Protected Elevators and the Disabled

Richard W. Bukowski, P.E., FSFPE
NIST, Building and Fire Research Laboratory
Gaithersburg, Maryland 20899 USA

It was 1989 and I was giving a talk to local federal agencies on the newly-released HAZARD I software and its promise for performance-based design for fire safety. After the talk several attendees came up to talk to me, including a gentleman in an electric wheelchair. He told me that he worked on the 10th floor of a nearby, high-rise office building and that when he first came to work there the safety officer did not really know what to do with him. He was instructed that in case of a fire evacuation, he was to go to the stairway. If there was someone there to open the door (he was quadriplegic and could not grip nor turn the knob) he should proceed onto the top landing. Otherwise he should wait at the stairway door for assistance. He told me that it was clear to him that they wanted to know where to go to collect the body.

It was just the next year, 1990, when the Americans with Disabilities Act (ADA) was passed to provide equal access to public buildings for all Americans. The objective of the ADA regulations was to permit people with disabilities access to the places where we live, work, and play with little thought of how they would get out in case of emergency. Fifteen years later we are still addressing this important issue.

The purpose of this article is to present the issues that need to be addressed in the development of elevators that can be used in fires to safely evacuate occupants, particularly those with limited mobility that affects their ability to use stairs.

Accessibility

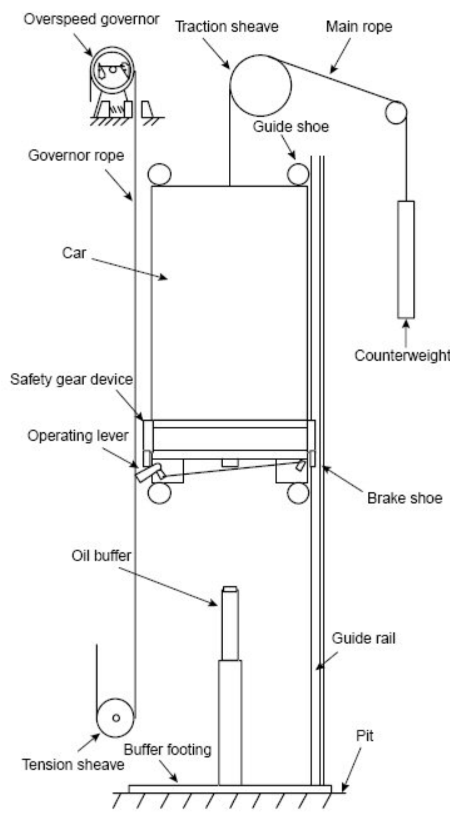
The ADA accessibility requirements are intended to result in public buildings that can be accessed and used by people with a range of limitations including vision, hearing, and mobility. The guidelines provide for signs that include Braille markings, strobe lights and other visible warnings, and doors with powered openers that are wide enough for wheelchairs. Smaller changes in elevation require ramps or platform lifts that eliminate barriers to wheelchair users.

Accessible elevators are required by the Building Codes and ADA requirements

Building codes contain special provisions for an accessible means of egress that either leads out of the building (including through a horizontal exit) or to an area of refuge, which may be served by an accessible elevator. Elevators are the primary means of routine ingress and egress for all occupants in most buildings and under most conditions, except during fires. Elevators are posted with signs warning that they are not to be used during a fire. Occupants and firefighters are relegated to stairways that may have only the capacity to carry the occupants from a few floors at a time, without the counterflow of firefighters trying to move up carrying equipment. And what about those people with disabilities (including both disabilities as defined by the ADA and those occupants who needed assistance to exit long distances) who now represent 6% to 10% of the occupant load?

Elevator Safety

While lifts for goods have been in use for thousands of years it is only since the development in 1854 of the automatic safety brake by Elisha Graves Otis that the passenger elevator became a reality. Often cited as the safest mode of human transportation, millions of people ride elevators daily without incident. This laudable safety record has been achieved through the pervasive safety culture of the elevator industry and the committees who write the safety codes that govern the design, installation, operation, maintenance, and inspection of passenger elevators. In the U.S., this is the American Society of Mechanical Engineers (ASME) A17.1 Committee.



Safety brakes located under the car are triggered by an overspeed governor in the machine room (drawing courtesy Mitsubishi)

The issue addressed by Otis' brake was a failure of the lifting rope causing the car to fall. Doors or gates on the landing opening and car prevented people from falling out or getting their body parts caught between the car and shaft wall. Additional improvements in safety and reliability over the years have led to the admirable safety performance of modern elevators.

