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International Applications of Elevators for Fire Service Access and Occupant Egress in Fires

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Current work with RJA includes projects worldwide that involve code compliance including performance-based design, fire hazard and fire risk analysis, fire alarm systems, mass notification systems, fire modeling, transportation systems, and fire protected elevator systems for egress and fire service access.

"Despite the absence of technical standards, tall buildings worldwide are incorporating elevators for occupant evacuation to achieve significant reductions in total evacuation times. Common requirements include emergency power, water protection, and hoist ways with protected lobbies with direct access to an exit stair."

For more than two decades, the elevator industry has told us that elevators may not be safe to use during a fire. The Safety Code for Elevators and Escalators [1] as well as building codes have required signs in every elevator lobby to advise occupants to use the stairs and not elevators in case of fire. Elevators are typically equipped with a special fire service operating mode with manual control by a firefighter in the car, but US elevators are not arranged to support high-rise firefighting operations as they are in England and other countries. The main concern of the elevator industry is that elevators may come to a stop for any number of reasons, entrapping the occupants where they might be exposed to smoke before the fire department can affect a rescue.

Background

Following the World Trade Center attacks of September 11, 2001, it became clear that evacuation of a very tall building can take far too long (evacuation of the WTC towers with the design occupant load was estimated to require 4 hours). Such evacuations also involve significant issues including fatigue, people with pre-existing disabilities or injuries received in the initiating event, and unfamiliarity with the egress stair system. Similarly, fire service access up stairs while carrying needed equipment was time consuming and exhausting.

Since 2004 the National Institute of Standards and Technology (NIST), American Society of Mechanical Engineers (ASME), the elevator industry, and other interested parties have been developing requirements and procedures for fire service access elevators and occupant self-evacuation elevators that will be safe to use in fires. However, the obvious benefits for timely evacuation of very tall buildings, the provision of an effective evacuation means for people with disabilities, and the ability to provide for egress from assembly spaces high in buildings without the need for increased stair capacity (at significant cost in reduced rentable space) through the entire building, all led to the application of egress elevators in numerous tall buildings throughout the world before the requirements and procedures under development could be promulgated.

During the development process, numerous technical papers were presented at international conferences by participants (and especially this author) discussing approaches that were under discussion and were likely to be incorporated into the final regulations [2, 3, 4, 5]. These papers became the basis for many of the arrangements that were incorporated into buildings as performance based design elements. Some existing buildings even incorporated elevator evacuation protocols that were shown to reduce total evacuation times. The result is many systems in use that do not incorporate all of the features deemed necessary by the experts and which are one-of-a-kind arrangements that may lead to confusion as the standardized systems are put in place.

...elegant

"I also admire Dubai's Burj Khalifa. It goes against all my sustainability values but it is such an elegant statement, as well as technical achievement, that I can't fail to be fascinated by it."

Peter Jackson, past chairman of the United Arab Emirates Architectural Heritage Society quotes in Cityscapes, Apr/May 2010

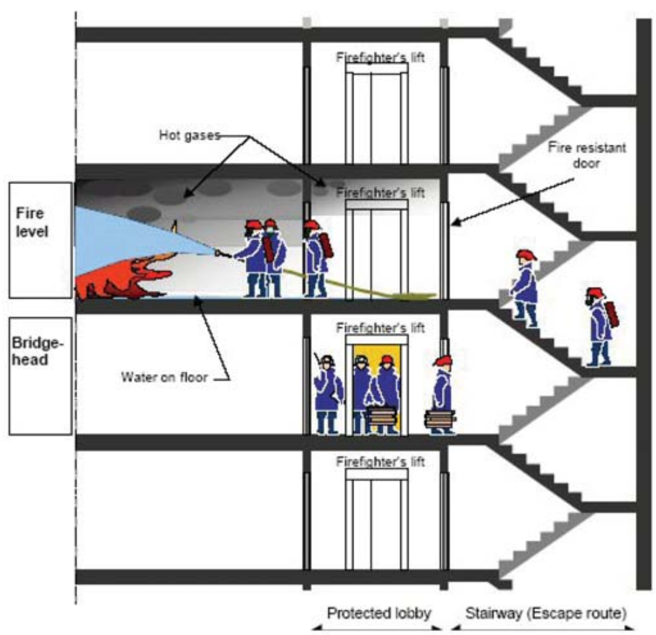

Figure 1. The use of the firefighting shaft in a high-rise fire (from BS5588/CEN standards)

The British firefighter lift standard has been extended for use throughout the European Union[6], and certain countries in the Middle East and Asia have applied this approach to very tall buildings; however, US fire departments have had some trepidations about embracing the technology.

