3.0 WATER SUPPLY SYSTEM SEISMIC VULNERABILITY

This section describes water system components, their vulnerability to earthquakes, and earthquake mitigation measures. The section is divided into five subsections including sources, treatment plants and pumping stations, pipelines, storage tanks and reservoirs, and system monitoring and control. The first four subsections are further divided into system component types within their respective group. Each system group component is described, and seismic damage and mitigation alternatives presented.

3.1 SOURCES

This subsection includes sources of water supply including watersheds, dams, and wells.

3.1.1 Watersheds

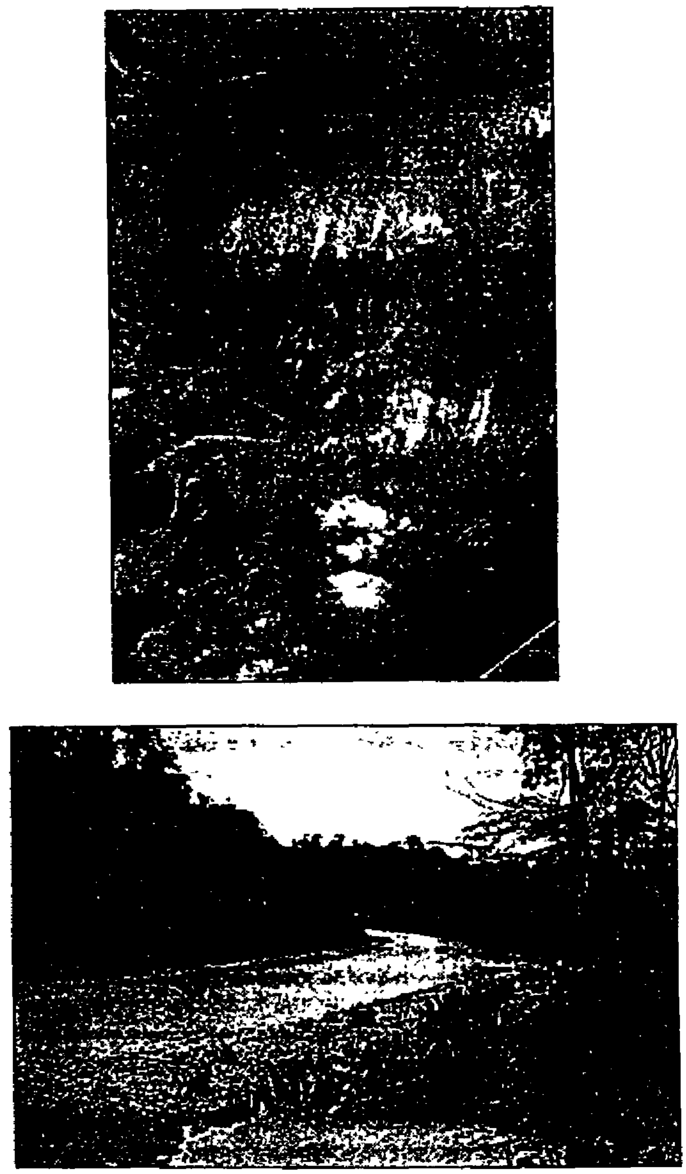
3.1.1.1 Description. Watersheds are areas where surface water generated from rainfall and snow melt is gathered. Usually watersheds feed a natural stream or river. Water is then either impounded behind a dam or diverted for immediate use.

3.1.1.2 Seismic Damage and Mitigation Alternatives. Landslides in watersheds can result in extreme turbidities when ground surfaces that are usually stabilized by vegetation become exposed, and are subject to erosion. It may be possible to stabilize areas susceptible to landslides, but will likely be very expensive. Access to slide areas may be very difficult during emergency response.

Watersheds are also subject to contamination by hazardous materials. Pipelines carrying petroleum products sometimes traverse watersheds, and may break in an earthquake. Highways or railroads may also cross watersheds. Trucks or tank cars may carry hazardous chemicals that could spill in both earthquake and non-earthquake conditions. The most effective way to control release of hazardous materials is to keep them out of the watershed. Close monitoring and practiced emergency response plans may become crucial if a spill occurs.

If water from a watershed becomes unusable, system operational flexibility becomes important. Alternate supplies or alternate intake sites (above the source of the contamination) are useful. For example, the City of Everett, Washington can draw water directly from their river source, or take it from a large off-stream impoundment. Limon, Costa Rica reactivated their groundwater supply after the 1991 earthquake raised turbidity in the watershed.

Treatment flexibility may allow treatment of more turbid raw water supplies. Operating a plant at lower loading rates and/or adding additional or different coagulants may allow the plant to produce water with acceptable drinking water quality. While these alternatives may be more expensive than "normal" operation, they may allow the purveyor to get through the disaster.



Photographs 3-1 and 3-2. Watershed providing water to Limon, Costa Rica water treatment plant had extensive landsliding, resulting in turbidity increases in the Rio Bannano to 2,400 NTU.

In addition to Costa Rica, non-earthquake landslides have caused emergency situations in both the Portland, Oregon Bull Run watershed and the Centralia, Washington watershed. Emergency response was crucial in both these instances. Alternate supplies would have been beneficial in both cases.

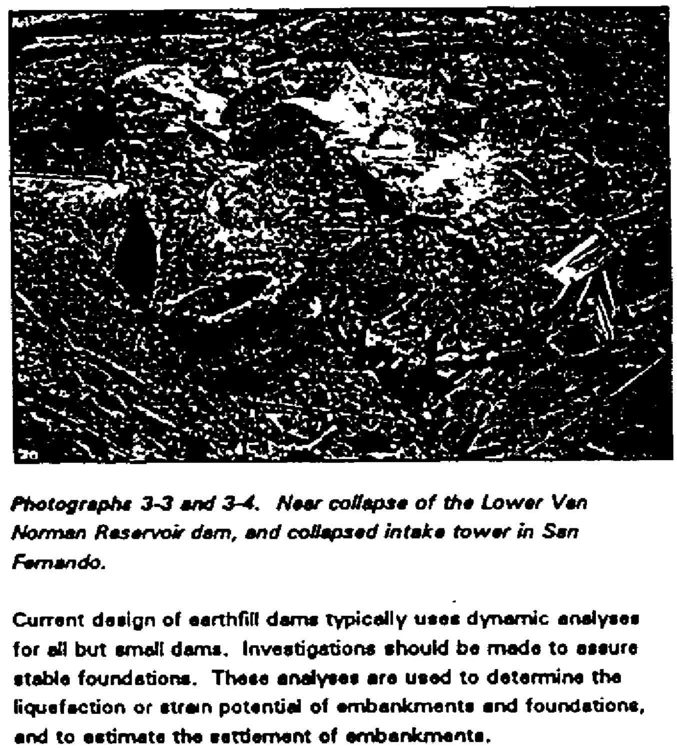
3.1.2 Dams/Intakes

3.1.2.1 Description. Dams retaining water for water systems are usually earthfill, rockfill, or concrete with gates, spillways, conduits, tunnels, and intake structures. Earthfill dams include an impervious core, typically a clay material, transition zones, drains, and sand filters adjacent to the core. Grout is frequently provided under the impervious core in the foundation material, and in the abutments to prevent water penetration through cracks and fissures in bedrock or flow through permeable native soils. Rockfill dams typically have concrete linings to prevent water penetration. Types of concrete dams include gravity and arch.

Water intake structures associated with storage reservoirs are typically tower-type structures that are vulnerable to inertial effects, and settlement and landslides at the bottoms of the reservoirs. Toppling of these towers allows coarse sediment to enter the distribution system, plugging pipelines and causing extensive damage to valves, pump bearings, and seals.

3.1.2.2 Seismic Damage and Mitigation Alternatives. Most engineered, mechanically compacted earthfill dams have performed well in earthquakes. Earthfill dams constructed predominantly with clayey soils have performed well. Earthfill dams experiencing failures in past earthquakes include dams constructed of hydraulic fill using saturated, poorly compacted, fine-grain cohesionless material; dams constructed on natural cohesionless, deposits that are not as dense as the embankments; or dams with unusually steep embankments.

Dam embankments may respond to soil failures by cracking (usually at the crest or near the crest and abutments), spreading or settling, or by slope stability failures or zonal separations. Liquefaction may occur in saturated zones of cohesionless materials that are loose or marginally compacted, such as hydraulic fills.



Photographs 3-3 and 3-4. Near collapse of the Lower Van Norman Reservoir dam, and collapsed intake tower in San Fernando.

Current design of earthfill dams typically uses dynamic analyses for all but small dams. Investigations should be made to assure stable foundations. These analyses are used to determine the liquefaction or strain potential of embankments and foundations, and to estimate the settlement of embankments.

Conservative crest details include providing transition and shell zones that extend to the crest to control any seepage that develops through cracks, and providing camber for static and dynamic settlement. Reduction of embankment slopes and elimination of embankment saturation through linings can reduce susceptibility to embankment failures.

Earthquake-induced landslides may block water outlet features or spillways or cause waves that overtop the dam and cause erosion. Where cracks are opened in the embankment or foundation, the danger of piping exists if cracks remain open. Seismic design practices for earthfill dams include providing ample freeboard to allow for settlement and other movements, adequate spillway capacity for maximum storms, and using wide cores constructed of material resistant to cracking.

Both soil and rock foundations may be damaged by fault rupture, resulting in loss of continuity or integrity of internal design features (e.g., drains and impervious zones), and water-release features (e.g., conduit and tunnels). A thorough investigation should be conducted by a seismologist/geotechnical engineer to identify fault structures and their activity.

