6.4 Mechanical, Electrical, and Plumbing Components

6.4.10 Elevators and Escalators

6.4.10.2 Traction Elevators

Traction elevators have made high rise construction possible. These systems are continually evolving to achieve faster speeds, smoother and quieter operations. Currently there are geared traction elevators, gearless traction elevators, and "machine-roomless" elevators that use flat belts instead of steel cable. Traction elevators are complex mechanical systems that have many moving parts and electronic components and failure of any of the components could disable the functionality of the entire system. Maintaining limited functionality of some elevators following an earthquake is critical for continued operations of essential facilities or the evacuation of hospital patients.

The primary components of the traction elevator system are the elevator cab (car), counterweight, cab guide rails, counterweight guide rails, guide rail support brackets, electric motor, electrical control panel, ropes, sheaves, safety braking mechanisms, door mechanisms, and a shock absorber at the bottom of the shaft. The system may be tied to a seismic switch or a smoke detector which would facilitate safe shutdown in the event of an earthquake or fire. Any of these components could be damaged if not properly restrained.

Provisions

BUILDING CODE PROVISIONS

Seismic loads for elevators are determined using ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures*, (ASCE, 2010), Chapter 13. Elevators are classified as mechanical components, and are sensitive to both story drift and acceleration. Elevators designed in accordance with the seismic requirements of ASME A17.1 *Safety Code for Elevators and Escalators* (ASME, 2007a) are deemed to meet the requirements of ASCE/SEI 7-10, provided the forces and displacements used in the design meet the provisions of ASCE/SEI 7-10.

- Elevators, hoistway structural systems, elevator equipment supports and attachments, and controller supports and attachments must be designed to meet the force and displacement requirements of ASCE/SEI 7-10.
- Bracing exemptions for small diameter piping and piping supported on hangers less than 12 inches long do not apply to elevator piping.

- Elevators that operate at speeds greater than 150 feet per minute must be provided with seismic switches that are triggered by earthquake shaking. The seismic switch will prevent a potentially damaged elevator from being used.

RETROFIT STANDARD PROVISIONS

ASCE/SEi 41-06, *Seismic Rehabilitation of Existing Buildings*, (ASCE, 2006) classifies components of elevators as acceleration sensitive. Shafts and hoistway rails that rise through several floors are both acceleration and deformation sensitive.

- Elevators are subject to the requirements of ASCE/SEI 41-06 when the performance level is Immediate Occupancy, or in regions of high and moderate seismicity when the performance level is Life Safety.
- The evaluation must consider the anchorage of the equipment and controllers, as well as the construction of the elevator shafts. The possibility of derailment or displacement of the elevator counterweights must also be considered.
- Acceptance criteria may be based on prescriptive procedures, or the elevator components may be analyzed for the force and displacement demands.

Typical Causes of Damage

- The most common cause of damage in elevators is counterweight derailment. Counterweights are the heaviest component in an elevator and typically weigh the same as the cab filled at 50% capacity. Elevators are often programmed to spend more time in the ground floor and therefore when earthquakes occur the counterweight is likely to be located in the upper part of the building where the largest acceleration demands occur. This means that often counterweights are subjected to forces that are larger than those experienced by the cab (car). Counterweight derailment is a very serious type of damage because once it is out of the guide rails the heavy counterweight may violently swing in the hoistway and collide against other components causing the damage to guide rails and rail brackets. In some cases collisions with the cab occur if the elevator is operated with its counterweight derailed. In other cases, severe pounding of a derailed counterweight against the guide rails or the hoistway can cause damage to the frame of the counterweight and individual block which are typically made of cast iron or steel plates may become loose and fall into the shaft or onto the roof of the cab.
- Counterweight and car guide rails often are bent as a result of large inertia forces acting on the counterweight and car that push the guiderails during the earthquake. Damage

typically occurs when the counterweight or car are between floors where the rails are not attached to the structure and therefore are subjected to large bending deformations. Guide rails also get damaged as a result of pounding against the counterweight or the car. Bent rails often need to be replaced, which may require several days.

