SEISMIC BRACING

INTRODUCTION

The cost for a building can be broken down into three parts, structural, nonstructural, and contents. Structural would be those components that hold the building in place, foundation, beams columns, girders, diagonal bracing, floors, load bearing walls, and roof. Those components that transfer the loads on the building to the ground. The nonstructural would be the lights, plumbing, heating and ventilation equipment, ductwork, ceiling tiles, transformers, and electrical distribution equipment. The contents would be the furniture, portable partitions, racks, shelves, production equipment, computers, filing cabinets, stock, material in cabinets, etc. Depending on the occupancy of the building, the breakdown between the three would vary. For example, in an office building, the structural costs are approximately 20%, the nonstructural costs are approximately 60% and the contents are approximately 20%. In a warehouse building, depending on the cost of the product being warehoused, the breakdown could be as low as 10% for the structural, 10% for the nonstructural, and as high as 80% for the contents. In a manufacturing building, the breakdown will also vary depending on the product produced, the production equipment, and the equipment needed for the production equipment. The breakdown could be as low as 10% for the structural, 20% for the nonstructural, and as high as 70% for the contents. Again, depending on what is produced, the nonstructural could go as high as 50% because the production equipment has special needs such as lots of electricity.

The potential for earthquake damage necessitates damage mitigation measures or seismic bracing. These measures can preserve the structural integrity of buildings and can avert loss of life. Seismic bracing can also protect both nonstructural, building elements, fixtures, electrical equipment, etc. and building contents.

“An earthquake resistant” building provides reasonable restraint through its structural members. The structure is protected against collapse, although damage to nonstructural elements and building contents can occur.

The severity of damage will depend upon the magnitude of the earthquake, the integrity and stability of the building and contents, the distance of the site from the focus of the quake and the local ground conditions.

Figure 1 is a Modified Mercalli Intensity Scale presented by Federal Emergency Management Agency (FEMA) in FEMA Publication 74. The scale text is revised (from U.S. Geological Survey work by Dr. Robert Nason) to emphasize non-structural damage affects.

Section 7 of the AXA XL Risk Consulting’s *OVERVIEW* Manual and its forms packet contains information on preparedness. PRC.15.2 contains pertinent background information on earthquakes and PRC.2.0.9 is a discussion of earthquake design for buildings. FEMA Publications E 74, 178, and 547 discuss practical applications for seismic strengthening and reducing risks of nonstructural damage. Seismic bracing for sprinkler piping is discussed in NFPA 13 and PRC.12.1.1.0.

LIGHT

I-IV: From barely perceptible to mild shaking without damage

V: Felt by nearly everyone, and many are awakened if the earthquake occurs at night. Some dishes or other fragile shelf items fall and break. Cracked plaster or drywall in a few places. Movement of trees, power lines, and other tall flexible objects noticed. Pendulum clocks may stop. Water may slosh in swimming pools. Only a few shelf items in grocery stores shifted or fallen. Flexible items such as liquids in containers, tall floor lamps or chandeliers, etc., may move more than other more rigid objects such as furniture. Windows or contents of cabinets may rattle.

VI: Felt by all, many frightened. The top portion of some unreinforced brick chimney on houses are damaged. Some furniture shifted slightly. Shelf items throughout a grocery store may fall, but not to the extent that it is difficult to walk through all of the aisles. Cracks or occasional falling of pieces of plaster. Occasional large storefront windows cracked.

MODERATE

VII: Everyone notices and is alarmed by the earthquake. Persons driving automobiles notice the shaking. Unreinforced chimney damage common to older houses affects less than half of buildings. Many or most aisles of grocery stores blocked by fallen shelf items. Some spring mounted but not seismically restrained heating-ventilating-air conditioning equipment begins to shift but generally does not fall off its spring supports.