Firefighter Lifts

In the mid-1980's the US began installing smoke detectors in elevator lobbies to initiate recall (Firefighters Emergency Operation) should smoke threaten the system. Signs were required stating that elevators are not to be used in fires. At the same time, England adopted a standard [7] containing requirements for a firefighter lift in buildings over 30 meters (100 feet) in height. The firefighter lift was part of a firefighting shaft that included an enclosed lobby on every floor with direct access to a stair containing a standpipe, all of which were intended to support high-rise firefighting practice.

Because most of the building is above fire department ladders, high-rise fires must be fought from the interior by moving people and equipment to a forward command post one- or two-floors below the fire, then advancing up the stairs to the fire floor where hoses are connected to the standpipe and advanced to extinguish the fire. In the US people and equipment (often 100 pounds of equipment is carried by each firefighter) move entirely up the stairs in a time-consuming and fatiguing process. With a firefighter lift, that can be used to move to the forward command post quickly and avoiding the exhaustion.

The American fire service did not trust the safety of elevators and continued to use the stairs until the events of September 11, 2001. Several (big city) departments began to incorporate elevator access into their high-rise fire fighting procedures with extreme caution. The NIST/ASME project included several representatives of the fire service to ensure that their safety needs were met by the requirements that were developed.

The NIST/ASME effort identified several areas where the British approach needed modification. First, the British standard requires the firefighter lift to be located in a separate hoistway. This can lead to piston effect drawing smoke into the hoistway as the car moves, and makes it more difficult to rescue an entrapped firefighter (should such occur) from the adjacent car. The separation serves no purpose since a fire in the hoistway would render the system unsafe, so this was not included in the US system.

Second, the British system has the firefighters advancing the attack hose through the elevator lobby. This will permit smoke to enter the lobby and compromise the elevator (see Figure 1). Since US elevators have the smoke detector triggered recall, this would be triggered and the elevator would be taken out of service. The US requirements include a door from the stair to the floor to advance the hose without going back through the lobby, maintaining the lobby smoke free and preventing recall.

In addition, the US system added real time monitoring of conditions in the lobbies and machine room and of power to the elevators, all displayed in the fire command center. Should things go wrong the fire department people can warn their colleagues by radio (other regulatory changes have addressed the reliability of fire department communications within high-rise buildings). Most international requirements for firefighter lifts are based on the British Standard, but it is likely that the US modifications will affect future system designs.

Case Studies:

Stratosphere Tower [8] (Las Vegas, NV)

One of the many unique buildings gracing the Las Vegas skyline is Stratosphere Tower (see Figure 2), which is essentially an 11-story building (called the "pod") atop a slim base ⮫

Figure 2. Stratosphere Tower, Las Vegas
© Marshall Gerometta

that is nearly 800 feet tall. The pod includes an observation deck, amusement rides, and a restaurant, and is accessed by four, double deck elevators that run between ground level and the bottom two floors of the pod. These floors are designated as areas of refuge (sized to accommodate the entire occupant load in a noncombustible, sprinklered and pressurized space) and contain additional elevators and escalators that provide access to the other floors.

The base contains no occupied spaces, only the two (separate) elevator hoistways each containing two elevators, and a single stairway (the base is so slim that a second stairway would not be "remote") (see Figure 3). From the outset it was clear that the elevators would need to be the secondary means of egress if not the primary. The project fire protection consultant began working with the Las Vegas Fire Department to develop a performance-based design that could be approved.

Because the elevators have only two stops (bottom and top) and there is no fire exposure to the hoistway through the entire base, many of the traditional concerns were not present. The double deck elevators were to be under the control of trained operators at all times, so no automatic protocol was needed. Two, separate machine rooms and a dedicated shaft for emergency power (all 2 hour) provided needed redundancy. One double deck elevator would be used for fire department access, leaving three for evacuation.