Rockfill dams have performed well, with some damage to material near the crest of the dam. Settlement of rockfill dams is also a possibility.

Concrete dams have also preformed well with little known damage. Cracking of dams and foundation failures are possible. Seismic-resistant design of concrete dams includes thorough foundation exploration and treatment, and selection of a good geometrical configuration. Dynamic analyses similar to those used for earthfill dams may be used to check designs, and to determine stresses and cracking potential of dams and dam appurtenances. Stabilization of existing dams can be achieved by buttressing, draining, or reduction in reservoir storage.

3.1.3 Wells

3.1.3.1 Description. Groundwater is withdrawn using wells or infiltration galleries. A well system is generally composed of seven elements:

1) Aquifer
2) Well casing and screen
3) Pump and motor
4) Power supply
5) Electrical equipment and controls
6) Connecting piping, valves, and appurtenances
7) The well house structure.

The well system may or may not be located in a well house. Discussion in this section will be limited to items 1 through 3, above. Items 4 through 7 will be discussed in Section 3.2 (Treatment Plants and Pump Stations).

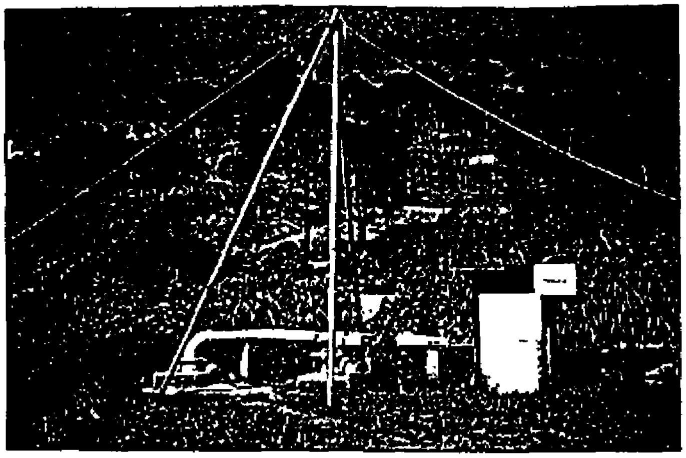
Wells typically consist of steel casings penetrating groundwater aquifers. Modern well casings are installed with concrete slurry well seals around their periphery to keep surface water from running down the annular space between the casing and the ground. Older wells sometimes do not have well seals. The casings are fitted with screens in the water-bearing formation to allow water to enter the casing. Some older wells were constructed by cutting slots in the casing rather than using screens. Municipal wells usually use vertical turbine pumps installed below the water table. The pumps can be driven by submersible motors attached directly to the bottom of the pump, or by line shafts connected to the motor at the well head. Line shaft pumps can also use right-angle drives, and be powered by internal combustion engines.

3.1.3.2 Seismic Damage and Mitigation Alternatives. The geohydrology of aquifers can change their production capacity. Shallow aquifers seem to be impacted more than deeper aquifers, as occurred in private wells in the Santa Cruz Mountains in the Loma Prieta earthquake. Aquifers can be contaminated by raw sewage from nearby sewers (City of San Fernando, 1971 San Fernando earthquake), septic tank effluent, or hazardous materials finding their way into the aquifer through permeable layers or along an unsealed well casing.

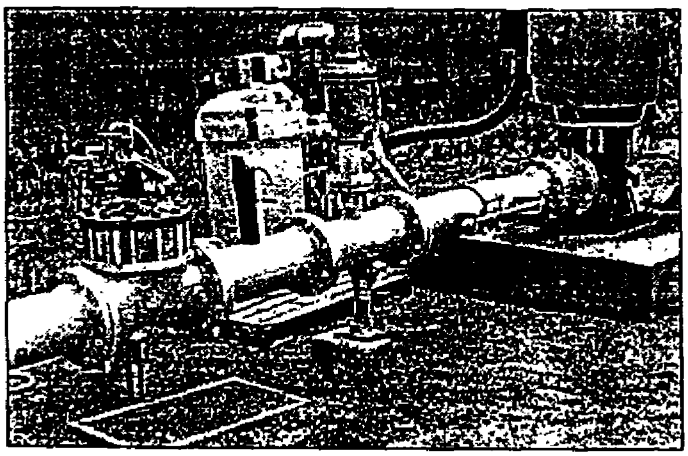
Photograph 3-5. Septic system contaminated a shallow well resulting in illness in many children south of Limon Costa Rica.

Aquifer geohydrology is almost impossible to control. Providing operational flexibility to use alternative water sources is recommended. Aquifer contamination can be controlled by providing well seals and a well head protection program. Septic systems should not be located near wells. Nearby sewers should be designed to be seismic resistant.

Well casings and pumps ~~will move with~~ earthquake wave passage with the surrounding soils. This movement can result in physically breaking or disconnecting pumps, motors, and/or discharge lines that do not have flexible couplings. Soils surrounding the well can consolidate resulting in the apparent extension of the well casing out of the ground. Connecting piping can break.



Photograph 3-6. A-frame over well used to pull broken pump in Baguio, Philippines.



Photograph 3-7. Settlement around well casing resulted in leaking well discharge pipe in Landers earthquake.

Pumps should be constructed of steel rather than cast iron, allowing them to absorb energy from shaking. The pump discharge head (on the top of the well) should be also be steel rather than cast iron. Provide flexibility between the well casing and surrounding building slab, and the well casing and connecting piping.

The well casing, pump discharge line (upcomer), and line shaft can be bent, crushed, or sheared off by ground displacement or vibration. Submersible pumps are not dependent on the line shaft and are, therefore, more reliable. If the casing is bent, withdrawal of the pump, regardless of type, may be impossible.

Photograph 3-8. Well casing bent 15 degrees from vertical as a result of lateral spreading in Dagupan, Philippines.

Avoid areas where lateral spreading is likely to occur, such as areas vulnerable to liquefaction on a slope or near a free face. If they cannot be avoided, stabilize the area or strengthen the well casing to resist lateral ground movement. Use of heavy well casings or double casings to the depth where liquefaction is expected may limit damage by allowing movement of the outer casing, but not the inner casing where pumping equipment is installed.

Well water can become turbid, but typically only for a period of several hours or less. Wells may start sanding (pumping sand). This typically occurs in wells with slotted casings, and not with properly designed screens. This can result in pump damage or motor burn-out. Use well screens rather than slotted casings, a practice currently used for most municipal wells in the United States.

Wells can also become contaminated when the well head is flooded. This occurred in Nicaragua in 1992 when a tsunamis flooded wells with water contaminated from latrines.

3.2 TREATMENT PLANTS AND PUMPING STATIONS

This subsection includes treatment plant and pump station facilities, and components of well facilities similar to pump stations. Each type of facility is described. They are then divided into common facility component groups to describe typical seismic damage and mitigation alternatives. Common facility component groups include process tanks and structures, equipment and piping, electrical power and instrumentation, and buildings and structures. In addition, following facility descriptions, foundation and geotechnical failures are discussed. This subsection concludes with a discussion of facility operational flexibility and redundancy.

3.2.1 Description

Water treatment plants are provided to enhance the water quality of drinking water supplies for public health and aesthetic reasons. Treatment plants can be categorized as surface water or groundwater treatment plants. Surface water plants are designed to remove turbidity and pathogens, and usually provide disinfection and corrosion control. Their raw water source is usually watersheds, rivers, and/or impoundments.

Groundwater treatment plants are typically used to remove iron and/or manganese or other organic and inorganic contaminants, or soften water. Their water source is wells or springs.

Treatment plants often use chemicals for coagulation (e.g., alum or ferric chloride, polymer), pH adjustment and/or corrosion control (e.g., caustic or lime), disinfection or oxidation (e.g., chlorine gas, hypochlorite, ozone, or potassium permanganate), and other miscellaneous uses (e.g., fluoride or activated carbon).

Typical water treatment plant components are listed below. In addition, many water treatment plants may include raw water or treated water pumping stations.

3.2.1.1 Process Tanks and Structures.

- Presedimentation tanks
- Aeration tanks
- Rapid mixing tanks
- Flocculators - paddles or baffles
- Sedimentation tanks/clarifiers
- Filters - gravity/pressure
- Water storage tanks/clear wells
- Backwash water tanks/sludge storage
- Channels and pipe galleries.

3.2.1.2 Equipment and Piping.

- Yard piping
- Plant piping
- Water pumps, blowers, and compressors
- Chemical feed pumps/equipment
- Chemical tanks
- Small water or fuel tanks
- HVAC equipment
- Lab/office equipment
- Storage shelving.

3.2.1.3 Electric Power and Instrumentation.

- Substations
- Transformers
- Control cabinets
- Conduit/cable trays
- Computers/computer floors
- Telemetry equipment
- Emergency generators - starting, fuel, cooling, and exhaust systems
- Control center
- Lighting.

3.2.1.4 Buildings.

- Operations buildings
- Maintenance buildings
- Chlorine buildings
- Buildings covering other process units.

Pumping stations include stations adjacent to reservoirs and rivers, and booster stations intended to increase head. Pumping stations typically comprise shear-wall-type buildings, pump and motor units, pipes, valves, and associated electrical, mechanical, and control equipment. Vertical turbine and horizontal split case pumps are the two primary types of pumps used. Often an emergency power supply comprising a standby diesel generator, battery rack, and diesel fuel tank is included in pumping stations to operate in emergency situations when electric power fails.