VIII: Many find it difficult to keep balance while standing. Shaking interferes with driving of automobiles. Widespread unreinforced chimney damage. Pipes may leak in buildings. Suspended ceilings without diagonal bracing partially fall. Spring mounted mechanical equipment without seismic restrainers breaks supports and falls. Tall unanchored shelving and storage racks lose contents or tip over.

SEVERE

IX: The shaking is very alarming to everyone and it is very difficult to stand. Widespread overturning of unanchored equipment if about twice as tall as wide, including some television set-sized items on tables or desks. Most unanchored shelving overturns. Sliding of other unanchored items.

X: Unusually severe ground motion, such as has been observed in only a very few earthquakes. People thrown to ground and cannot stand up. Most unanchored nonstructural objects except tables and desks fall. Objects do not fly through air but may bounce and overturn due to vertical shaking.

Figure 1. Modified Mercalli Intensity Scale Emphasize Nonstructural Damage Affects.

POSITION

AXA XL Risk Consulting recommends seismic restraint for structural building elements is designed per PRC.2.0.9. A licensed structural engineer familiar with seismic response applications must design restraint devices at facilities located in AXA XL Risk Consulting earthquake hazard zones 5, 6, and 7 to meet anticipated acceleration per earthquake hazard zone rating. Nonstructural building elements and contents to this section. These include partitions, parapets, signs, raised floors, false ceilings, internal furnishings, building service equipment, mechanical piping and fixtures. Suspended equipment should be independently braced.

Restrain objects that can topple by anchoring and fastening them at the base and at the top. Strap shelving and file cabinets together at the top corners to form stable shapes, then stabilize by anchoring to floors and walls. Figures 2 and 3 show these applications. Protect stacks, piles, racks and open bin shelving (see Figures 4) with wire, mesh or lip on the shelf. Open bins will spill their contents, therefore label stock that cannot be protected from spilling. Install swivel casters on large stand-alone equipment to act as base-isolation dampers (see Figure 5).

Desk or bench top equipment can be bolted down directly, restrained by edge lip or provided with adhesive material or fabric hook and loop fasteners such as Velcro™ adhered to the desk top and underside of equipment as shown in Figure 6. Anchor and cushion fragile, delicate and precision equipment subject to damage from vibration, bumping or jarring.

Anchor floor mounted equipment such as indoor transformers and switchgear and brace at the top to structural elements: Brace floor stands for items such as horizontal tanks, and battery racks in two opposing directions as shown in Figures 7 and 8. Fit operating equipment requiring highly flexible shock absorbing mounts with restraints and motion stops such as shown in Figure 9.

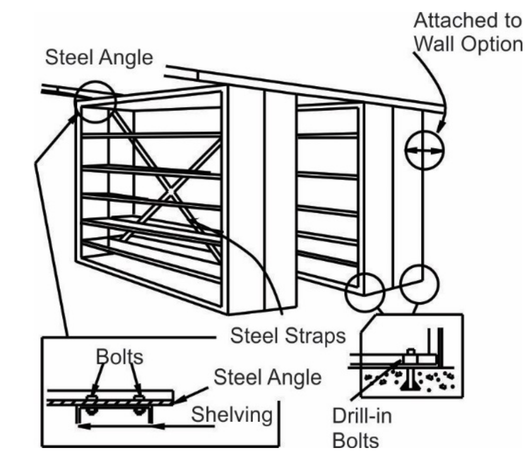

Figure 2. Restrain From Toppling.

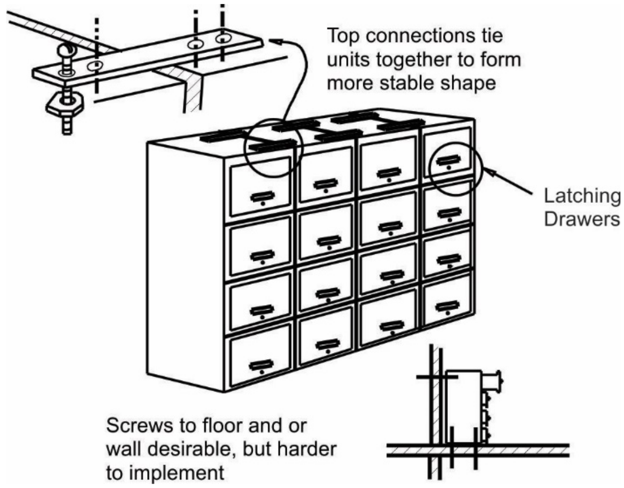

Figure 3. Stabilize Shape.