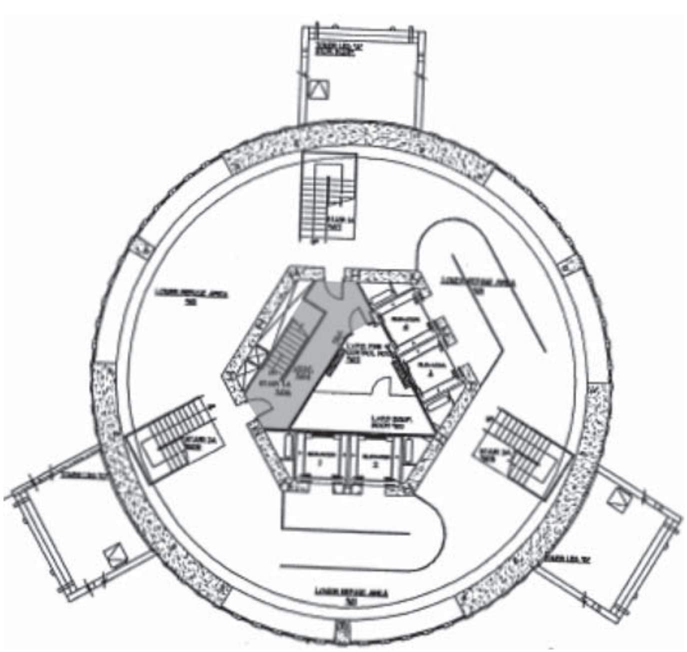

Figure 3. Plan of the lower two floors of the pod at Stratosphere Tower, Las Vegas showing the elevators and single egress stair within the shaft

In consultation with the fire department it was decided that the performance criterion would be to evacuate the entire occupant load in one hour by elevator. If one elevator was out of service for maintenance or repair, the permitted occupant load (of 2600) would be reduced by one third to maintain the one hour target. Entering and exiting occupants are counted as they pass through turnstiles to control the occupant load. The design was approved and the building is nearing its 15th anniversary.

Petronas Towers (Kuala Lumpur, Malaysia)

The Petronas Towers took the title as tallest building(s) in the world in 1998. One tower is the corporate headquarters building for Petronas Oil (the national oil company of Malaysia) and the other is leased space. The two towers are connected at the 41st and 42nd floors by a 58-meter (190-foot) long skybridge (see Figure 4). Built in accordance with a combination of US and British codes, both towers have a reinforced concrete core and contain firefighting shafts (with elevators) in accordance with BS 5588 part 5.

Figure 4. Petronas Towers are connected by a skybridge at mid-height

When first occupied the emergency plan was based on the assumption that the separation of the towers meant that no single event would impact both. Thus, to reduce evacuation time the plan was for occupants of the affected tower below the skybridge to use the stairs to the level of exit discharge, and occupants at or above the skybridge to use the stairs to the skybridge, cross to the other tower, and use the elevators to grade.

Shortly after the September 11, 2001 attacks in New York, there was a bomb call to Petronas Towers that did not specify in which tower the bomb was supposed to have been placed. The authorities decided to evacuate both towers simultaneously; resulting in chaos. The bottom half of both towers evacuated without problem, but the occupants above the skybridge in Tower 1 tried to cross to Tower 2 as the occupants above the skybridge in Tower 2 tried to cross to Tower 1. The skybridge jammed and it took several hours to untangle the mess [9].

In the aftermath, knowledge of the work underway in the US caused the authorities to consider elevator evacuation. The new plan was for the lower floors to evacuate by stair as before, but at or above the skybridge occupants were to use the elevators in their tower to grade. A drill to test the new plan resulted in simultaneous evacuation of both towers in just 20 minutes.

