Elevator Safety in Seismic Regions

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Abstract

Recently we have witnessed many natural disasters around the world. In 2004, four major storms struck Florida, USA. The hurricane Ivan severely damaged Florida and the Gulf Coast. The latest earthquake in the Indian Ocean and following tsunami killed nearly 220,000 people and destroyed or damaged houses and cities beyond belief. These are not the last disasters, others will inevitably follow.

If natural disasters can not be prevented, at least the level of suffering can be reduced by taking preventative and protective actions.

In this article, the suitability of different types of elevators in seismic areas is discussed and hydraulic elevators are found to be the most suitable type under seismic conditions.

1. Introduction

Many countries around the world and Turkey in particular, are subject to frequent earthquakes, most significantly from the North Anatolian Fault Zone (NAFZ), which stretches across the country and is responsible for many of Turkey's major earthquakes. Two of the latest examples are the 1999 Izmit and Düzce earthquakes that occurred on the NAFZ. Earthquakes cannot be predicted, in the sense of "where, when and how big"? Fortunately, most of the earthquake endangered areas have been mapped and their probability and severity ratings are now available. For example, the investigation on the North Anatolian Fault Zone in the Marmara Sea reveals that the probability of strong shaking in the giant metropolis of Istanbul is 62±15% during the next 30 years and 32±12% during the next decade [1]. Planners and engineers can utilize such information so that steps can be taken to avoid earthquakes becoming major disasters.

Civil engineers do not expect most buildings to be in perfect condition after a major earthquake. The goal is to make sure that they remain standing, and that occupants can leave safely. The forces from an earthquake are so large; in most cases it would be too expensive to design a building that would remain undamaged. The no-damage philosophy has been traditionally reserved for critical structures like nuclear power plants. For most buildings, the idea is to be able to go back and repair them after even large earthquakes. However, the buildings should remain intact against moderate earthquakes. In recent years, engineers have tried to institute "performance-based design," which would allow owners to specify the acceptable level of damage, giving the engineer guidance on how much strength would be required. At a pre-specified strength of earthquake, buildings should remain intact and at the same time the electrical, gas and water layouts, elevators, escalators and other equipment should remain operative. Consequently, while taking preventive and protective actions against seismic phenomenon, the choice of technology and equipment that are used in buildings becomes of prime importance.

Since the 1964 Alaska Earthquake, the study of elevator safety and performance in the event of earthquakes has become one of the most important interests for the elevator engineers. As a result of a number of studies, the elevator design codes were altered significantly [1]. The A17.1 safety code for elevators and escalators in seismic zones tries to ensure minimal damage to lift systems by using seismic switches, protecting the car from colliding with the counterweight, introducing more elastically installed guide rails, developing new brackets and rollers, introducing structural support frame in which the elevator can move up and down freely during an earthquake and other measures [1, 2]. Though the structural enhancements applied to new and existing installations, elevators still experienced an unacceptable amount of damage from earthquakes of even moderate size (6 to 7.1 in Richter scale) [2]. The severest earthquakes can have a magnitude in an excess of 8.0 and it can be assumed that there will be a lot more damage in future quakes than previously expected.

The 1999 Izmit earthquake did extensive damage to residential and industrial buildings in Izmit and surrounding areas near Istanbul. A list of damaged components of elevator installations in this earthquake is listed below [1];

- Counterweights out of their rails and some colliding with the cars
- Hosting ropes damaged or out of their sheaves
- Rail brackets broken or damaged
- Governor cable hung up
- Roller guides broken or loose
- Compensating cables out of their grooves or damaged
- Some shafts collapsed and cars buried at the bottom

2. Types of elevators

The reasons why elevators can be in a hazardous condition even after moderate earthquakes are;

1- The existing safety code for elevators and escalators in seismic zones is not adequate and upgrade techniques for various components in an elevator system are necessary.
2- Constructing the wrong type of elevators in seismic regions.
3- Local enforcing authorities do not accomplish their obligations to impose seismic enhancement of elevators in earthquake danger areas.

