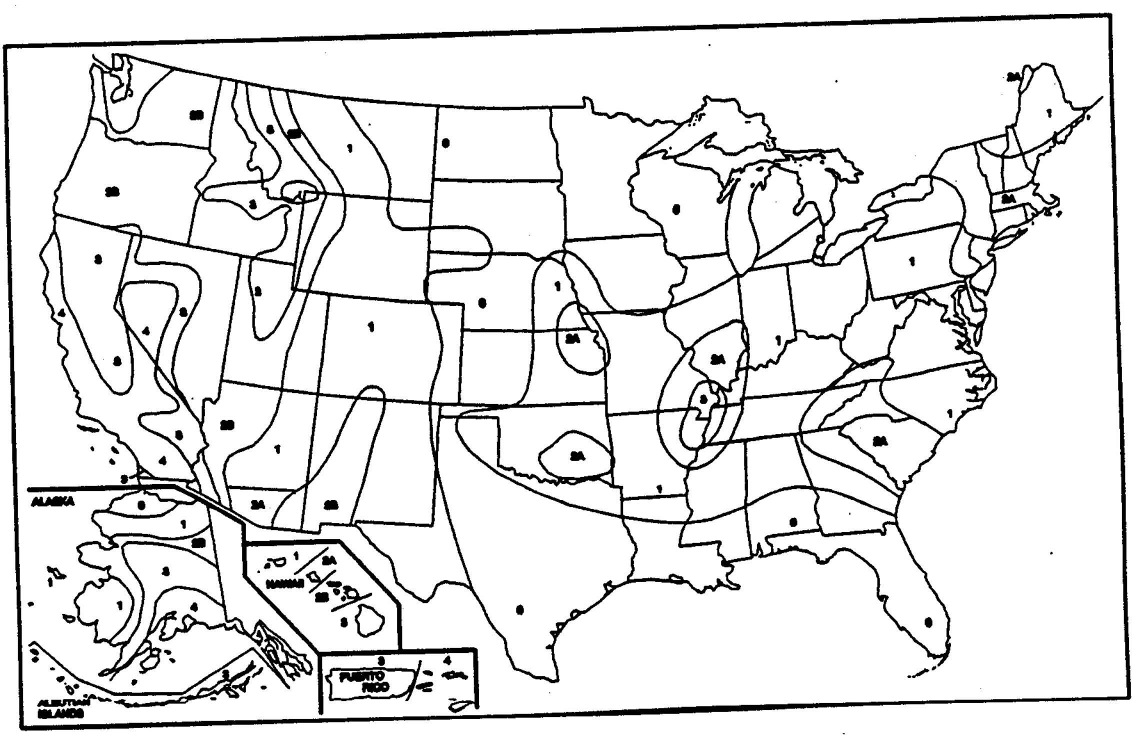


Figure 4 Elevators with exterior lobbies: (a) elevator in tower separated from building, and (b) exterior elevator separated from building.