Well facilities include equipment and piping, electrical power and instrumentation equipment, and buildings described in this section.

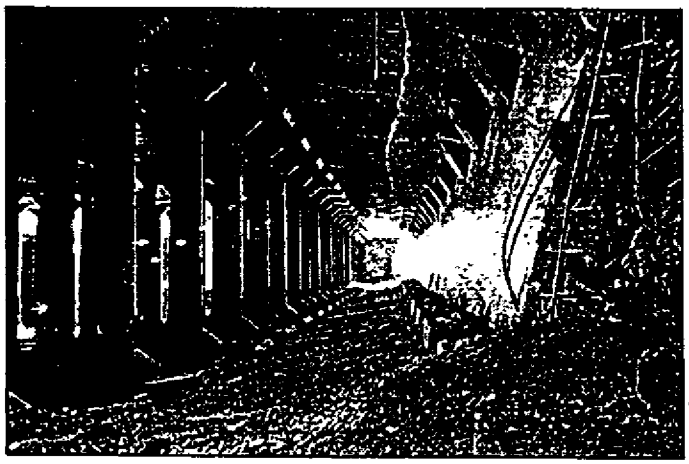
3.2.2 Foundation and Geotechnical Failures and Mitigation Alternatives

Tank structures and channels/large conduits in water treatment plants are vulnerable to differential settlement, increased lateral soil pressures, and flotation. Landslide may also be a concern at particular sites.

Differential settlement is most likely when a structure is founded on soils subject to densification or soils/foundations that are inconsistent across the structure. Differing supporting fill thickness or using different types of foundation across a structure are examples.

The facility should be located so as to avoid soils that may densify. Structures should be founded on a consistent foundation throughout. Otherwise, structures should be designed to resist expected soils failure or with provision to accommodate the expected movement.

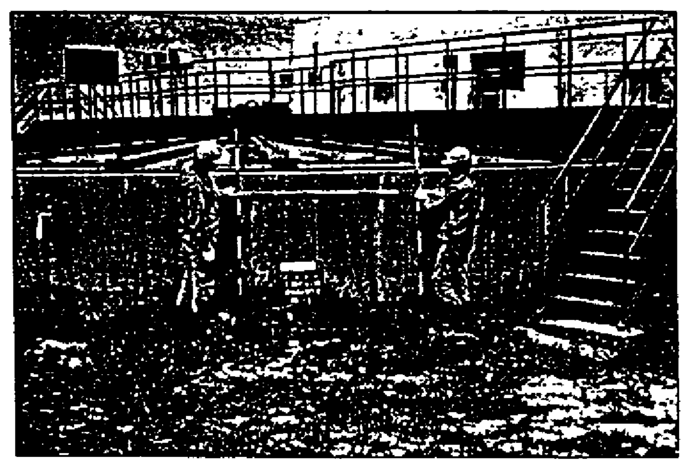
Earthquakes will increase lateral soil pressures on inground structures. Methods developed by Mononobe and Okabe (ASCE 1983) provide direction on accounting for increased active soil pressures. Passive soil pressures may be activated when liquefaction-induced lateral spreading occurs. Refer to Chapter 2.0 for a discussion on liquefaction mitigation.



Photograph 3-9. Inside of Jensen Water Treatment Plant clearwell damaged as a result of geotechnical failure.

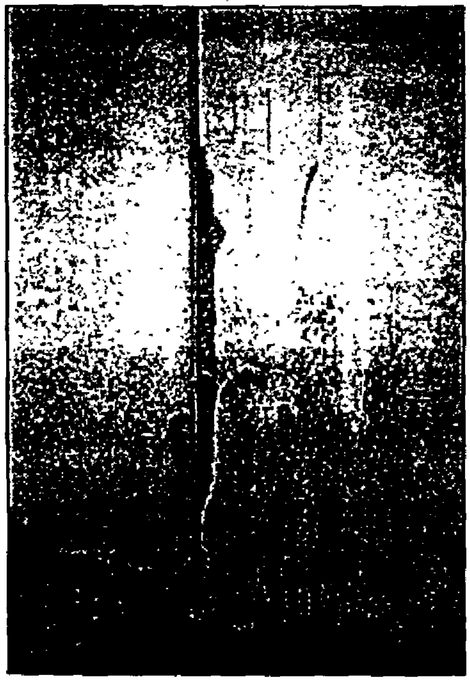
Photograph 3-10. Ground cracking above clearwell.

Liquefaction may cause underground structures in areas of high groundwater to float or subside differentially. Refer to Chapter 2.0 for a discussion on liquefaction mitigation. Keeping tank full offers some mitigation from flotation.



Photograph 3-11. Floating wastewater tank resulting from liquefaction in Niigata.

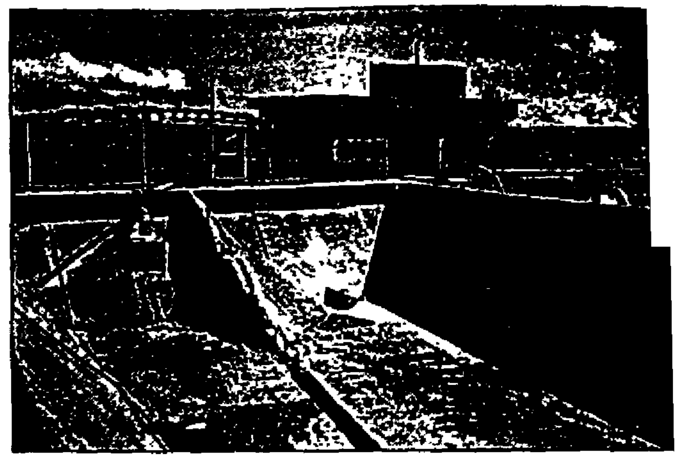
Pounding damage or permanent movement between adjacent, but unattached or inadequately attached structures, may result in the opening of expansion joints in basins. Provide flexibility between such structures.



Photograph 3-12. Construction joint opened along wastewater channel in Santa Cruz during the Loma Prieta earthquake; leaking caused extensive undermining of the structure.

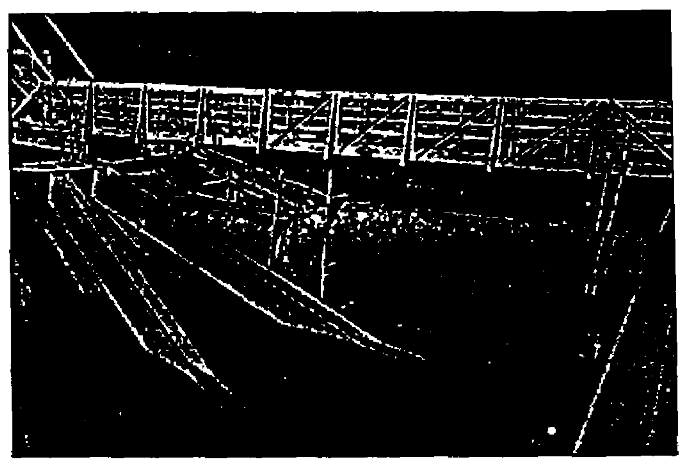
3.2.3 Process Tanks and Structures

Reinforced concrete process tank structures have performed well in the United States in earthquakes where they were not subjected to geotechnical failure. In several earthquakes outside the United States, lightly reinforced concrete baffles have failed. New concrete structures should be designed in accordance with the new American Concrete Institute, Concrete Environmental Engineering Structures, ACI 350.

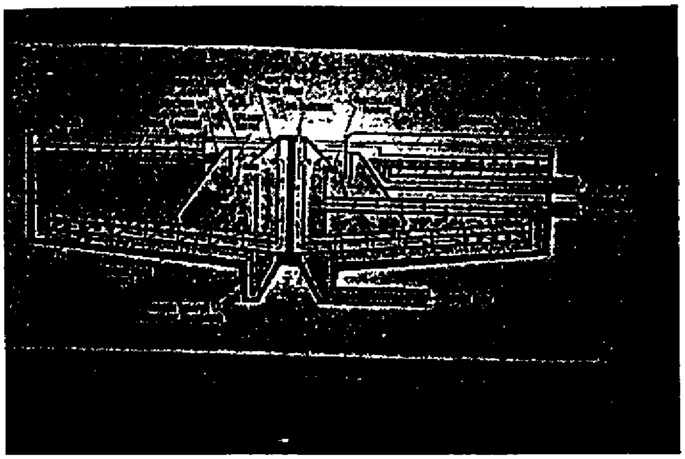


Photograph 3-13. Water treatment plant tank baffle collapsed in Baguio, Philippines.

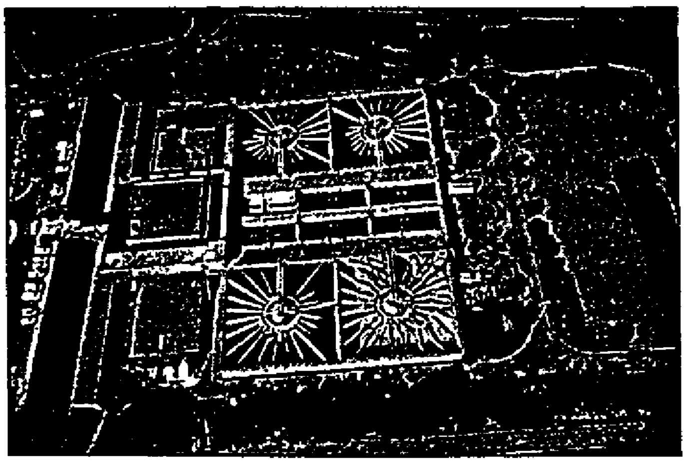
Process tank baffles and other immersed and floating elements have been damaged from the effects of very significant hydraulic loading acting on the element.