Figure 5. Taipei 101, C. Y. Lee ©Taipei Financial Center Corp

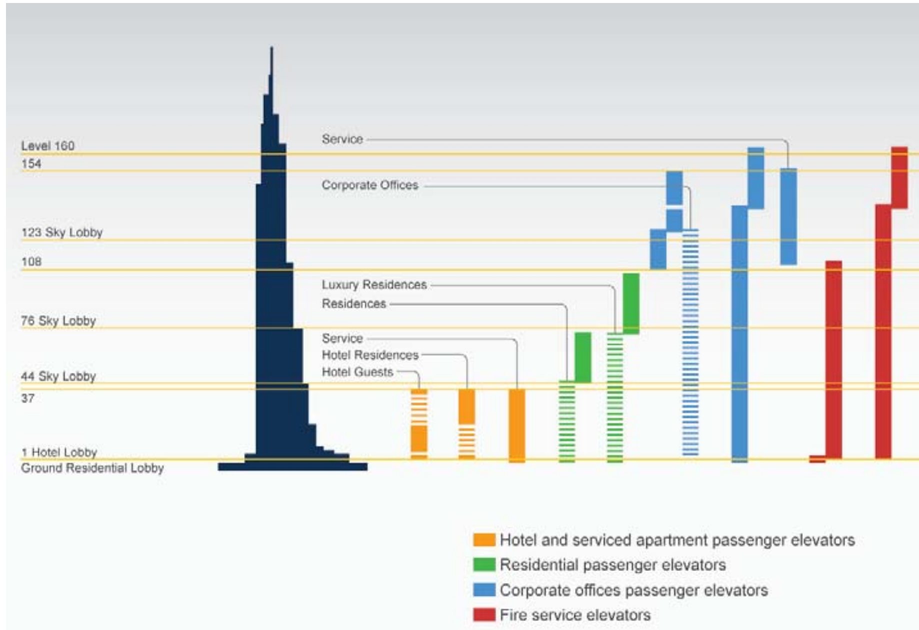

Figure 6. Burj Khalifa has banks of elevators serving different use areas but the longest runs require a transfer at the 500 meter level

Taipei 101 (Taipei, Taiwan)

Taipei 101 took the tallest building designation from Petronas Towers in 2004 (see Figure 5). Originally planned for traditional stair evacuation, a drill conducted as the building neared completion resulted in an evacuation time of about 2 hours. Aware of the activities underway in the US, the Taipei Fire Department wondered if they could do better using the elevators. They ran another drill incorporating the elevators and observed an evacuation time of 57 minutes. This became the plan used when the building opened. Taipei 101 included a firefighter lift in accordance with BS 5588 Part 5 as originally designed [10].

In the case of both Petronas Towers and Taipei 101, the inclusion of evacuation by elevator was made after construction so only limited modifications could be made to enhance reliability, but both buildings were already reinforced concrete core and fully sprinklered, so expansion of emergency power to all egress elevators was considered sufficient.

Supertall Buildings

After September 11, many people thought that high-rise buildings would not be built any more, but just the opposite was true. There was a surge in plans to build ever higher led by developers in Asia and the Middle East. Building heights soared past the 500 meter height of Taipei 101 to 800 meters for Burj Khalifa, and to 1,000 and 1,200 meters for buildings currently being planned.

In very tall buildings, zoned elevators are generally more efficient in daily use; moving more people with less wait time and fewer elevators. Also, current elevators are limited to a maximum lift height of about 500 meters (1,640 feet) due primarily to the weight of the steel cables. The development of new cable materials (polyimide ropes or PU coated steel belts) should result in more height capability. Coupled with innovations such as double deck cars, destination dispatch (where people are grouped by destination), and multiple cars in a single hoistway, the efficiency of vertical transportation in very tall buildings has increased substantially. Further, most very tall buildings are mixed-use, separated vertically. It is common to provide separate elevator banks and lobbies for the different uses, so some elevators travel through another use zone between grade and the destination floors (see Figure 6 – Burj Khalifa). This is often a section of "blind shaft" (no openings) which is less exposed when passing a fire floor due to the rated shaft wall, but presents issues of access for extraction of entrapped passengers should an elevator stop in the blind shaft section.