Actually the reasons for damage could be one of the above or all of them. The existing safety code can be improved at the expense of increased elevator cost. The local or central enforcing authority's responsibility, at this stage, is not the interest of elevator engineers. Then the dilemma is to find out 'What is the most suitable type of elevator in seismic regions?' and later to improve the code by considering the most suitable type. In this way, engineers may save time and energy in the development of reliable elevators against earthquakes. Here, comparisons have been made to lead us to the right answer.

In traction elevators, machines can be with or without a gear (gearless). Geared machines are used in low/medium-rise buildings whereas; gearless machines are used in taller buildings with bigger capacities and higher speeds. The gear ratio is normally chosen to be 20:1 to 40:1 based on the load and the speed of the elevator. The higher the gear ratio, the lower the system efficiency will be, since much of the power is consumed in the gear. In traction drives, both the geared and gearless systems, a counterweight is used to offset the car weight and 40 to 50 percent of the payload [3]. Therefore, the counterweight will tend to pull down whenever the break is released.
In traction elevators, the car, the counterweight rails, their brackets and guiding assemblies are the most vulnerable. During earthquakes the top floor shakes at greater amplitude than the ground floor. Therefore, installation of a drive unit and its equipment at the top of the building becomes more critical. The counterweight, which is the heaviest component of the elevator system, and the car exert large inertia forces, due to their large mass, to the rails and cause damage and derailment. Disengagement of the counterweights from its rails and swinging into the shaft and colliding into the car are the most common dangers. The seismic switch has been suggested to sense the initial waves of the earthquake (the P wave) so that the elevator is brought to the next stop in a direction away from the counterweight and shut down if more damaging shock waves (the S waves) arrive. However, if the epicenter of the quake is very close to the building site, i.e. P and S waves arrive simultaneously, a controlled shut down may not be completed and the damage due to counterweight may not be avoided. A number of protective methods may also be accomplished to prevent the counterweight from being disengaged. However, these methods would hardly guarantee to stop counterweight hazards, be costly and cannot compete with the advantage of having no counterweight. A control practice of 822 traction elevators in Cigli region of Izmir revealed that insufficient conditions that were generated by the existence of the counter weight system were the first amongst the most important 20 check points [4]

If the elevator is equipped with the counterweight, the direction of the movement depends on the weight of the car after releasing the brake. If the car is not moving due to the balanced loads, a hand wheel must be operated manually costing valuable time.

Earthquakes can also damage electrical, gas and water layouts of buildings and cause hazardous situations such as explosions, fire and floats. These later situations may increase fatalities even more. Elevators should withstand seismic forces during the quake and at least remain active until the rescue operations are completed for possible trapped passengers. Passengers may need to be rescued immediately because of likely aftershocks or smoke migrating into the shaft due to fire or other reasons. Under such conditions, it is not realistic to wait for fire fighters or service personnel to free the passengers. Therefore, easy-rescue of trapped passengers from cars is essential as the safety code for elevators in seismic zones is improved.

2.1 Hydraulic elevators

In general, the hydraulic elevator has dominated the low rise market because it is cheaper to build, install and service, and because it has decidedly better safety records than other types. Especially in earthquake danger areas, the hydraulic elevator has proven itself to be clearly the safer option. During the Seattle earthquake of February 2001, 11% of the traction lifts suffered varying degrees of damage as against only 1% of the hydraulic lifts. This fact should make us re-think once more about the risk of having traction elevators in natural danger areas.

Hydraulic elevators are suitable for low rise buildings, normally up to 6 floors, and generally have no counterweights. The car is moved by means of a hydraulic ram, which is actuated by a hydraulic power unit, directly or indirectly. In this case a separate machine room is usually employed, though the machine-roomless hydraulic elevator option is sometimes taken. A safe machine room can almost always be conveniently positioned in the basement or first floor of the building. The direct location next to the shaft is not essential. The possible noise sources of the drive unit are also largely separated by the machine room. The possible shaft dimensions are in some cases smaller for hydraulic lifts than traction lifts, since the hydraulic ram can be applied to the car in many different ways.