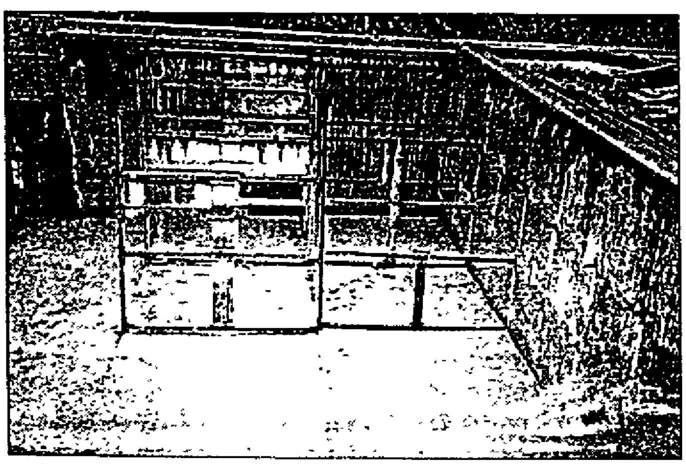
Photograph 3-14. Hydraulic loading heavily damaged reactor/clarifier mechanism at Rinconada Water Treatment Plant.

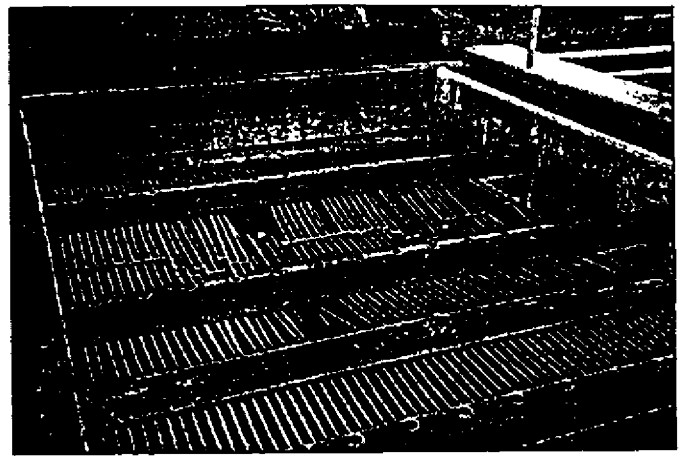


Photograph 3-15. Sectional view of Rinconada reactor/clarifier.

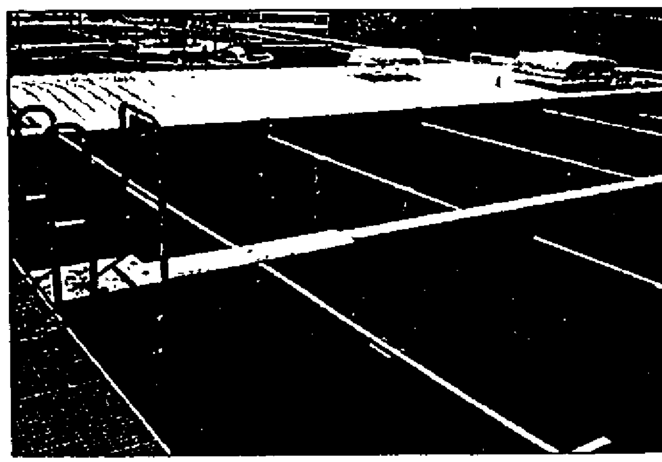


Photograph 3-16. Aerial view of Rinconada plant shows a number of failed launders in three tanks. The fourth tank was out of service and was not damaged.



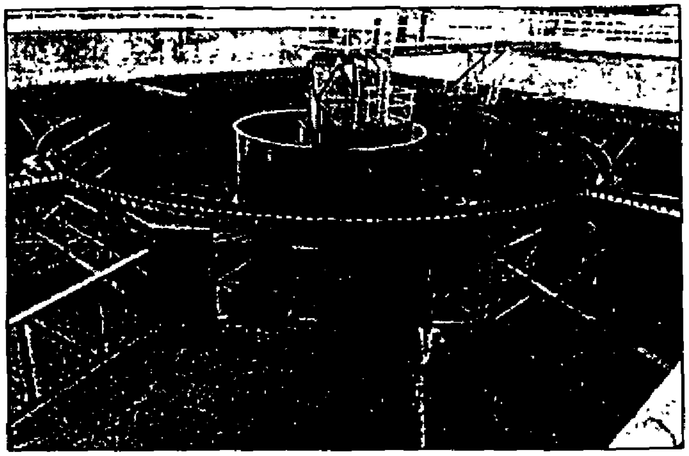


Photographs 3-17 and 3-18. Flocculator baffles and clarifier inclined plates damaged in Limon, Costa Rica Water Treatment Plant.

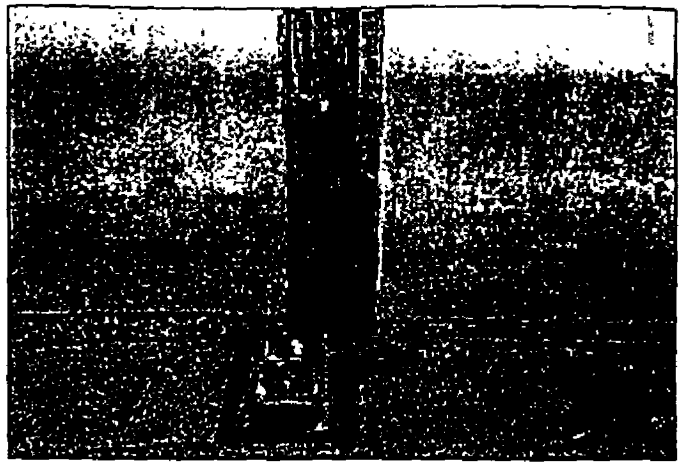


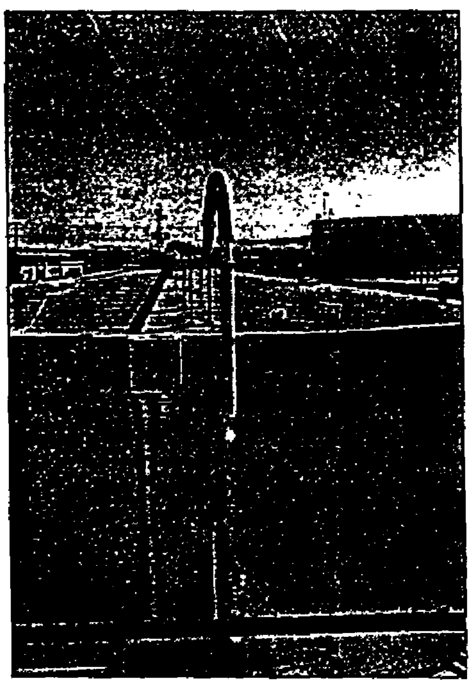
Photograph 3-19. Repaired flocculator wooden baffles had been broken like match sticks at Montevina Water Treatment Plant in the Loma Prieta earthquake.

Similar damage has occurred at wastewater facilities to secondary clarifier baffles and floating wastewater sludge digesters. Sloshing water has pushed rectangular access hatches out of their frame allowing them to drop to the bottom of the basin. Damaged baffles falling to tank bottoms need to be removed before sludge collector mechanisms can be operated.

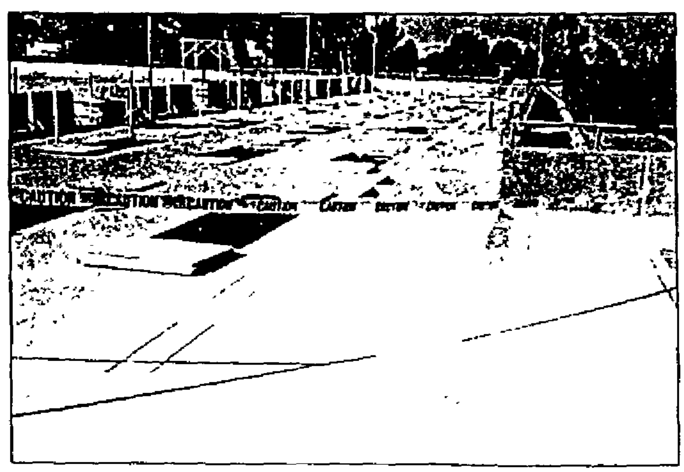


Photograph 3-20. Damaged baffles in secondary clarifier from Loma Prieta earthquake.





Photographs 3-20, 3-22, and 3-23. Sludge digester floating cover moved, bending guide rail, and breaking guide wheel in Loma Prieta earthquake.