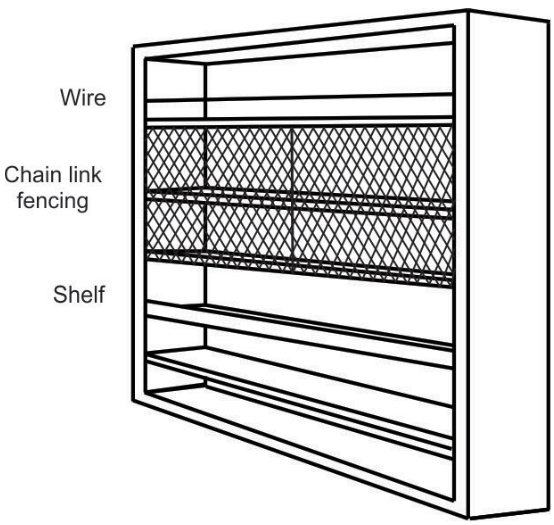

Figure 4. Shelf and Rack Stock Protection

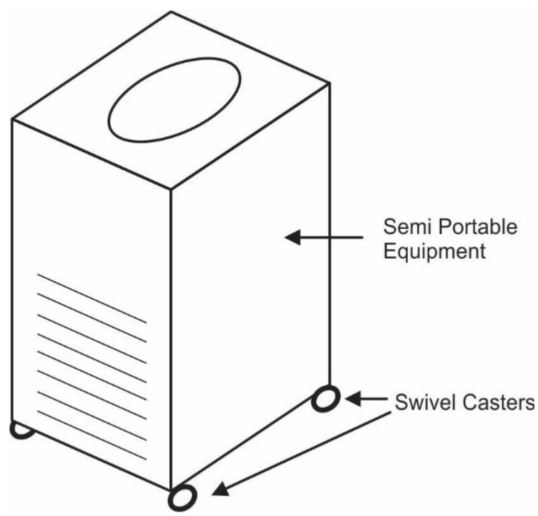

Figure 5. Semi Portable Equipment on Swivel Casters

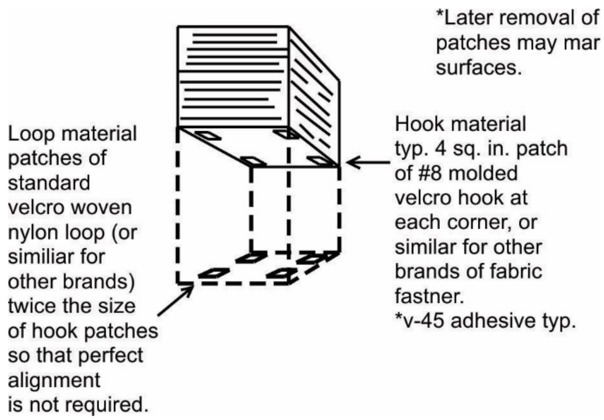

Figure 6. Anchor To Desktop.

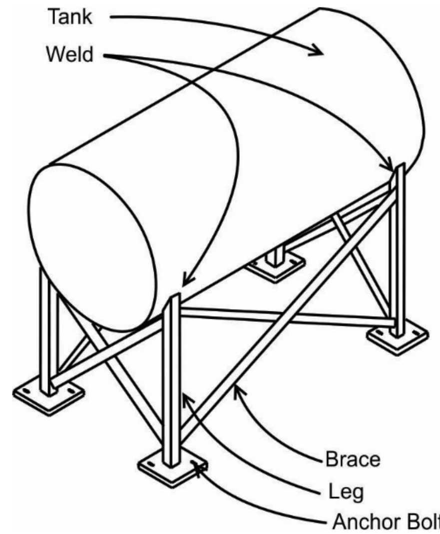

Figure 7. Braced Floor Stand.