One World Trade Center (New York, US)

Designed by Skidmore, Owings & Merrill LLP, the new One World Trade Center is currently under construction on the former WTC site (see Figure 7). The building incorporates

Figure 7. One World Trade Center, SOM © dbox Studio

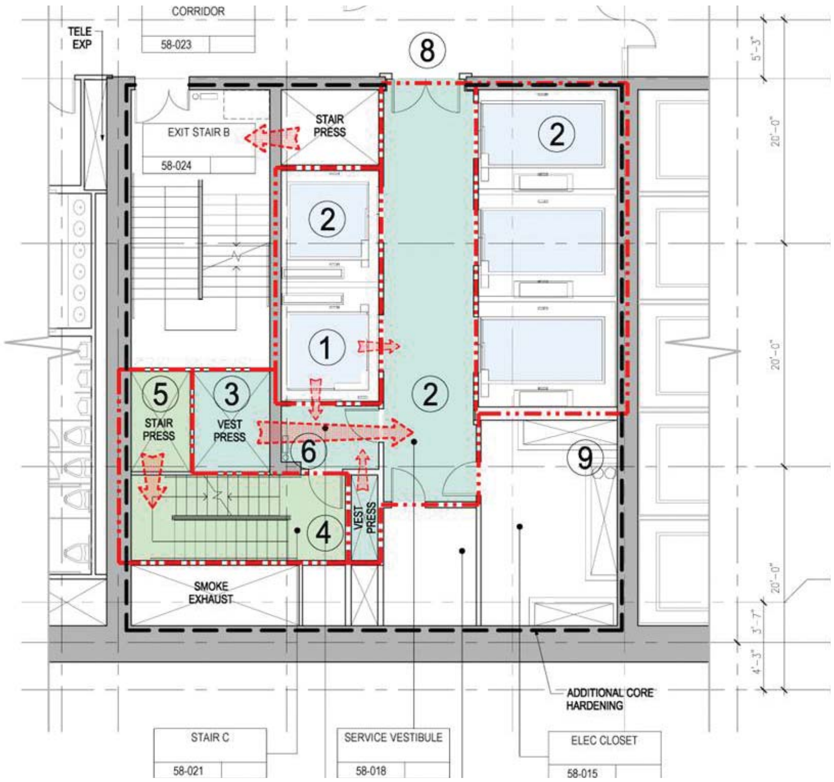

Figure 8. One group of service cars provide fire access and egress in One World Trade Center

many design features in response to the recommendations from the NIST WTC investigation, including some elevators for occupant evacuation, and a fire fighting shaft including both a stair and elevator.

In the building, one group of (five) service cars is configured for use in fires; one for fire service access and four for occupant evacuation (see Figure 8). As service cars, they are of larger capacity and stop at every floor, but the number is only a fraction of the total, so clearly most occupants are expected to use the stairs. Until the building evacuation plans are available it is not clear who will have access to these elevators (the disabled?) and how this will be controlled (fire wardens?). The emergency generator supplying this group is located at the top of the building so that the feeders do not need to be protected for the entire height of the building [11].

Applications in Asia

Building regulations in many Asian countries have incorporated firefighting shafts per the British standard in tall buildings, which is why these are found in the likes of Petronas Towers and Taipei 101. While there are some local variations such as whether the fire service elevator is dedicated or a designated car in daily use, or whether shared lobbies are permitted, the specifications are quite similar.

The building codes in China and several other Asian countries require the provision of refuge floors every 15 or 20 floors in high-rise buildings. These areas (usually located on mechanical floors) provide a space to rest, transfer between stairways, or to await assistance during an evacuation. As egress elevators have been added to the system they frequently utilize shuttle cars (high speed and capacity cars that travel only between the refuge floor and a skylobby) to move people quickly to a safe place from which they can use stairs or another elevator to reach the level of exit discharge. The reduction in total egress time with and without these elevators has been estimated for several buildings to be on the order of 25% (2 hours 15 minutes for stairs only versus 1 hour 45 minutes for stairs and elevators from the refuge floors). A limitation for people with disabilities is that they still need to use the stairs to reach a refuge floor from which they can access the elevator.