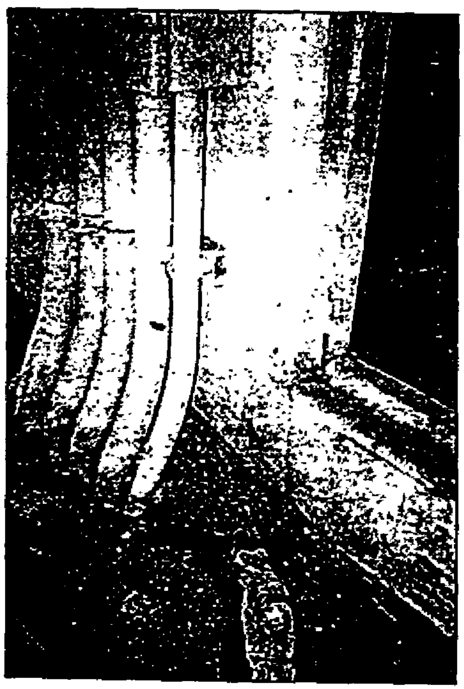


Photograph 3-24. Sloshing water pushed access hatches out of their frames, causing them to fall into the primary wastewater tank at Palo Alto in the Loma Prieta earthquake. Hatches had to removed before the sludge collector could be operated

Baffles and other immersed elements should be designed to either withstand the large loading or, more reasonably, to break away and be quickly replaced. Break-away elements should be secured to keep them from falling to the tank bottom and jamming sludge collector mechanisms. (Kennedy/Jenks/Chilton 1990a) There is no reasonable approach to accommodate sloshing for floating digester covers.

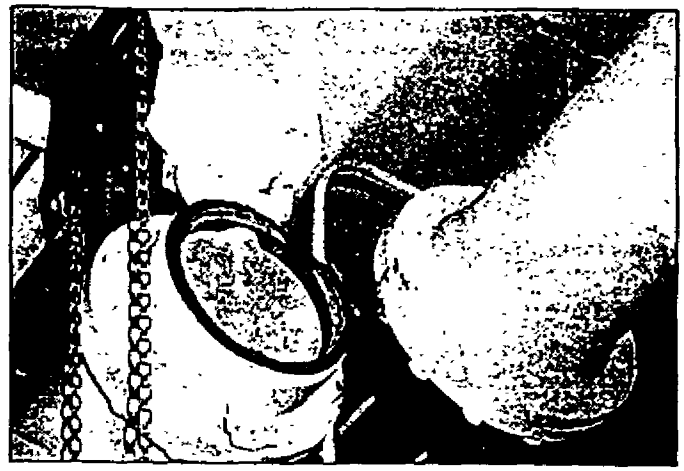
3.2.4 Equipment and Piping

Yard piping is vulnerable where it interfaces structures, particularly when differential settlement occurs. This is of greatest concern when structures are pile supported and the piping is direct buried. Provide flexibility at interfaces using double flexible couplings in series or proprietary flexible joints.

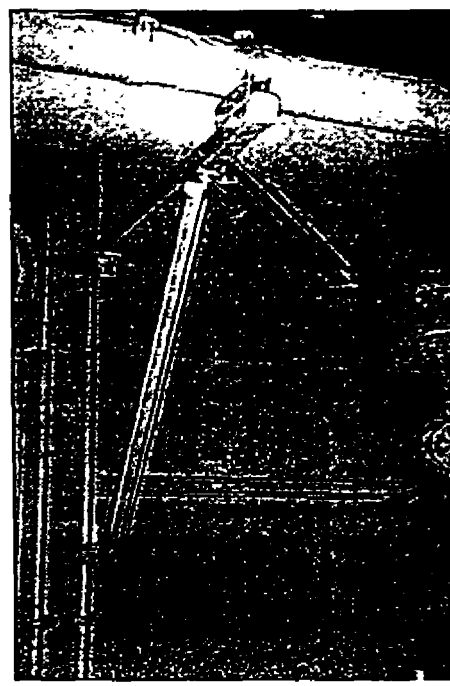


Photograph 3-25. Cracking from differential ground settlement around pile-supported treatment plant structure.

Rod-supported plant piping swings, breaking at weak points such as threaded connections and cast iron valves. Support plant piping in three orthogonal directions in accordance with UBC and Sheet Metal and Air Conditioning Association (SMACNA) requirements. Equipment and pipe connections move relative to each other, and will cause the system to break at the weak point. Provide flexible connections. Flexibility should be provided in connections and piping where they span across expansion joints or between structures on different foundations.

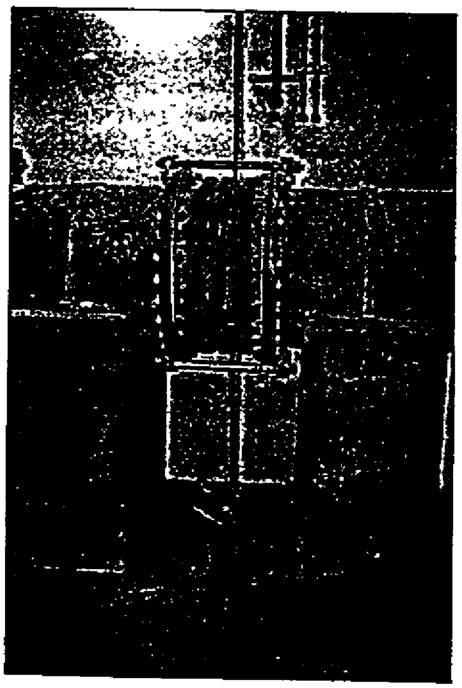


Photograph 3-26. Broken plant piping at Olive View Hospital in San Fernando earthquake.



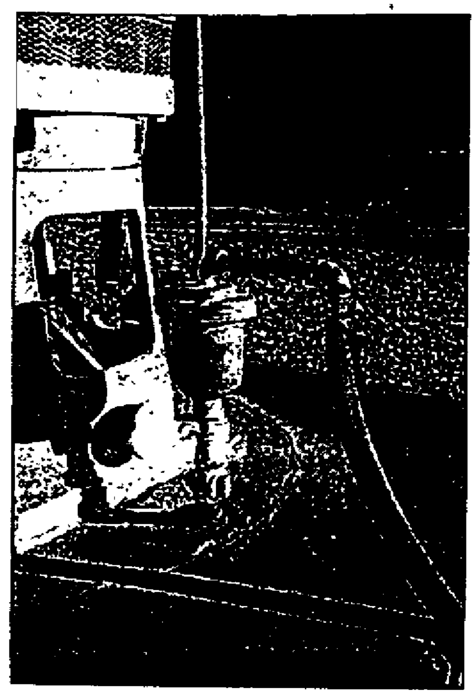
Photograph 3-27. Pipe support providing support in three orthogonal directions.

Photograph 3-28. Flexible coupling on both suction and discharge of sewage pump.



Photograph 3-29. Flexible joint in pipe where it crosses a flexible joint in the building structure.

Pipe appurtenances such as air release valves respond as inverted pendulums, amplifying ground motions, and breaking. Anchor them.



Photograph 3-30. Heavy air release valve supported on small diameter pipe broke off in Loma Prieta earthquake.

Pipe, pipe supports, and equipment may be damaged by relative settlement of building and associated equipment, or by differential movement between two segments of the supporting building structure. Support pipelines off a single structure.

In general, anchored equipment performs well, even if the anchorage is not designed for the level of design seismic loading.

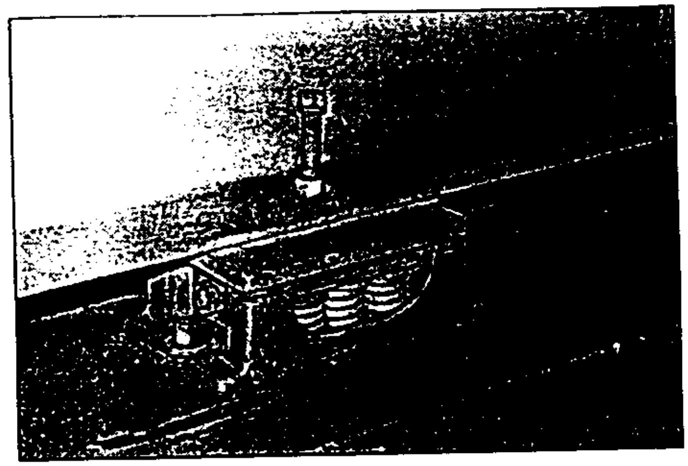
Unanchored or inadequately anchored equipment may slide or topple, damaging the equipment, or causing attached piping and conduit to fail. Check for overturning. Equipment with a low center of gravity has less of a tendency to overturn, but may still slide. Anchor the equipment in accordance with UBC loading criteria. Anchored equipment has an excellent performance history in earthquakes, even if anchors are under-designed.

Photograph 3-31. Dry chemical feeders toppled in Limon, Costa Rica Water Treatment Plant, damaging one feeder. Photo shows installation after repair.

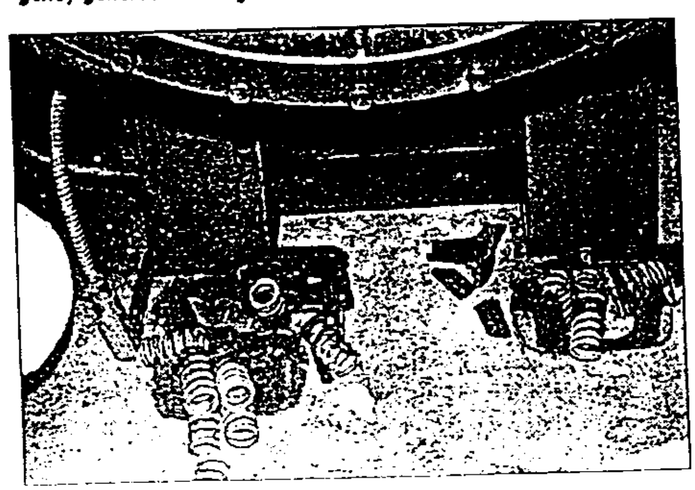
Use cast-in-place anchors when possible. Chemically bonded drilled anchors are acceptable for floor installations, but pull out in fire; they should not be used overhead. Drilled wedge anchors are acceptable for floor and wall installations, but should not be used overhead. Drilled wedge anchors should not be used for rotating equipment as they may work loose. Do not use self-drilling, drilled sleeve, or powder driven anchors.