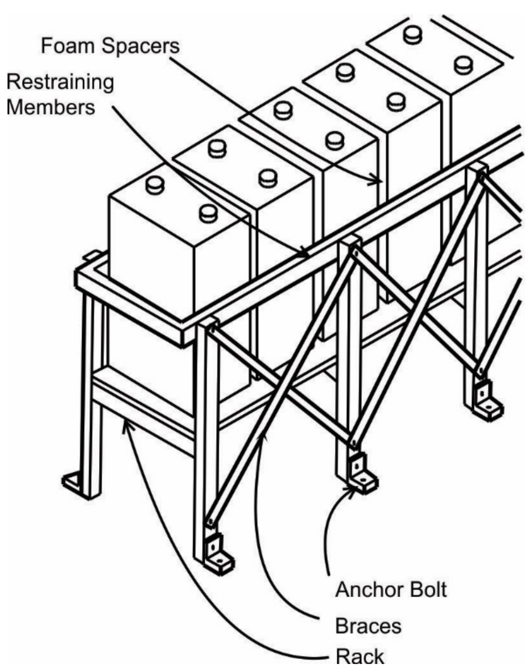

Figure 8. Braced Rack.

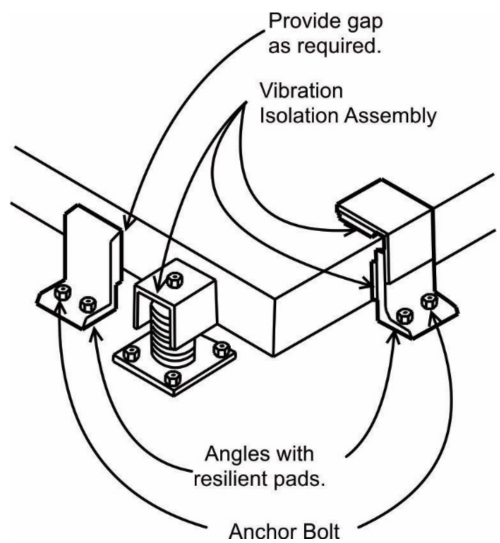

Figure 9. Motion Stops.

Provide flexible connections for piping and wiring conduits at isolation, shock absorption and energy dissipating installations or where vibrations will differ significantly. For example, anchor a suction tank to its foundation and anchor the pump and driver separately as a unit assembly to a base on the floor of the adjoining pump hose. The tank will oscillate at a different fundamental frequency in an earthquake than the pump house and pump assembly. Use flexible connectors in the piping between the pump and tank. Use of flexible connectors for piping at building entrances, across faults and ground/soil type changes (soil vs rock). Also provide emergency equipment, such as power generators, with this protection.

The potential for rupture of water, gas and fuel, electrical supply and communication conduits (piping or wiring) is high, particularly where materials are brittle types. Provide isolation valves and switches, excess flow safety devices and disconnects to minimize damage and retain as much service as possible.

Sway brace and securely support ceiling tiles, light fixtures, diffusers and other hanging objects. Figure 10 shows bracing for ceiling mounted and suspended components in opposing directions. Lateral bracing for suspended ceilings and lighting fixtures are shown in Figures 11 and 12. The concept is also used for ducts, piping, cable trays and other equipment as shown in Figures 13 through 16.