A fundamental industry assumption is that entrapment in an elevator is a *fail-safe* condition and a special system has been implemented to ensure that trapped passengers can be extracted quickly and safely. Every elevator is equipped with a telephone to summon help, and every elevator maintenance contractor has technicians on call 24/7 to respond. Even in major incidents such as the 2003 blackout in the Northeast U.S. and Canada, hundreds of entrapment calls were cleared in only a few hours. The acceptance of temporary entrapment leads to the common arrangement that, if the many safety controls on an elevator sense something is going wrong, the elevator controller shuts the system down. In recent times it has been recognized that there are two conditions where entrapment is not a safe condition – during an earthquake or during a fire.

Door Restrictors

A more recent safety device required on passenger elevators is called a door restrictor. These are devices that restrict the ability of a passenger to force open the car door unless the floor of the car is within at least 75 mm but not more than 450 mm (3 in to 18 in) above or below the level of the landing. Passengers have been known to force open the doors and fall down the hoistway if the car became stuck or even to “joyride” on the top of the car, especially since the roof hatch began to be locked from the inside. These door restrictors have been successful at eliminating many injuries and deaths (according to decreases in reports of deaths and injuries from falling down shafts all of which occur in elevators not retrofit with door restrictors), but became an issue in the WTC Towers on September 11, 2001. There were several cases of occupants entrapped in cars that were not close enough to the landing to release the restrictor. The industry is now studying ways of releasing restrictors in an emergency that would not lose their safety function in other circumstances.

Elevators and Earthquakes

The vertical and lateral motions associated with a seismic event can affect the operational safety of an elevator. In an earthquake it is possible for the elevator or its counterweight (for traction elevators) to be jarred out of their guide rails. The most dangerous result is where the car runs into the counterweight. Thus the elevator code requires that all elevators located in Seismic Zone 2 or greater are designed with greater clearances, retainer brackets where the car and counterweight attach to the rails and with seismic switches set to activate at an acceleration of 0.15 g. Activation of the switch causes the car to stop, and move in the direction away from the counterweight to the next available landing where the doors open and the car is locked out of service until the system is manually reset. This can only be done from the machine room by an elevator technician after determining that the system can operate safely [ASME 2004].

Elevators and Fires

Beyond the direct impacts on the safe operation of the elevator, there are several interactions between the elevator system and the building during a fire. One is the hoistway as a vertical shaft spreading smoke through the building. Most landing doors open horizontally and are far leakier than other types of doors. The shaft itself is subject to what is known as *stack effect*, which is a vertical airflow resulting from differences in indoor to outdoor temperatures and the height of the shaft. This shaft flow draws air into or out of the shaft through the landing doors depending on the position of the landing relative to the *neutral plane* and the direction of the shaft flow. [Klote and Milke 1992]

Stack effect flows are driven by differences in indoor and outdoor temperatures with upward flows in winter (outdoors colder than indoors) and downward in summer (outdoors warmer than indoors). The greater the difference, the greater the flow; therefore stack effect is larger in more extreme climates and for taller shafts. Even without a fire, stack effect flows can cause problems in tall buildings, resulting in strong flows and noise at landing doors near the top and bottom of the shaft. These flows can cause jamming of landing doors and may require seasonal door adjustments by elevator technicians. During a fire, stack effect flows can carry smoke and fire gases to remote parts of the building. For example, in the MGM Grand [Fire Journal 1981] and DuPont Plaza [Klem 1987] fires which both occurred near the ground floor level, there were fatalities on upper floors due only to smoke carried up elevator shafts by stack effect flows.

It is important to note that both examples occurred in unsprinklered (at least in the area of the fire) buildings. A recent analytical study by the author [Bukowski 2005] showed that stack effect flows sufficient to create safety problems on upper floors would not be likely in fully sprinklered buildings (with working sprinkler systems) or in buildings not tall enough (less than 75 feet under less than extreme weather conditions) to produce strong shaft flows. In some mission critical applications it might be appropriate to provide for the small likelihood of a failure of the sprinkler system. [Bukowski 2005]