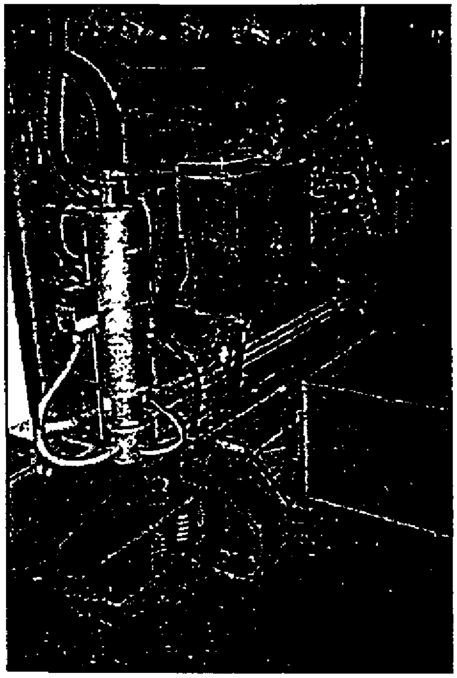
Horizontal pumps and their motors, and engines and attached generators, should be mounted on a single foundation to prevent differential movement. Vertical turbine pumps hanging in tanks should be avoided if possible--or designed for seismic loads, as a minimum.

Emergency generators require functionality of a series of support systems. Vibration isolators not designed for seismic loading are vulnerable. Use snubbers on vibration isolated bases or anchor directly to the floor. Review the vulnerability (i.e., anchorage, support, flexibility) of fuel, cooling, starting (i.e., batteries or compressed air), and exhaust systems.



Photographs 3-32, 3-33, and 3-34. Spring vibration on emergency generator damaged in Whittier earthquake.



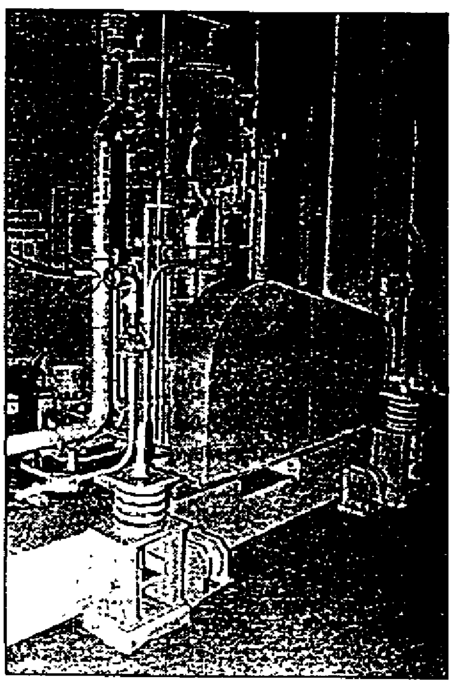


Photograph 3-37. Fuel tank bounced around, severing piping, and draining, in Baguio, Philippines water booster pump station.

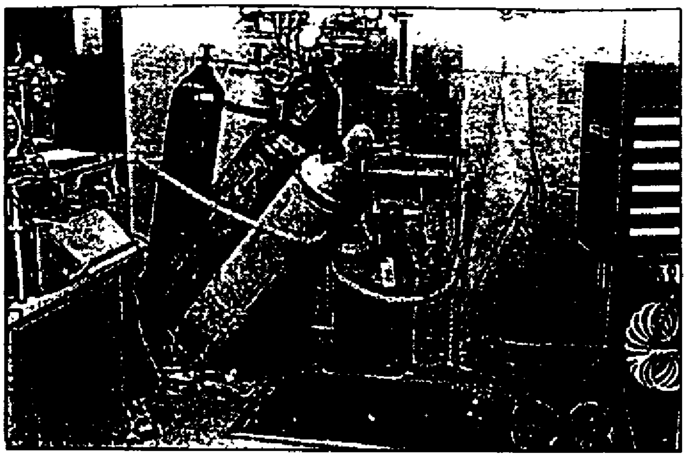
Earthquake ground motions are amplified by building structures. The higher in the building the equipment is located, the higher the earthquake load it experiences. Use UBC for anchorage design. Heavy equipment loads must be taken into account in the building design. Heavy equipment, such as sludge-processing equipment, should be located as low as possible in the building.

Hazardous chemical equipment and piping should be protected from falling debris.

Chlorine cylinders (150 lb) topple, breaking connecting piping. Restrain them top and bottom. Chlorine containers (1 ton) roll/slide, breaking connecting piping/pig tails. Anchor them with chain binders or nylon straps. Alternatively, use sodium hypochlorite systems. Gaseous chlorine containment and stabilization in the 1991 Uniform Fire Code (UFC) are recommended. Provide Chlorine Institute repair kits stored outside the potentially hazardous area.

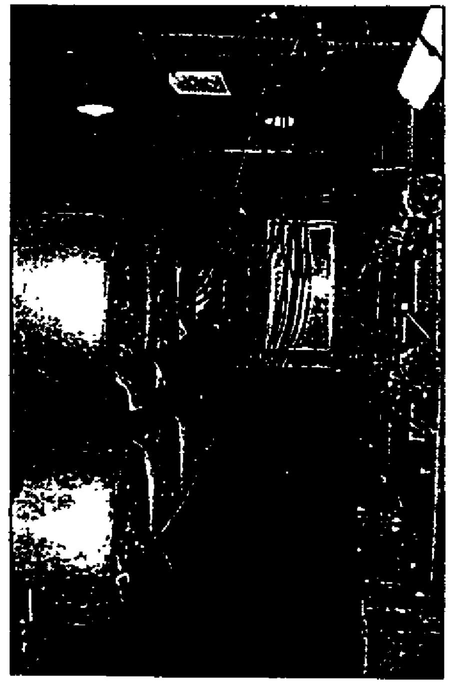


Photograph 3-35 and 3-36. New Zealand designed and U.S. manufactured snubbers, respectively, on vibration isolated equipment.

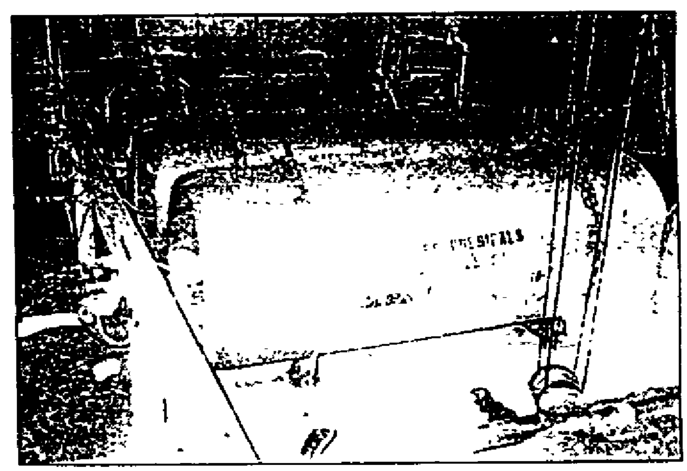


Photograph 3-38.* *Fallen compressed gas cylinders with single chain.

Photograph 3-39. *Compressed gas cylinders restrained with chains top and bottom at Seattle Metro facility.*

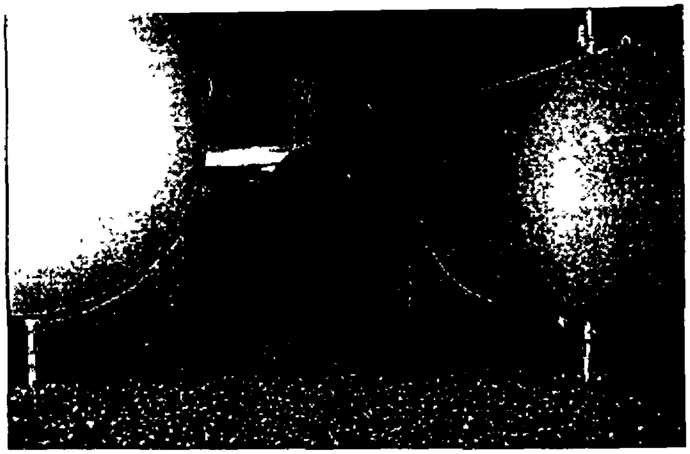


Photograph 3-40.* *Unrestrained chlorine ton containers can slip off the stack, severing the pig tail.

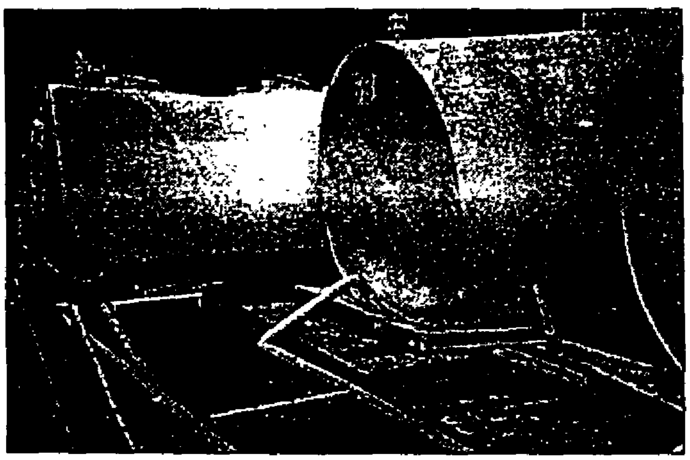


Photograph 3-41 *Chlorine ton containers restrained with double-chain binders successfully road out Loma Prieta earthquake in Santa Cruz.*

Large horizontal tanks such as chlorine, liquid natural gas, propane, diesel, or surge tanks may slide, breaking connecting piping. Provide adequate load transfer from the tank to the foundation, particularly longitudinally. Restrain them to saddles to prevent slippage and rupture of attached piping.