Vestibules required in China and Korea

Both China and Korea have requirements for vestibules at the entrances to egress stairs and elevators (see Figure 9). Their purpose is to provide areas of rescue assistance for people with disabilities or for people who need to rest temporarily to do so out of the flow. The Chinese regulations permit common vestibules but the Korean regulations require them to be separate and integrated with an area of refuge staging floor. These arrangements place certain constraints on the layout of the stairs and the building core. Note the use of a scissor stair with the egress elevator.

The Korean regulations further require a firefighter elevator to be located within 30 meters of the exterior of the building. The Korean regulations do not currently address egress elevators, but where these have been provided in very tall buildings they have been located within the building core.

Middle East Applications

Most tall buildings being designed and built in the Middle East are being equipped with

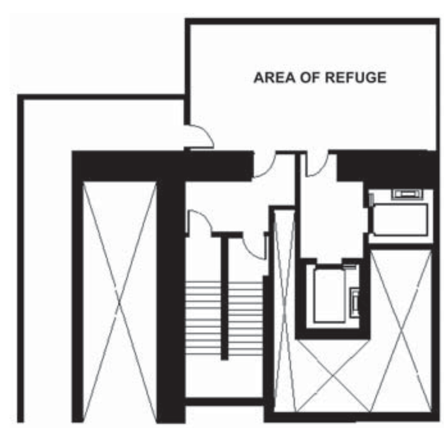

Figure 9. Korean regulations require a separate vestibule for stairs and elevators. In China the elevator vestibule could have a door into the stair and serve both.

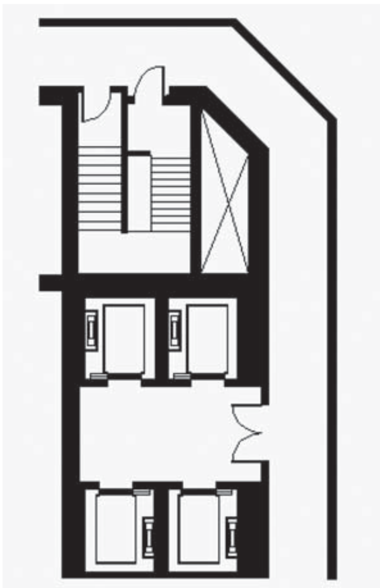

Figure10. Egress elevators in the Middle East include a separate vestibule even where located on a staging floor. Note the use of a scissor stair.

occupant evacuation elevators following similar requirements to those under development in the US and firefighting shafts following the British design. Some egress designs utilize refuge floors and some do not. In general, not all elevators are arranged for evacuation use and the design may assume about half the occupants use elevators and half stairs. They typically provide protected lobbies to wait for the elevator with direct access to an exit stair should they decide not to wait (see Figure 10). The emergency plans typically follow phased evacuation and they assign (trained) building staff to operate the elevators in an emergency to control the process.

The Burj Khalifa (Dubai, UAE) now the tallest building in the world, incorporates some elevators for occupant egress from each of the three use areas (hotel, office, and residential). Comparison of total evacuation time by stairs alone and by a combination of stairs and elevators estimated a 45% reduction in total evacuation time (to 90 minutes) with the elevators.

Other Middle-East projects have incorporated egress elevators in their design at the request of the developers and owners as a building feature thought to enhance the marketability of very tall buildings. The emergency plans call for phased evacuation managed by building staff with occupants gathering on staging floors via scissor stairs. Since the stairs are only used to reach the staging floor there is no cumulative flow from higher sections of the building, reducing the required stair capacity. The building is also equipped with a separate fire fighter elevator and stair that eliminates counter flow in the egress stairs.

Conclusions

Despite the absence of technical standards, tall buildings worldwide are incorporating elevators for occupant evacuation to achieve significant reductions in total evacuation times. Common requirements include emergency power, water protection, and hoist ways with protected lobbies with direct access to an exit stair. Unique characteristics of the US approach include utilization of all (public) elevators (to accommodate all occupants and minimize total evacuation times), displays to provide real time information to occupants waiting in the lobbies on every floor, and the addition of certain real time monitoring from the fire command center. The common use of trained operators outside the US may offset the need for monitoring. No one is taking a reduction in stair capacity for the elevators (yet) except that additional capacity normally required for the occupant load of assembly spaces on upper floors is often waived. ■

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