- Guide rails are attached to the structure by steel brackets. As shown in Figure 6.4.10.2-1 the rails are attached to the brackets by clamps that hold the flanges of the rail to the bracket. Both brackets and clamps are damaged as a result of the forces acting on the counterweight or car. The most common type of damage consists of bending of the brackets.
- Lateral motion of counterweight and of the car relative to the guide rails is constrained by a guide rolling system typically consisting of three guide wheels (or guide shoes). Guiding systems are comprised of several parts. Details vary from manufacturer to manufacturer, on the load capacity of the elevator, the travelling speed and on whether the guide is for the car or the counterweight. An example of a spring adjustable guide rolling system is shown in Figure 6.4.10.2-15. The axle bolts, pins, and supports of these rolling systems are particularly vulnerable during earthquakes where very large forces are produced in these small mechanical components as a result of inertia forces acting on the counterweight and car.
- Landing switches and limit switches are sensing elements that allow an adequate positioning of the car at each floor level. These switches consist of brackets extending into the hoistway. Damage to these elements consists of being bent by lateral motion of the car or the counterweight. They can also be damaged from steel ropes swinging in the shaft and colliding with the switches or by falling counterweight block.
- At the top of the elevator is a room that houses the elevator machines. The main components housed in the elevator machine room are the electrical motors which are usually directly attached to the shaft. The elevator machines must be properly anchored to the base otherwise a sliding may occur during earthquakes.

Damage in Prior Earthquakes

Earthquake	Date	Magnitude	Number of Derailed Counterweights
Nisqually	February 28, 2001	6.8	224
Van, Turkey	October 23, 2011	7.2	218
Darfield, New Zealand	September 3, 2011	7.1	30
Whittier Narrows	October 1, 1987	5.9	91
Loma Prieta	October 17, 1989	6.9	249
Northridge	January 17, 1994	6.7	690

- According to survey responses collected by the Division of Occupational Safety and Health Elevator, Tramway, and Ride unit, following the 1994 Northridge earthquake, the following issues were observed:
  - Water damage-sprinkler pipes pulled apart flooding machine rooms and pits causing water on top of cars, damage to door operators and door detectors, and soaking car processors and car station. Several oil buffers had to be rebuilt.
  - Falling debris in hoistways, falling plaster, loose concrete blocks, broken glass resulted in damaged door interlocks and misalignment of hatch switches and bent fascias.
  - Building settlements bent elevator guide rails; structural damage, loose and bent divider beams shifted guide rails and bending support brackets.
  - 3,528 cabled elevators were removed from service by a seismic protective device. 710 devices did not operate as intended. Some devices were located in the elevator pits which were flooded.
  - 968 electric cabled elevators sustained earthquake damage.
  - 2 minor injuries were reported, one of which was sustained by a fireman trying to open hoistway doors.
  - 39 elevators required rescue.
  - 57 instances were reported where "unauthorized persons" reset earthquake devices. Fortunately, only 5 elevators sustained additional damages.
  - 688 counterweights came out of guide rails. 8-1b rails were inadequate even with additional intermediate guide rail bracket retrofit. Several counterweight frames were twisted and bent with a few dislodged subweights. Some counterweight roller guide shoe mountings disintegrated.
- Following the 2010 Chile Earthquake, it was reported that 50%-80% of hospital elevators were damaged. In a number of locations, patients had to be carried down many flights of stairs, often cluttered with fallen debris, in order to evacuate them to safety. The most common damage was due to unrestrained movement of the counterweights, resulting in damage to the guide rails. Movement of unrestrained mechanical equipment was another problem. One security camera at a military hospital in Santiago, Chile captured a sequence through the open door of an empty elevator cab where the counterweights derailed and then the subweights came crashing down on top of the cab. (Source: Bill Holmes, March 2010).
- In addition to property damage, passengers may become trapped in the cab following an earthquake and may need to await extraction by qualified elevator technicians. Failure

of elevators are particularly critical to high-rise buildings that may become inoperable without elevators.

In recent shake table testing of a full scale 5 story building performed at UC San Diego (see Section 6.1.3), a fully operational machine-roomless traction elevator was subjected to severe earthquake motions. The elevator remained operational for all but the largest tested earthquake motion although in a normal installation, the elevator would have tripped off line by seismic sensors. For the largest motion (inter-story drifts exceeding 3%) the gypsum wall board partition distortions caused the elevator shaft doors to jam thus making the elevator in-operable. Elevators have interlocking controls that when the shaft doors are not operational, the elevator is not operational.

Figure 6.4.10.2-1 Examples of an elevator counterweight (Photo courtesy of Eduardo Miranda, Stanford University).