Photograph 3-42. Large propane tanks may slip longitudinally, breaking connecting piping.



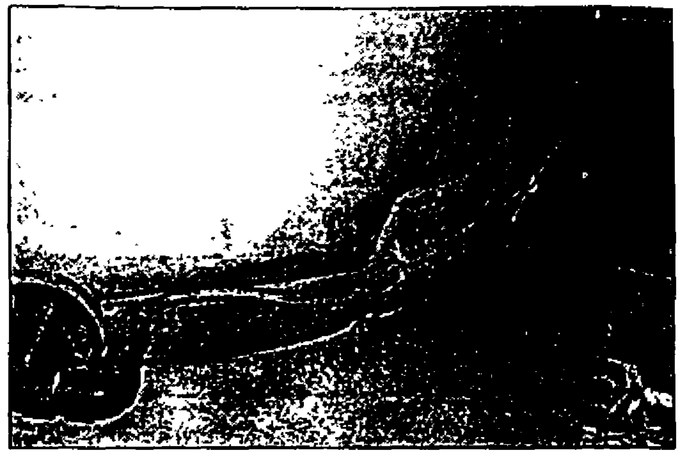
Photograph 3-43. Collapsed horizontal fuel tanks without adequate longitudinal saddle support structures in Limon, Costa Rica.

Chlorine evaporators are particularly heavy. They are often not installed with adequate anchorage making full use of the bolt holes provided by the manufacturer. Anchor them.

Provide secondary containment for hazardous chemicals.

Install fail-safe control devices on chemical feed systems. Locate vacuum control valves as close to chlorine tanks as possible.

Chemical tanks may slide or topple, breaking connecting piping and draining their contents. Anchor in accordance with the tank manufacturer's directions.

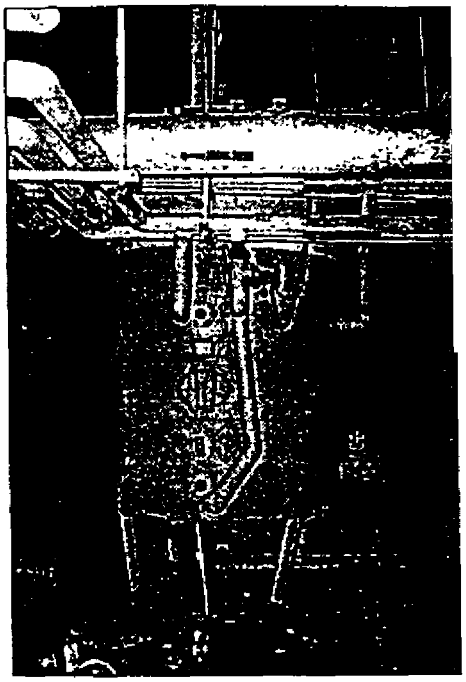


Photograph 3-44. Unanchored chemical tanks may slide, breaking connecting piping.

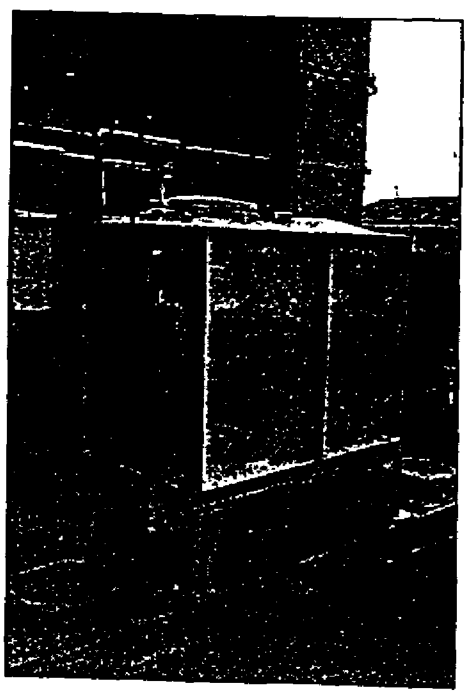
Buried tanks and manholes may float in liquefiable material. Positively anchor them in place.

Photograph 3-45. Buried fuel tanks in Dagupan, Philippines floated in liquefied soil.

The legs of equipment and small tanks without cross bracing may bend and collapse. Provide cross bracing on the legs.

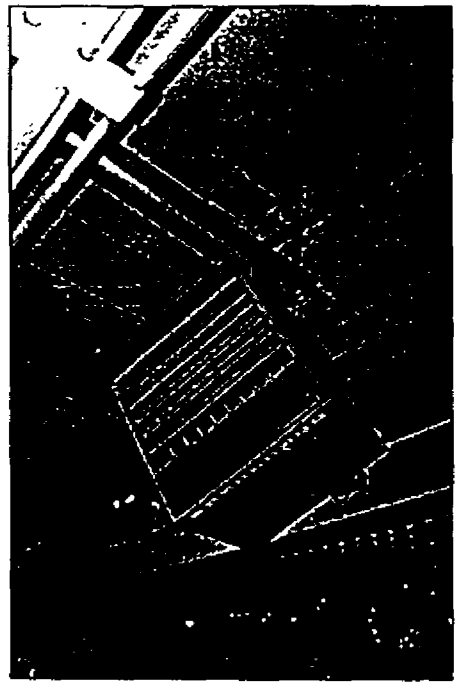


Photograph 3-46. Unbraced tank legs buckled in San Fernando earthquake.



Photograph 3-47. Braced legs on tank supporting structure in Japan.

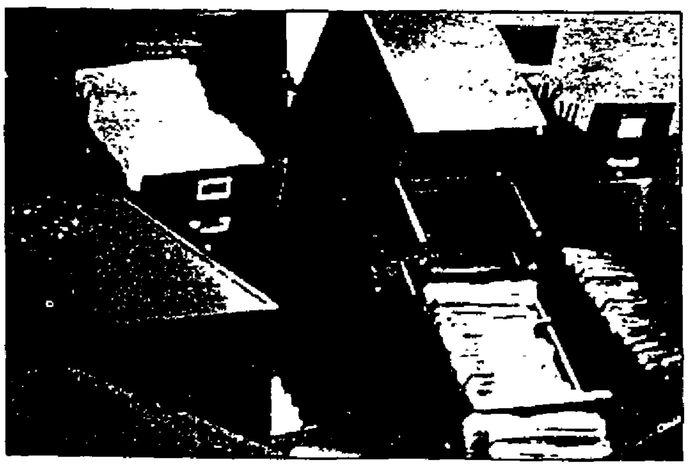
Provide lateral support for HVAC equipment that may otherwise fall to floor. In some instances, failed HVAC equipment has blocked egress routes. The HVAC system may be critical for ventilation of areas with hazardous atmosphere.



Photograph 3-48. Failed support for HVAC unit in Loma Prieta earthquake.

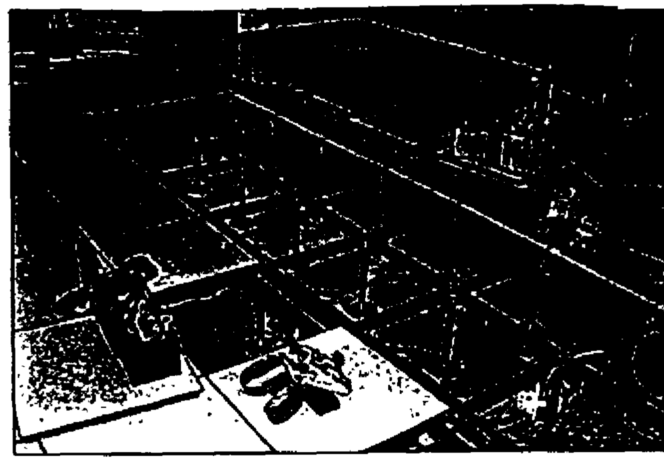
Laboratory equipment, chemicals, and other supplies should be secured. Office equipment/computers may slide on to the floor. Anchor them to the desk. File cabinet drawers may roll open, and topple. Use latching file drawers, and tie adjacent file cabinets together.

Photograph 3-49. Plexiglass shelf retainers for chemical storage at Rinconada Water Treatment Plant kept chemicals on shelf during Loma Prieta earthquake.

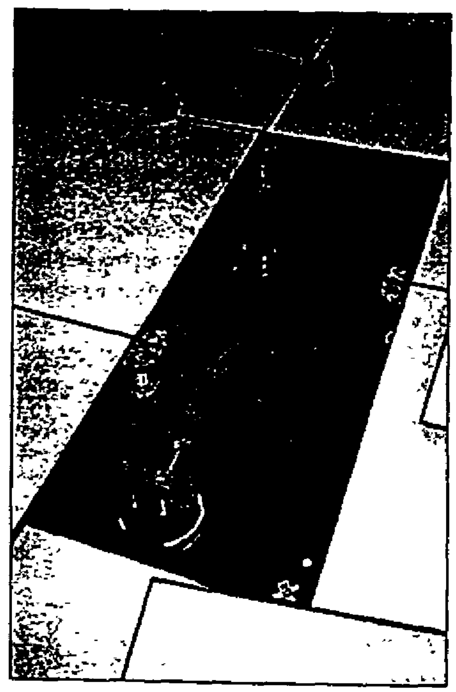


Photograph 3-50. File cabinet drawers opened and cabinets toppled in Loma Prieta earthquake.