Nonstructural elements of buildings can be strengthened by bracing or improving fastenings also. Parapets, building appendages, interior partitions, signs and stacks are usually exposed and lend themselves to bracing attachment. Mechanical and electrical equipment whether floor, wall or ceiling mounted should be securely anchored, (bolted or welded) to minimize movement. Piping, cable trays, ductwork and wiring conduits can be braced and strapped. Raised floors, such as computer room floors and dropped ceilings can also be braced and equally important, equipment should be braced with and through the supplemental floor or ceiling to structural members. Production and process equipment responds to earthquake forces in like manner and should also be anchored, braced and restrained. Any non-structural component or building element which can break away, tip, topple, slide or fall needs to be secured at top and base, braced and restrained or isolated and restrained.

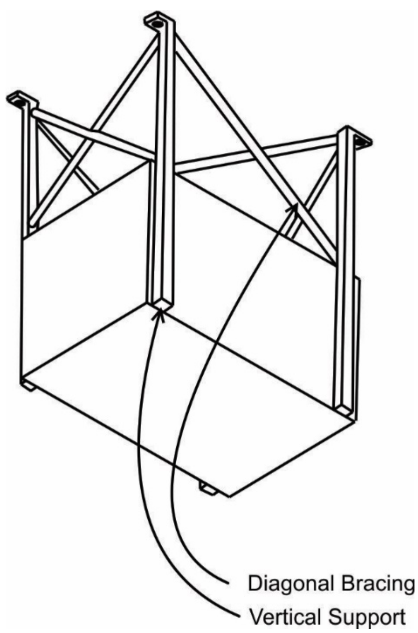

Figure 10. Duct Bracing.

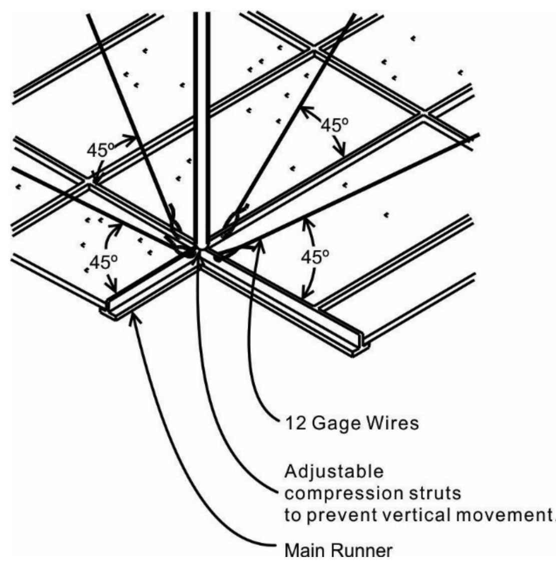

Figure 11. Drop Ceiling Bracing.

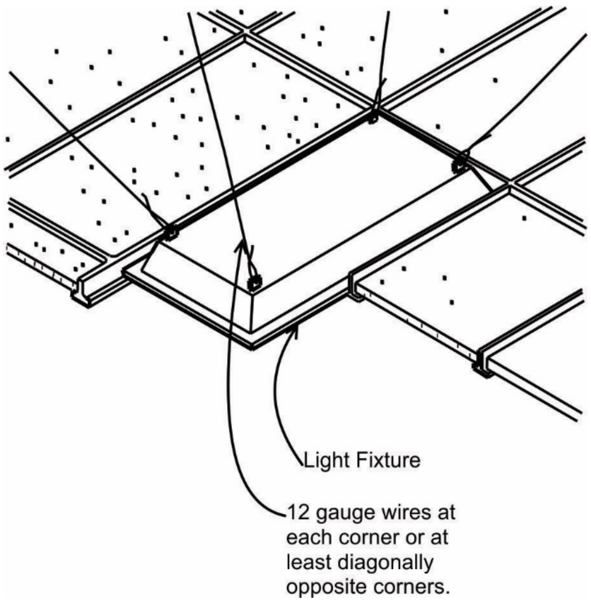

Figure 12. Ceiling Fixture Brace.