Figure 6.4.10.2-2 Examples of brackets and clips attaching the elevator guide rails to the structure (Photo courtesy of Eduardo Miranda, Stanford University).

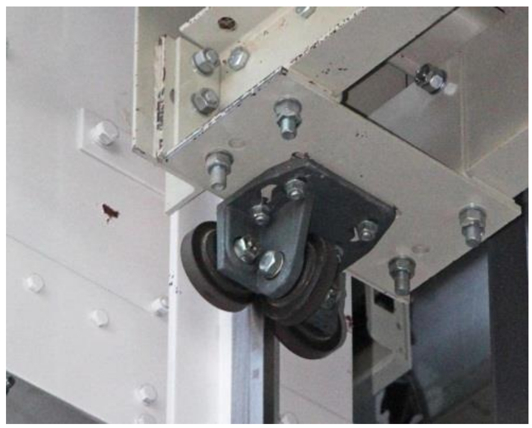



Figure 6.4.10.2-3 Examples of rolling guides at the bottom of a car (Photos courtesy of Eduardo Miranda, Stanford University).

DAMAGE EXAMPLES

Figure 6.4.10.2-4 Examples of damage to elevator machines produced by inadequate anchorage to the structure (Photos courtesy of Eduardo Miranda, Stanford University).

Figure 6.4.10.2-5 Details of bent bracket (left) and large displacement at the base of elevator machines (Photos courtesy of Eduardo Miranda, Stanford University).

Figure 6.4.10.2-6 Overturned control panels in the 2010 Chile earthquake (Photos courtesy of Eduardo Miranda, Stanford University).

Figure 6.4.10.2-7 Damage to guide rails caused by derailment of the counterweight in a hospital in Chillan during the 2010 Chile earthquake (Photos courtesy of Eduardo Miranda, Stanford University).

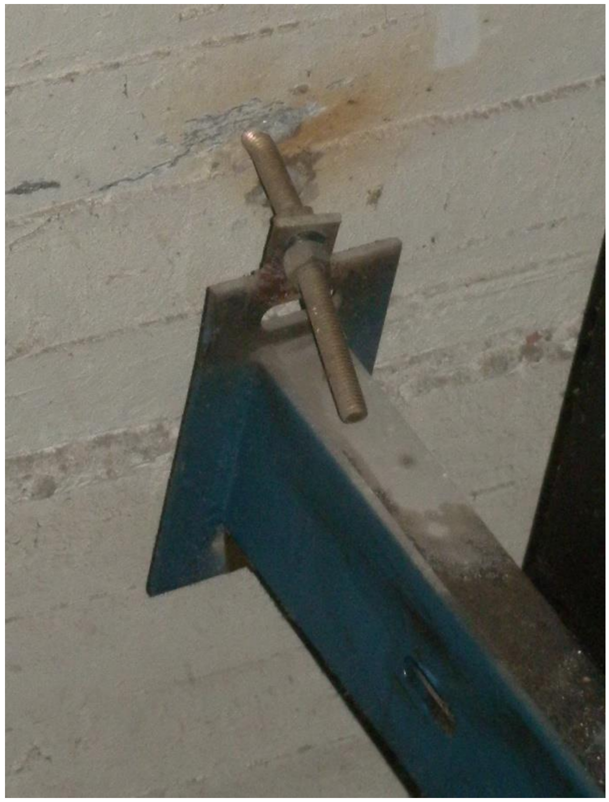


Figure 6.4.10.2-8 Damage to guide rail support brackets in the 2010 Chile Earthquake (Photo courtesy of Gilberto Mosqueda, SUNY Buffalo).

Figure 6.4.10.2-9 Derailed car roller assembly of the guide rail at the Santiago airport in the 2010 Chile Earthquake (Photo courtesy of Gilberto Mosqueda, SUNY Buffalo). The three rollers are supposed to travel along three sides of the stem of the T-shaped steel guide rail.

Figure 6.4.10.2-10 Glazing failures caused additional hazards at Santiago airport elevator in the 2010 Chile Earthquake (Photo courtesy of Antonio Iruretagoyena, Rubén Borsochek & Associates).