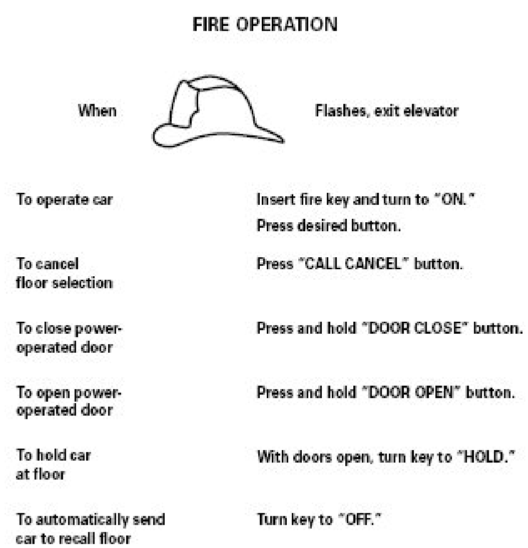
Elevators and Water

Water from fire sprinklers or hose streams can result in safety problems for elevators during fires. Water can enter the hoistway and cause electrical shorts in safety controls causing them to fail. Water on the drum of the elevator machine can cause the car to slip although the safety brake would stop a car from overspeed or falling down the shaft.

To address this situation, elevators protected by sprinklers in the hoistway or machine room are equipped with a shunt breaker to deenergize main power before a sprinkler activates. Connected to a heat detector that would activate before the sprinkler, the shunt breaker activation removes power and stops the elevator, but can result in entrapment. The shunt breaker will not protect the system from water from sprinklers or hose streams at landings leaking into the hoistway.

Firefighters Emergency Operation

In the mid-1970's the elevator industry developed *firefighters emergency operation* to improve the safety of the system during fires. Smoke detectors are installed in the elevator lobby within 6.4 m (21 ft) of any landing door on each floor. The smoke detectors protect the elevator system by detecting any encroachment of the fire and triggering *Phase I* recall. Here the elevator cars are sent immediately to the designated landing which is generally the level of exit discharge. There the elevators stop, the doors open, and the elevators are locked out of service. If a fire is detected on the designated landing, the cars are sent to an alternate floor.



A fire operation instruction panel is required in every elevator fitted for this service (courtesy ASME)

Upon their arrival, firefighters are able to place individual cars back into manual service by use of a *firefighters key*, in what is called *Phase II* operation. While operating in this mode, a light on the car control panel marked with the symbol of a firefighters hat is illuminated. In this mode, the controls in the car operate in a special manner designed to protect the firefighter operating the car. For example, the car will move to a selected floor but the doors will not open. Depressing the *door open* button opens the doors but only as long as the button is depressed. Thus, if smoke enters the car and the firefighter reacts by jumping back, the door will close.

Additional smoke detectors installed at the top of the hoistway and in the machine room monitor the system integrity. If activated, the *firefighters hat* light in the car begins to flash warning the operator that the system may become erratic and to move to a safe location.

It is generally accepted by the experts that as long as the system is operating in normal service (before Phase I activates) the elevators are safe to use, even if there is a fire in the building. Such a fire would need to be sufficiently remote from the elevator lobby so as to not have activated a lobby smoke detector triggering Phase I recall.

Elevator Assisted Egress

In the wake of the September 11, 2001 attacks on the World Trade Center Towers, the concept of protected elevators for occupant egress and for fire service access from tall buildings received new interest. The primary issues are the need for more rapid egress from very tall buildings and additional capacity to support simultaneous evacuation of occupants who were now reluctant to await a phased evacuation. Since even minimal additional egress capacity by stairs has a very large cost penalty in lost leasable space, use of the elevators that are already present is a logical approach. But arguably the most important issue is to provide for self-evacuation of people with disabilities and those for whom evacuation down long stairways presents significant difficulties.

1993 and 2001 WTC Evacuations

In the 1993 bombing at the World Trade Center, it was found that many more occupants experienced difficulties than just those with traditional disabilities. People with temporary disabilities such as broken legs, people with asthma, pregnancy, or obesity all reported difficulties in mobility or stamina that limited their own evacuation abilities and that of others behind them in the stairways.