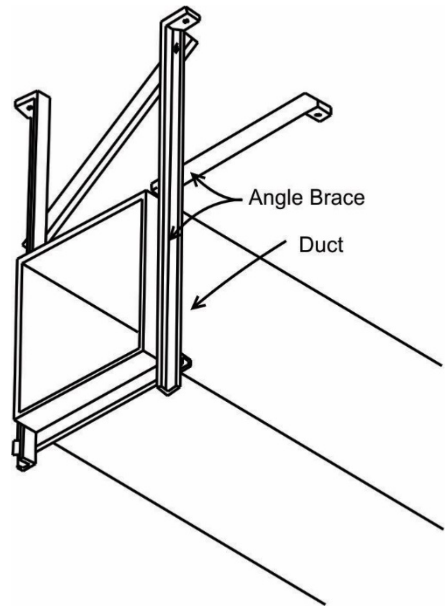

Figure 13. Duct Bracing.

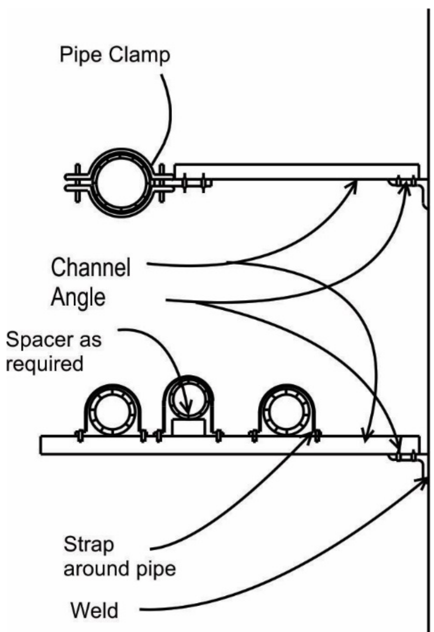

Figure 14. Sidewall Pipe Bracing.

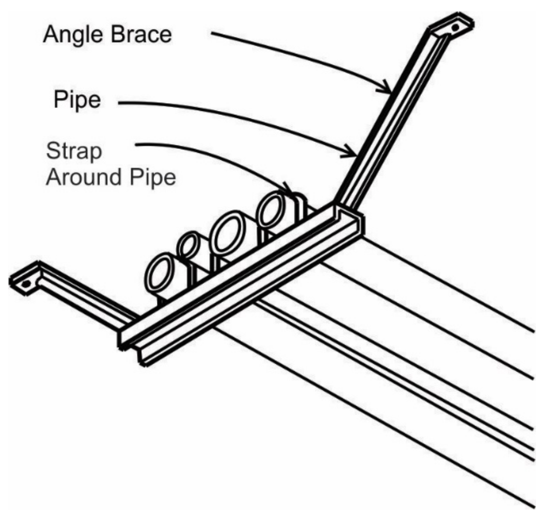

Figure 15. Ceiling Pipe Bracing.

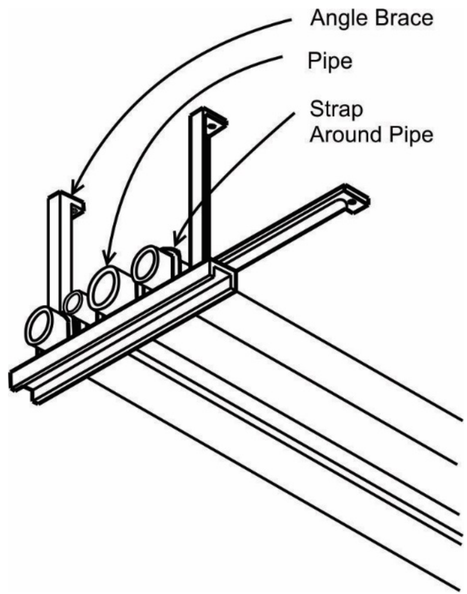

Figure 16. Ceiling Pipe Bracing.