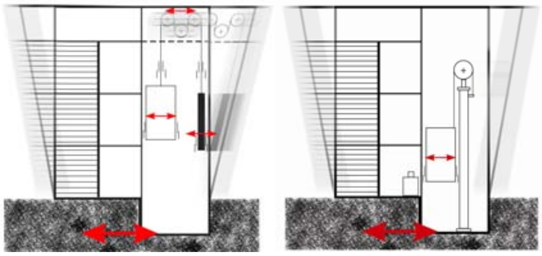
The central ram (direct acting), which requires a pit and a hole under the car, is the simplest arrangement, which can be balanced to reduce shoe loadings. Indirect acting, which has a rope-pulley arrangement, can achieve higher rises without the necessity for expensive telescopic rams and deeper pits, but it does require a safety stop system in case of rope breakage or over-speed.

Lowering the car to a floor level is simple by applying the manual lowering knob or lever in the machine room. Through the optional inclusion of a small hand pump, the car can also be raised to a higher floor level if required [5].

Hydraulic systems require fewer components than do traction systems. The fewer the components, the simpler the installation and the smaller the chance of break down or failure. Therefore they are more reliable and easier to install than equivalent traction elevators. Furthermore, they are very cost effective, since they can be planed without reference to a major elevator manufacturer. All the parts required are readily available from the hydraulic component trade, generating healthy competition in the procurement and servicing of such systems [6].

The main advantages of hydraulic elevators include:

1) The elevator load is carried by the foundation of the building, whereas with traction elevators, by the building itself (Figure 1).,
2) The machine room is conveniently positioned in the basement or on the first floor for servicing or rescue,
3) The rescue procedure can normally be performed in minutes by an informed member of the household (Figure 2),
4) The installation and servicing costs are lower. Alternative maintenance companies may offer better, lower priced servicing,
5) Damage through earthquakes to hydraulic elevators are generally a fraction of that caused to traction elevators,
6) The hydraulic elevator needs no counterbalance, which could otherwise be life threatening in the event of a disaster.



(a) Traction elevator (b) Hydraulic elevator

Figure 1 (a) Massive inertia loads set in motion through building sway combined with the heavy main drive, car and counterweights. Potentially excessive damage and injury.

(b) Reduced inertia loads with the elevator load completely carried by the foundation of the building. Possibility of major damage or injury greatly reduced conceivably by a factor of 10 to 1.

(a) Traction Elevator (b) Hydraulic elevator

Figure 2 (a) In the event of fire, access to evacuation equipment at the top of the building can be difficult. Releasing the brake may cause the car to go either up instead of down.
(b) In the event of fire, easy access to the power unit at the bottom of the building. By opening the manual lowering, the car always travels downwards. By operating the hand pump, the car travel upwards.

2.2 Conventional traction elevators

An alternative to the hydraulic elevators in low rise buildings is the conventional traction elevator. These are usually equipped with a counterweight, which lowers the energy consumption of the elevator. These systems can be planned with or without gear boxes, which in turn affects the energy consumption and the smoothness of the ride. As a rule, a separate machine room is required and can be located either above the lift shaft or even behind or at the bottom of the lift shaft. It is however important that this is placed directly next to the shaft. All components required for these systems are also available from the component trade which creates healthy competition [3]. The main advantages of traction elevators with machine room are:

1) Higher traveling speeds are possible
2) Less power consumption due to the counterweight.

On the other hand, rescue operations require experienced personnel, otherwise it may result fatal disasters and counterweights can cause unsafe operation in seismic zones as explained previously. Additionally, in the case of low rise buildings, speeds exceeding 1m/s would rarely be necessary.

The separate location of the machine room has advantages when it comes to the maintenance, repair of the system, but in the case of fire and smoke migration rescue of passengers becomes difficult if the machine room is located inconveniently above the shaft.