Recently Bukowski and Kuligowski [Bukowski and Kuligowski 2004] benchmarked evacuation times for egress systems designed in accordance with modern building codes. They found for office occupancies that it requires about 5 minutes to empty a floor and ½ to 1 minute per floor to egress down stairs without delays for queuing, congestion, or resting (total evacuation times would further need to include pre-evacuation times). Based on this benchmark, the World Trade towers would have required 1 to 2 hours (without congestion delays). Observed evacuation time in the 1993 bombing and total evacuation time in 2001 estimated for a full occupant load of 25,000 by state-of-the-art egress models that included queuing and congestion was about double the best case times or about 4 hours. [Fahy and Proulx, 2002]

One crucial observation from 2001 involves the evacuation of 2 World Trade Center (South Tower) in the 16 minutes between the aircraft strike on the North Tower and the strike on the South Tower. Having seen what happened to the North Tower, many of the occupants in the South Tower decided to evacuate. Since their building was undamaged many used their normal procedure of elevators. NIST estimated that about 3000 people evacuated from above the (eventual) aircraft strike zone using the stairs or elevators [Averill 2005]. After the South Tower was hit NIST estimated that only 18 additional occupants escaped from above the impact region.

Protected Elevators

NIST has been working on the development of protected (also called hardened or Phase III) elevators in cooperation with the elevator industry, fire alarm industry, and key codes and standards organizations in the hope of developing the needed technology and code provisions to put these into practice. This work is making slow but steady progress and should be ready for demonstration in a year or two.

Early work focused on the issues discussed previously including water sensitivity and protection of the elevator system from the fire. Enclosed and (real time) monitored lobbies would provide a protected space for occupants to await the elevator as well as an additional layer of passive protection for the hoistway. Information displays and communication to the fire command station would provide reassurance to those waiting, and direct access to a stair would provide a second way out for those capable of using it. It is expected that people with disabilities would be given priority access to the elevator cars. [Bukowski 2003]

An important benchmark of elevator evacuation performance can be seen in the typical design objective for elevator systems. The number, capacity, and speed of elevators are typically designed to move 15 % of the total occupant load of the building in 5 minutes. This means that a typical system utilizing an efficient evacuation protocol (e.g., ignoring hall and car calls and operating in a shuttle mode between a 3-floor fire zone and the level of exit discharge) would be capable of evacuating the entire occupant load of 3 floors of a 20 story building or 6 floors of a 40 story building in 5 minutes.

Layers of Protection

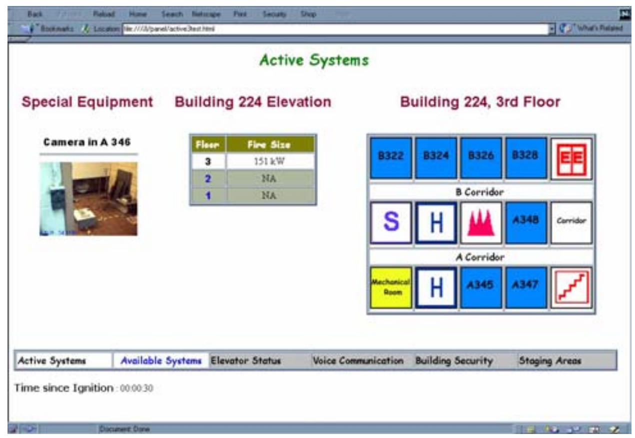
In order to protect the elevator system from compromise by the fire and provide a protected space in which to wait, protected elevator systems would incorporate enclosed lobbies on each floor above the level of exit discharge and would be found in fully sprinklered buildings. In a 1993 report done for GSA, Klote et al [Klote 1993] found that separate staging areas were not needed in fully sprinklered buildings since the entire building remains tenable as long as the sprinkler system is operational and the fire is not shielded from the sprinkler. The addition of protected lobbies adds an additional layer of protection, not only for the elevator, but also for occupants awaiting the arrival of the elevator. This is particularly important for occupants who cannot use the stairs and who need to be protected in place until they can egress using the elevators or be assisted by others.

Hoistway pressurization

Another function of the lobby is to prevent smoke from exposing people waiting for the elevator as well as to prevent smoke from entering the hoistway. While the lobby enclosure can be made smoke tight, the door will be opened repeatedly as occupants enter, so a pressurization system would be needed. Based on prior NIST work, it is important to minimize pressure differences across the landing door that might lead to jamming [Klote 1982]. Thus, a system where the hoistway is pressurized and a positive pressure of the lobby (with respect to the rest of the floor) is produced by leakage through the landing door, will provide the desired result. Pressurization of the order of 12 Pa (0.05 inches of water) is a reasonable design value [Klote and Milke 1992].

Real-Time Monitoring

An important layer of protection is the ability of the fire service to monitor the conditions within the lobbies, hoistway and machine room in real time to ensure that there are no threats to people or systems. These monitoring functions will be carried out by the fire alarm system and displayed in the fire command station on a special fire service display. These displays comply with National Fire Protection Association (NFPA) and National Electrical Manufacturers Association (NEMA) standards so that they are consistent in form and operation across all equipment manufacturers. All conditions and functionality critical to the safe and reliable operation of the system are monitored.