DISCUSSION

As noted in PRC.2.0.9 the principal cause of damage in an earthquake is shaking which results from the effects of vibration originating at the source of the earthquake. The same principles of seismic design apply to existing structures as well as new building design. The technique for strengthening of existing buildings differs in connecting to, infilling between and reinforcing elements of construction already in place. An existing building structural system can be improved (strengthened) by addition of reinforcement, addition of redundant elements or provision of a supplemental system.

Cover plates can be used to modify steel beams and columns (see Figures 17 and 18). Concrete elements can be encased in reinforced concrete for added stiffness. A reinforced concrete shear wall can be infilled within an existing frame opening to strengthen the structure.

Bracing by diagonal strapping (Figure 19) or, in steel construction, braced frame designs ranging from X-brace and K-brace to tension rod bracing are used to strengthen structural frames. Supplemental strengthening in the vertical plane can take the form of additional bay bracing or buttress bracing. Floors and roof, which typically transmit forces in the horizontal plane, can be strengthened by tightening fastenings, nailing attachments and connections. Add supplemental capacity, such as an overlay wood or steel beam, plywood sheeting or reinforced concrete casting. The intent is to improve stiffness of the structure and minimize or eliminate free gap space between elements. On occasion to improve the seismic response of a building it may be more practical to provide a complete redundant braced frame, remove an upper story, provide an energy absorption system employ a base isolation system, or become involved in major reconstruction.

Floor to wall and wall to roof connections are critical points of fastening. Footings and foundations also may need to be improved, particularly if the structure is sited on poor ground or soft soils. Underpinning of footings and supplemental piles are viable methods of strengthening the building base. Attachment of wall to foundations connectors may also need to be toughened to resist uplift (improve hold down) as well as to resist shear.

Contents of buildings, if not adequately anchored, supported or braced, can be damaged. Building utilities such as boilers, pumps and piping, transformers, substations, domestic water, air and gas piping and emergency equipment will be exposed to earthquake motions. Underground piping is subject to rupture by shear and tension, offset, compression buckling and joint rupture. Fixtures, furniture and standing equipment can topple, fall, slide or tip, spill stock and collapse.

Equipment on desks or benches may slide off, ceiling tiles fall, partitions crack and break and glass windows break. Piled stock may topple. Equipment not properly anchored to the floor may slide or tip and pull wires and pipe connections. Container leakage can also be serious. Inline units may misalign. Control equipment in particular may be susceptible to shaking and shake damage.

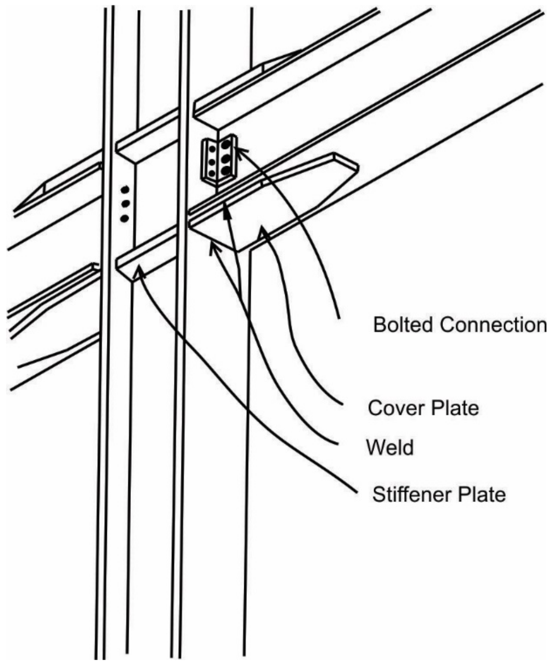

Figure 17. Beam Stiffener.