2.3 Machine-roomless elevators

Introduced in 1995, Machine-Roomless equipment (MRLs) are also available from most of the elevator manufacturers. With the advance of permanent magnets (PM), Permanent Magnet Synchronization gearless traction machines (PMS) have been developed with high torque and low speed with a focus on eliminating reduction gear and improve the system efficiency. With the speed-reduction mechanisms, such as worm gears and planetary gears, the machine has to be of great size and weight. Whereas the traction sheave of a gearless machine is seated on the same axle shaft of the motor, providing a simpler way of power transmission. The noticeable reduction in both size and weight of the PMS machines and their unique dynamic features, such as high stability and precision, stronger torque and low speed, accurate control of rotor positioning, self-locking stop without power consumption have found wide applications in elevator drive systems and enabled engineers to construct Machine Roomless elevators. Because they are gearless, MRL drives are lubrication free and consume less energy [7]. MRLs, where the drive unit is placed inside or next to the shaft, are utilized for low- to mid-rise elevator installations and they are increasingly being used. The main advantages of MRLs are;

1) No machine room is required
2) Energy consumption is even lower

Table 1. Evaluations of elevators for low rise buildings.

			Hydraulic	Traction	MRL	Note
Total		Speed	0	2	1	
	Safety	Rescue	2,5	0,5	0	Easy-rescue of trapped passengers
		Safety-maintenance	2	1	0	
		Safety-running	1,5	1	0,5	
		Resistance to quakes	3	0	0	
		Safety Points **%**	9 75	2,5 21	0,5 4	=12 points =100
	Cost-effectiveness	Energy consumption	0	1	2	In operation
		Installation Cost	2	0	1	
		Service cost	2	1	0	
		Client dependency	1,5	1,5	0	
		Service requirement	2	0	1	
		Environment friendliness	0	1	2	Oil leakage
		Cost Points **%**	7,5 42	4,5 25	6 33	=18 points =100
		Noise in the shaft	1	1	1	
		Machine room dependency	1	0	2	Location + necessity
		Total Points **%**	18,5 47	10 26	10,5 27	=39 points =100

The hazards

On the other hand, MRLs are in general found to be less safe than the conventional arrangement with a machine room. (On the message board of Elevator World stands, Topic: The MRL is it Dangerous?). This means that much is discussed on improving safety in elevators and still too little is realized, particularly in earthquake danger areas. The prime example is the MRLs traction drives that obviously bring new dangers to the work of the mechanics during construction and servicing of the elevator. The 'rescue of passengers' procedure during an emergency becomes more complicated, jeopardizing the efforts of mechanics and firemen who in many cases will not be familiar with a particular construction. Moreover, inside the shaft the temperature and humidity conditions are very detrimental on mechanical, electro-mechanical and electric/electronic equipment. It is not clear that the manufacturers have taken sufficient care in their designs to provide extra protection to the equipment in such hot and humid environments, especially in hot climates. The percentage of humidity and dirt in the shafts is declared to be 81% by the research in Reference 4. The latest trend of placing the control panel in the shaft, disregards the safety factor, a strange development for an industry which until now had prided itself on having the highest possible safety standards.

The monopoly

The reason for the major companies forsaking the safety of the machine room is apparent. They save the cost of the machine room in the first place and secondly they patent whatever solution they adopt to install a special drive in or next to the elevator shaft. The patent, usually of questionable innovative niveau, serves to ban the eventuality of better competitive terms being offered by other qualified servicing companies. The client is naturally heavily committed in many ways to the supplier when it comes to the maintenance and procurement of the spare parts, which can have an alarming effect on prices [6].

3. Comparison of elevators

It is incorrectly predicted by many that MRLs will eventually replace hydraulic elevators in their entirety [8]. Hydraulic elevators have proven their safety and reliability for the last forty years as the most cost effective and easy-to -install means of vertical transportation. In spite of the fact that MRLs saves space and enhance building design, it is only the hydraulic elevator that can most efficiently accommodate large lifting capacities, with minimum maintenance and accomplish safety regulations comfortably.