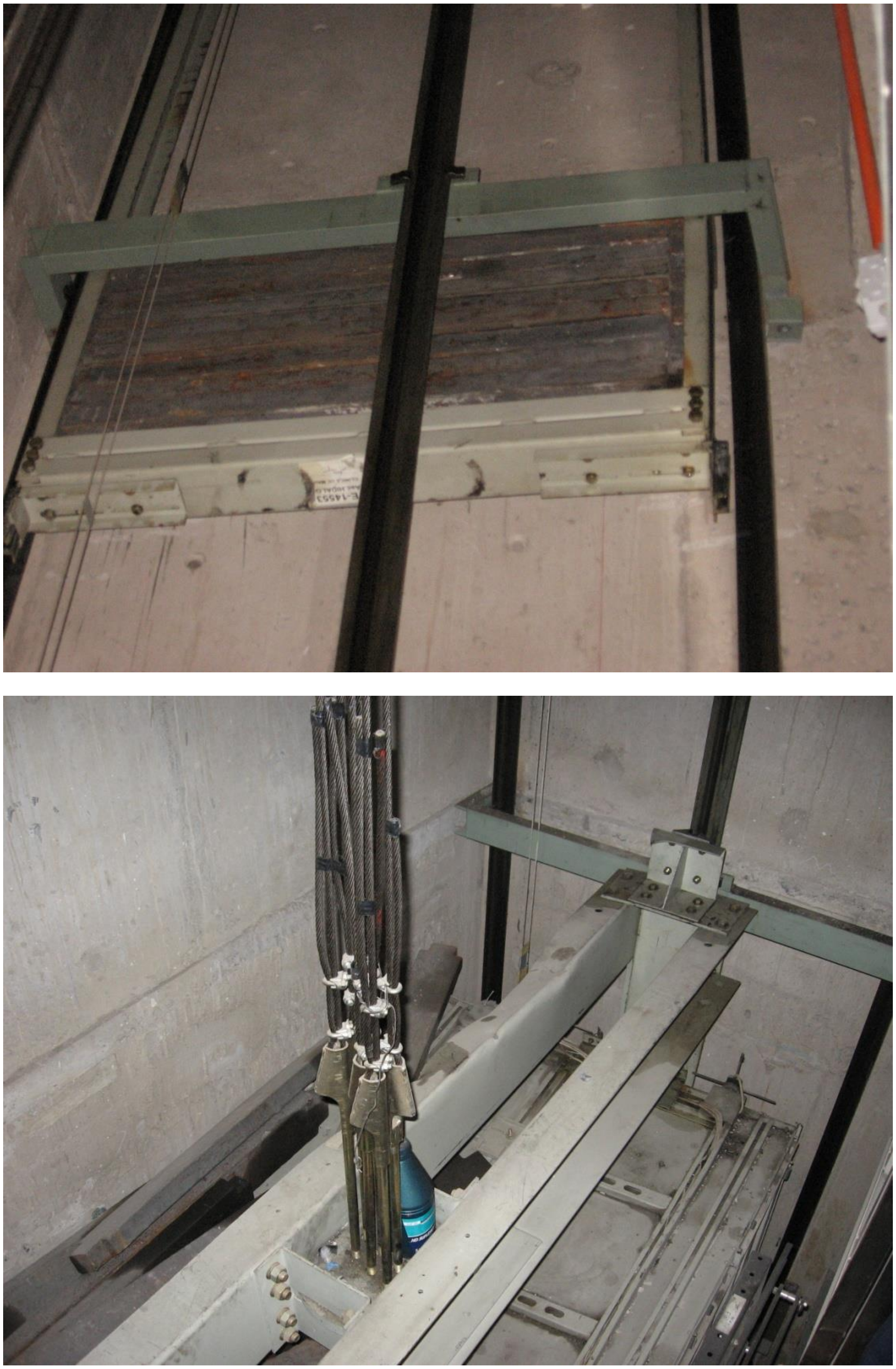


Figure 6.4.10.2-11 Unrestrained movement of the counterweights damaged the counterweight assembly and bent the counterweight guide rails; over half the subweights dropped onto the top of the cab and damaged the cab framing in the 2010

Chile Earthquake (Photo courtesy of Rodrigo Retamales, Rubén Borsochek & Associates).

Figure 6.4.10.2-12 Anchor bolt failure of the elevator generator set due to inadequate edge distance for the bolts at the Los Angeles Regional Public Hospital in the 2010 Chile Earthquake (Photo courtesy of Bill Holmes, Rutherford & Chekene).