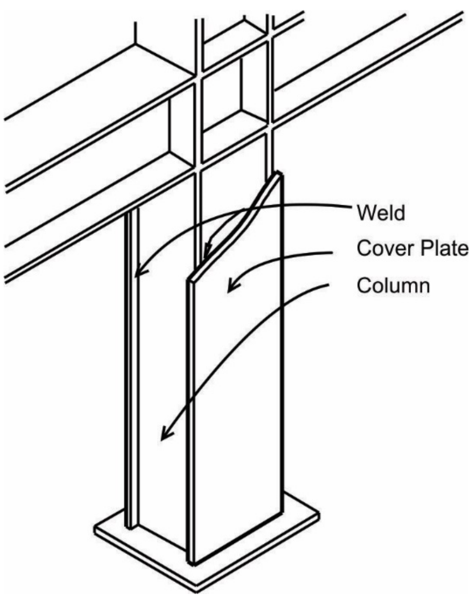

Figure 18. Column Stiffener.

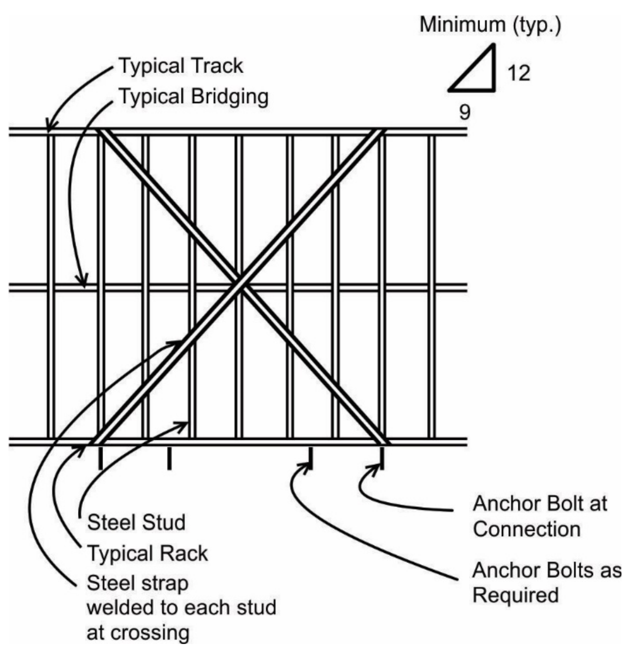

Figure 19. Wall X Brace.

GLOSSARY

Appendage - An architectural component such as a canopy, marquee or ornamental balcony.

Base - The level at which the horizontal seismic ground motions are considered to be imparted to the building.

Braced frame - An essentially vertical truss, or its equivalent, of the concentric or eccentric type that is provided in a building frame or a dual system to resist lateral forces.

Building frame system - A structural system with an essentially complete space frame providing support for vertical loads, with shear walls or braced frames providing support for lateral loads.

Concentric braced frame - A braced frame in which the members are subjected primarily to axial forces.

Damping - The internal energy absorption characteristic of a structural system that acts to attenuate induced free vibration.

Diaphragm - A horizontal, or nearly horizontal, system designed to transmit lateral seismic forces to the vertical elements of the seismic resisting system.

Eccentric braced frame - Braced frame where at least one end of each brace intersects a beam at a point away from the column-girder joint.

Fundamental period of vibration - The time it takes the predominant mode of a structure to move back and forth when vibrating freely.

Horizontal bracing system - A horizontal truss system that serves the same function as a diaphragm.

Moment resisting frame - A structural system frame providing support for vertical loads with members and joints are capable of resisting lateral forces primarily by flexure.

Redundancy - The presence of multiple alternate load paths such that when one significant element fails there is another to take over its load in the lateral force resisting system.

Shear wall - A wall, bearing or nonbearing, designed to resist seismic forces acting in the plane of the wall.

Soft story - Story in which the lateral stiffness is less than 70% of the stiffness of the story above.

Structure - An assemblage of framing members designed to support gravity loads and resist lateral forces.

Supplemental element - A member added to an existing lateral-force-resisting subsystem that shares in resisting lateral loads with existing members of that subsystem.

Vertical resisting elements - Part of the structural system located in a vertical or near vertical plane that resists lateral loads, typically a moment frame, shear wall or braced frame.