Conditions in lobbies and status of elevators can be displayed in real time in the building fire command station

Information systems

Crucial to the safety and peace of mind of occupants using the system is the provision of real time information on the system status. Displays in the lobbies will show waiting occupants that the elevators are in service and how long they will need to wait to be served. People who are capable of using the stairs will be free to do so if they feel the wait is too long, either taking the stairs to a lower level to reenter and await an elevator, or all the way to the street. Should it be necessary to take the elevators out of service, the lobby display would indicate that those capable should use the stairs and others could communicate directly with the fire command station to request assistance.

Evacuation mode

Elevators are the most efficient at moving people in "shuttle mode" where the times associated with deceleration, loading, and acceleration are minimized. Thus it has been proposed to establish an evacuation mode of operation that will optimize system performance.

In general, evacuation mode would be triggered on a general alarm in the building. All elevators would be captured and returned to the level of exit discharge to unload any passengers. An automatic message in the elevators would explain that there is an emergency reported in the building and the elevators are being put into service to assist in evacuation. Signs on the discharge level would warn people not to enter. One (pre-designated) car would be held for fire service access and the rest would go into evacuation service; moving to the first priority floor group (fire floor, one above and one below). Destination buttons in the car (Car calls) would be disabled and the buttons that summon the elevator to a floor (hall calls) would register where occupants are awaiting the elevator for egress but would not direct service.

Once the first priority group of floors is evacuated, the system would serve additional floor groups in a logical order until all occupants have been evacuated. If Phase I recall is activated at any time in the process, evacuation mode would end, but cars could be put into Phase II service if the fire service considers it safe to do so.

Mobility Impaired Occupants

The evacuations of the World Trade Center towers in 1993 and in 2001 provided some common lessons regarding egress of people with impaired mobility. First, there are more people who have difficulty in moving long distances down stairs in very tall buildings than those who usually come to mind. People with temporary disabilities (broken legs/sprains using canes or crutches, pregnant, or those injured in the initiating event), asthmatic or other respiratory conditions, obese or other conditions that limit stamina, all have been observed to require extra time and frequent rest stops. In the WTC evacuation 6% of the survivors reported having some pre-existing condition that limited their mobility. If you add to that, people injured by the initiating event or just after beginning to evacuate the number could be higher. Even women in high heels and men in new dress shoes were reported to have caused backups in stairs by moving more slowly [Averill 2005]. While 6% is not unreasonable for traditional disabilities, designing for a disabled population of 10% would be conservative for many buildings. In some buildings such as residences for the elderly, the proportion could be considerably higher. A recent paper [Sekizawa 2004] mentions a fire in Japan where 80% of the elderly occupants were unable to evacuate down the stairs and used the elevators successfully.

This smokeproof elevator is installed at an Italian residential facility for mobility impaired people to provide access and egress. The glass hoistway enclosure permits the fire service to determine if the elevator is in use. (courtesy CNR)

In the September 11, 2001 evacuation, first responders moving down stairs in WTC 1 after the collapse of WTC 2 found 40 to 60 mobility impaired occupants on the 12th floor where they had been moved. About 20 of these occupants were being assisted down the stairs just prior to the collapse of WTC 1. It is unclear how many of these or the 20 to 40 others who had been staged on the 12th floor perished [Picciotto 2002].

Conclusions

Protected elevators that can provide for unassisted egress of occupants with disabilities can result in significant reductions in total evacuation times for tall buildings and more efficient flows in stairs by people capable of using them. Considering the optimum flow rates down stairs of 30 seconds per floor without congestion or the need to stop and rest, elevators designed to move 15% of the occupant load in 5 minutes could evacuate 60 floors (including wait times) in the same time it takes for occupants to descend 60 floors, or 30 minutes.

By reducing stair flow impediments through the use of elevators for up to half the population it should be possible to totally evacuate buildings of any height in the order of 30 minutes. Those using the elevators would include all people with disabilities and those highest in the building, while the stairs would be used by the most physically capable from the lower floors. This approach is used by the 88-story Petronas Towers in Kuala Lumpur, Malaysia where a total evacuation time in a drill was reported to be 32 minutes, utilizing a combination of stairs and elevators. [Arliff 2003]

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