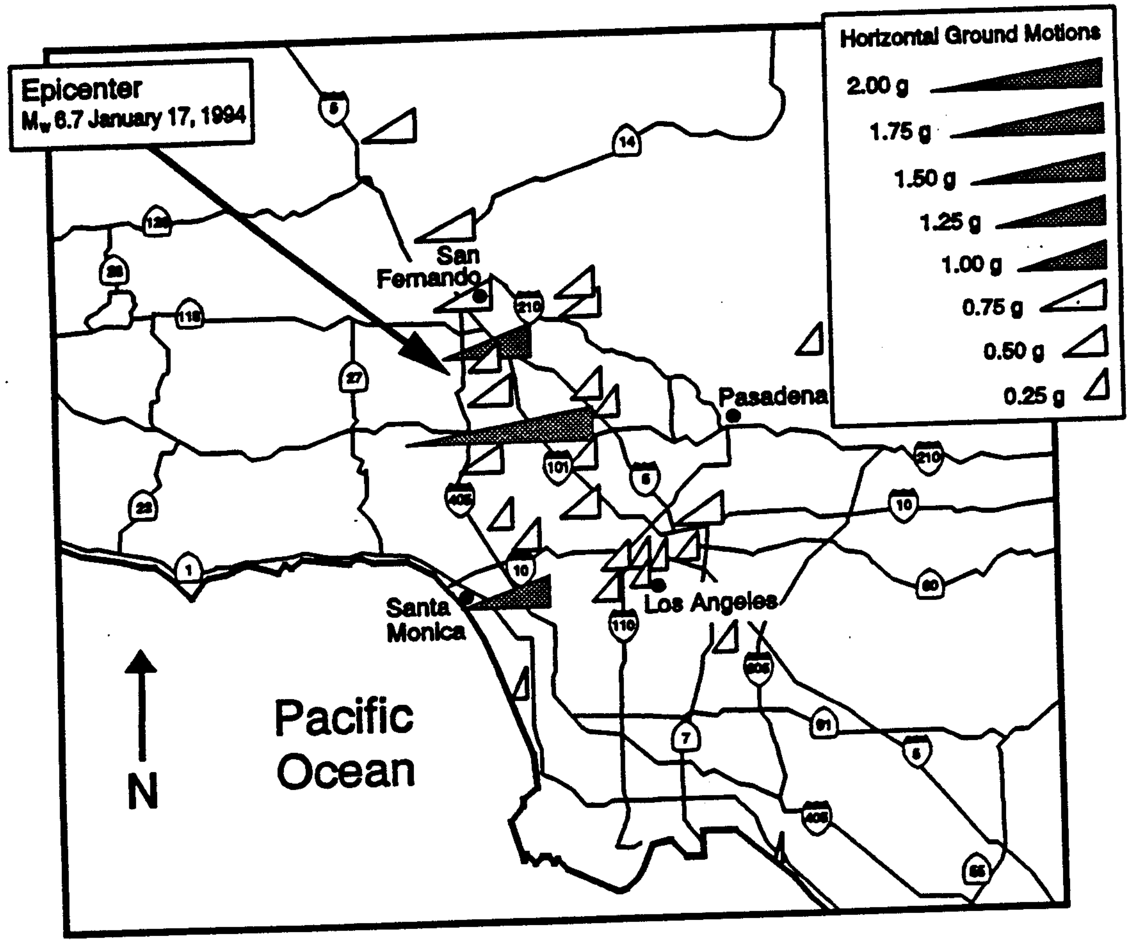


Figure 6 Peak horizontal accelerations at ground level during the Northridge earthquake (EQE 1994)

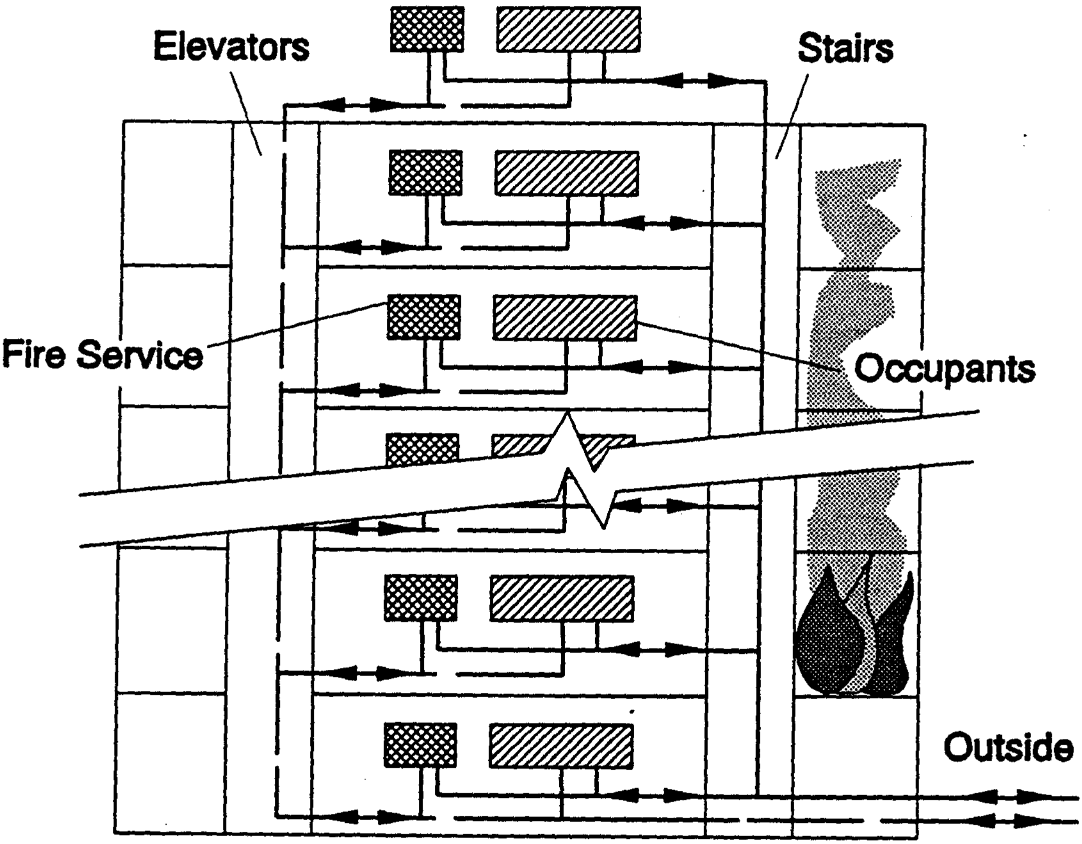


Figure 7 Diagram of people movement during a fire emergency

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