Seismic Mitigation Considerations

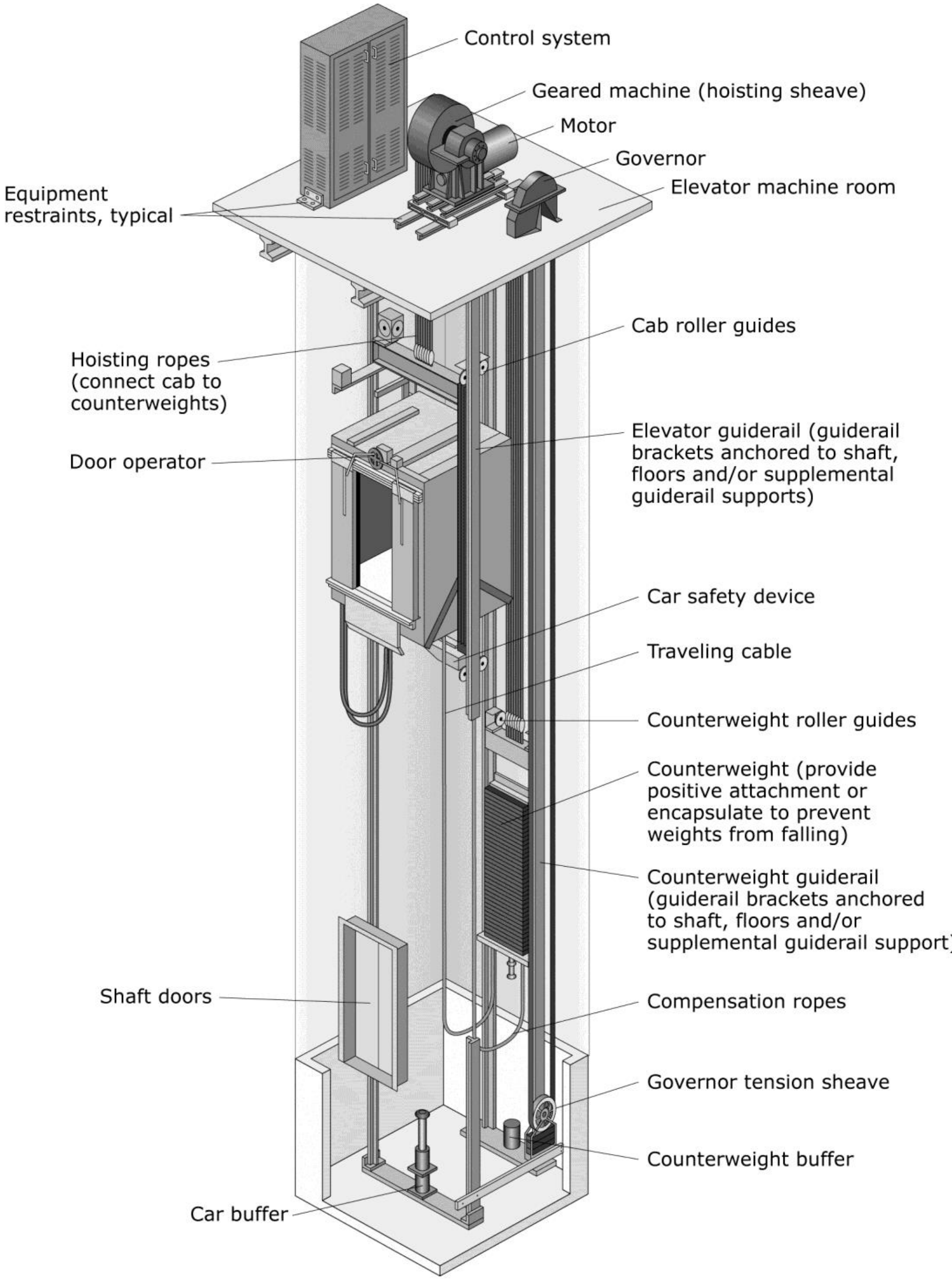
- All of the components of the traction system need to be restrained, anchored, or detailed to resist lateral forces in all directions and accommodate seismic movement. The system must be designed to accommodate the anticipated inter-story drift over the height of the elevator travel. Guide rails and door frames must all be detailed to accommodate lateral deformations. All of the mechanical and electrical equipment, sensors, and guides need to be properly anchored or restrained.