The environment and energy factors

Other arguments are that, hydraulic elevators are said to have environmentally unsafe and consume higher energy. Such premeditated statements are away from reflecting the reality. This is because environmental friendly hydraulic elevators can easily be accomplished in comply with the code without too much effort. In addition, biodegradable hydraulic fluids have been already introduced and used increasingly [9].

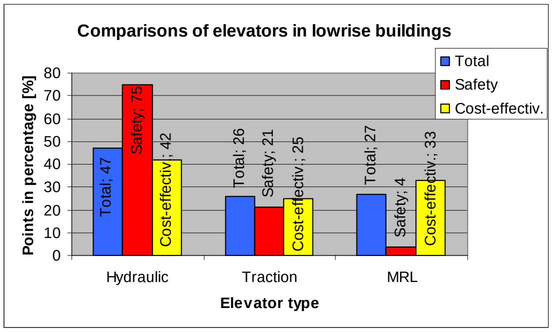


Figure 3. Comparisons of elevators for low rise buildings.
Total: Total constraints
Safety: Rescue + Safety-maintenance + Safety-running + Resistance to quakes
Cost-effectiveness: Installation cost + Service cost + Client dependency + Service requirement + Energy consumption + Environment friendliness

When it is considered that traction elevators use electrical energy in both directions and the hydraulic elevator only in the up direction, the energy consumption difference in operation is not very excessive if the choice of the power unit is made adequately. Moreover, fuel energy consumption through more frequent service calls necessary for traction elevators, shifts the environment and energy equation in favor of the hydraulic system [5].

Buildings in earthquake endangered areas are generally low rise since near the fault zones high buildings are prohibited by central or local authorities. Code requirements on increasing safety during earthquakes [1, 2] result in more costly solutions for traction elevators than for hydraulic elevators due to the counterweight and other additional equipment needed for traction elevators.

Hydraulic, conventional traction and MRL type elevators are compared with respect to various design constraints in low rise buildings and results are given in Table 1. Total assessment mark of 3 is divided among the three elevator systems for each design constraint and the percentage points for total points, safety and cost-effectiveness are shown in Figure 3.

The points awarded for different conditions may vary for among assessors but the general trend would be unlikely to change. As can be seen from the Table 1 and Figure 3, hydraulic elevators in total obtain 47% of the total points, followed by MRL 27% and Conventional Traction 26%. If a combination of Rescue + Safety-maintenance + Safety-running + Resistance to quakes constraints (Safety) are compared as then these percentages become; 75, 21 and 4 for hydraulic, conventional traction and MRL types respectively. When cost-effectiveness is considered, hydraulic elevators gets the highest point with 42%, followed by MRL, 33% and conventional ones 25%.

4. Conclusions

Turkey is a country that has strong threat of earthquakes. The latest Marmara Earthquake caused enormous damage. However, people forget too quickly that similar ones can happen at any time.

Vertical transportation people, particularly in seismic regions, should consider the safety of people first rather than increasing their profit by selling less safe equipment. Standing to profit from the machine-roomless policy until the responsible national code committees take corrective action would be too costly in natural disastrous areas. In the meantime, low rise elevators will be more expensive and less safe.

With the abandonment of the machine room, the industry has taken a giant step backwards and is now engaged in taking small inadequate steps sideways, feigning safety improvements.

Hydraulic elevators are ideal for use in Seismic danger areas which are mainly occupied with low rise buildings. In the event of an earthquake, hydraulic elevators are safer to operate than traction elevators. Because they are built in the foundation of the building, they do not normally have counter-weights and in the case of over speeding of the car, have safety rapture valves to stop the car should the main pipe line be severed. During power loss cars can be lowered down easily and quickly. Should it be necessary to move the car upwards, small hand pumps which should be included in the machine room installation, are all that is needed.

In the light of abovementioned, it appears that hydraulic elevators are the most suitable type for earthquake endangered areas.

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