- All elevators should be inspected by qualified elevator technicians following an earthquake. Elevators should have a seismic switch or safety features that allow for safe shutdown in an earthquake.
- Elevator safety is governed by the prescriptive requirements in ASME A17.1/CSA B44 *Safety Code for Elevators and Escalators* (2007a), a document that is continually evolving reflect new elevator technologies. In addition, ASME A17.7/CSA B44.7, *Performance Based Code for Elevator Safety* (ASME, 2007b), is the next step in the evolution of elevator safety codes in the United States and Canada. Local or state jurisdictions may have other elevator requirements.
- As an example of state jurisdictions, the California Office of Statewide Health Planning and Development (OSHPD) provides special requirements for elevators in California hospitals, such as Title 24, Section 3007. These include requirements for a seismic switch connected to the essential electrical system, a visible or audible alarm, the ability to function at a "go slow" speed of not more than 150 feet per minute until the elevator can be inspected, and an additional sensor that will disable the elevator if the governor tail sheave is dislodged. For these systems, the seismic anchorage, guards and switches all need to be inspected annually.
- The internet provides a resource of information regarding elevators. A few websites are linked below:
  - The website http:science.howstuffworks.com/elevator1.htm describes the workings of a traction elevator and provides links to other resources
  - Jobsite safety in the elevator industry is discussed on http://safety.elevator-world.com/disaster.htm
  - The websites of the Elevator and Escalator Safety Foundation, http://eesf.org/, and major elevator suppliers such as The Otis Elevator Company and Schindler Elevators provide additional resources.
  - The National Elevator Industry, Inc. has other resources including a discussion of the performance based code for elevator safety (http://www.pbc-elevators.com/).

MITIGATION EXAMPLES

Figure 6.4.10.2-13 Small “machine-roomless” traction elevator with flat belts at the Academy of Sciences, San Francisco, California (Photos courtesy of Eduardo Fierro, BFP Engineers). Clockwise: Overview of elevator at roof; view of guide rails and sheaves; top of cab showing belts; view down shaft at belts, counterweight, guide rails and guide rail brackets.

Mitigation Details



Notes: Provide lateral restraints for guiderails to resist design forces and accommodate anticipated interstory drift.
Elevators should be installed, maintained, inspected and repaired by qualified elevator technicians.
Inappropriate seismic restraints may compromise the safe operation of these systems.

Figure 6.4.10.2-14 Schematic view of geared traction elevator system (ER).

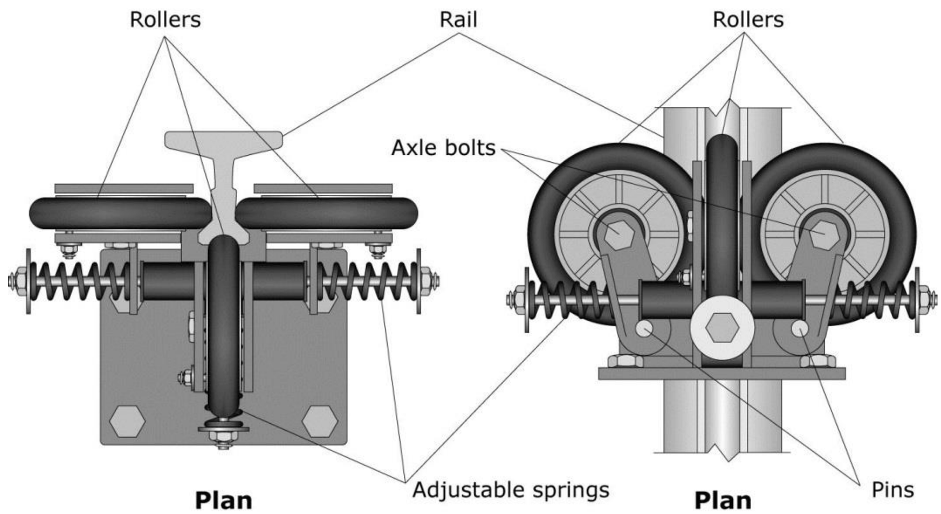


Figure 6.4.10.2-15 Spring loaded elevator guide with polyurethane rollers. Details of elevator guides vary from manufacturer to manufacturer, elevator load capacity, elevator speed, and whether used for guiding the car or counterweight.