Raised computer floors not specifically designed for lateral seismic loading are vulnerable to collapse. One alternative is to positively anchor the computer itself to the floor.

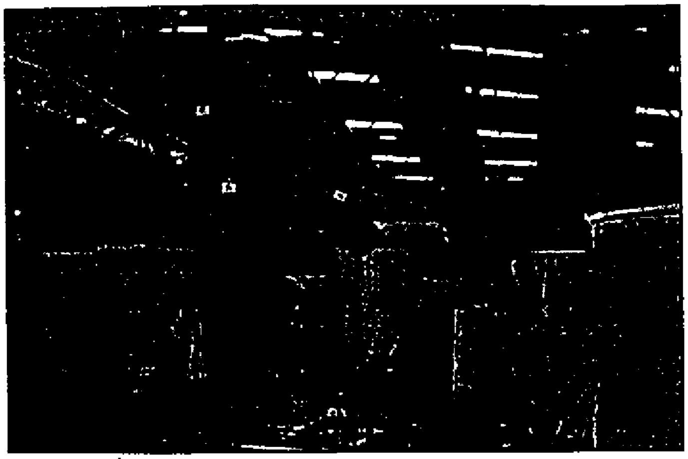


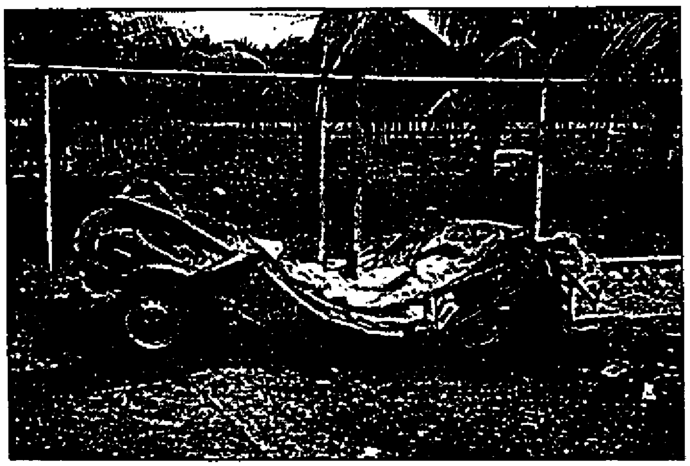
Photograph 3-51. Raised computer floors vulnerable to collapse.



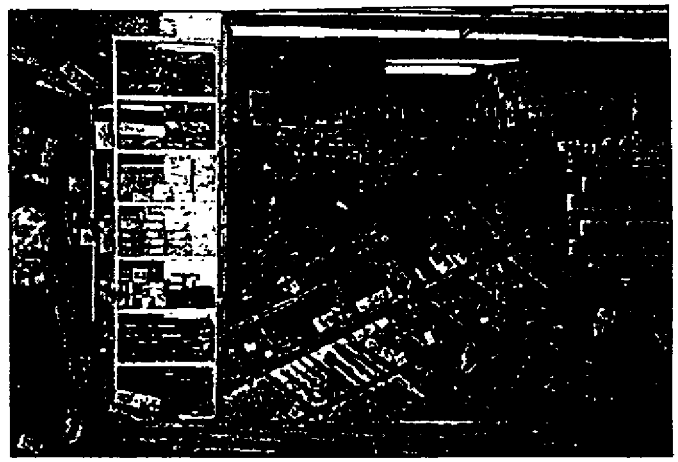
Photograph 3-52. Base isolated computer floor at Japanese water treatment plant.

Storage shelving may topple and/or stored materials fall to the floor. Design/evaluate pallet racks in accordance with UBC requirements. Provide lips to keep stored material on the shelf.





Photographs 3-53 and 3-54. Stacked rolls of paper fell on car in Limon, Costa Rica.



Photograph 3-55 and 3-56. Auto parts store shelving overturned in Erzincan, Turkey earthquake.

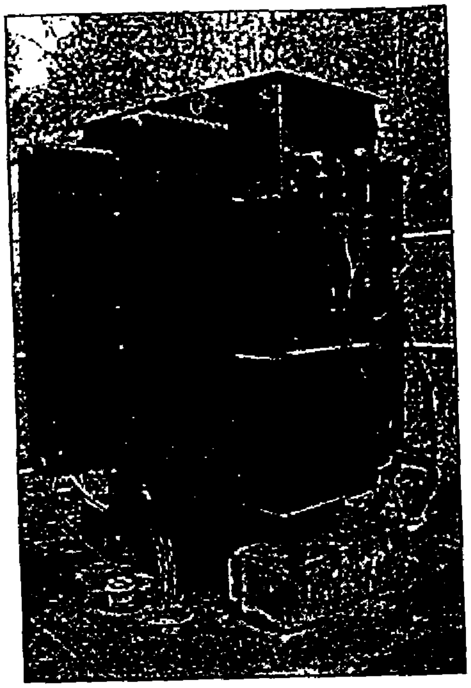
Suspended ceiling panels and light fixtures are vulnerable to collapse. Support light fixtures directly from the fixed ceiling. Upgrade the suspended ceiling as appropriate.

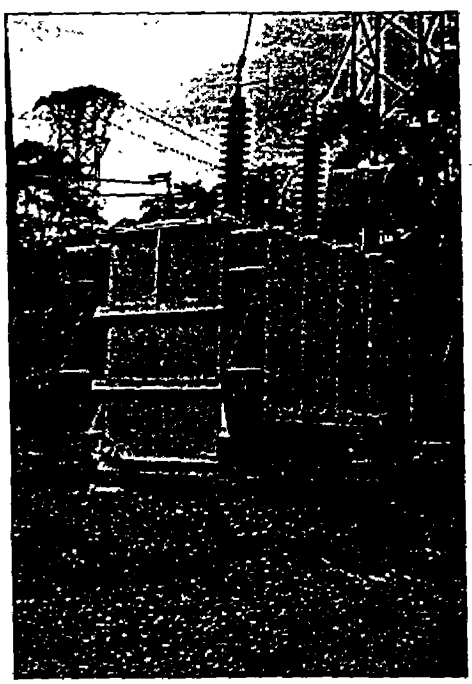
3.2.5 Electrical Power and Instrumentation

Provide emergency power supplies for critical system elements. Assume electrical power will be out of service regionally. Work with the local power utility district to get priority service for critical facilities.

Photograph 3-57. Emergency generator used at Palo Alto Wastewater Treatment Plant following Loma Prieta power outage.

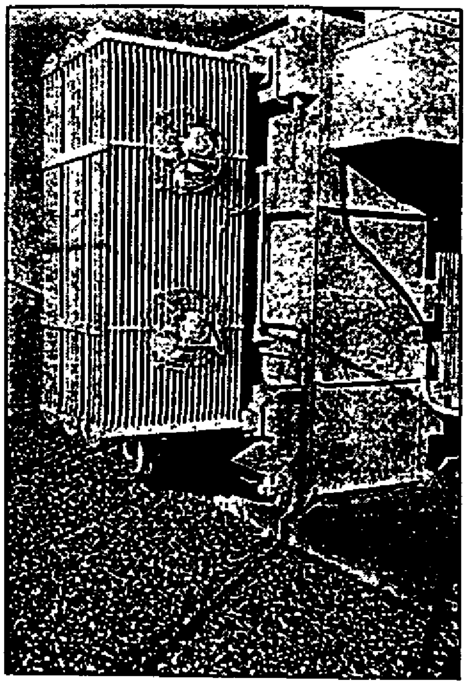
Unanchored transformer units may slide/topple. Pole-mounted transformers that are anchored may also fall, or the pole itself may topple due to soil liquefaction. Work with the local power company to anchor transformers and assess the liquefaction susceptibility of the site.





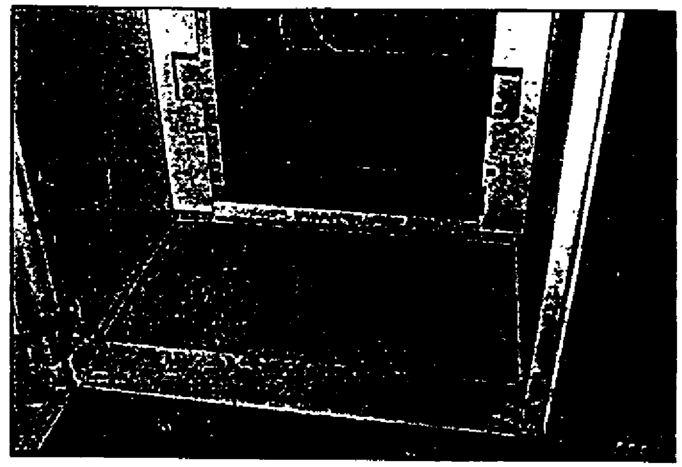
Photographs 3-58 and 3-59. Unanchored transformer (at large wastewater pump station) vulnerable to such earthquake forces as in Costa Rica.

Photographs 3-60 and 3-6. Unanchored pole platform transformer toppled in Erzincan, Tu.key. Pole with transformer toppled as a result of liquefaction at its base in Costa Rica.

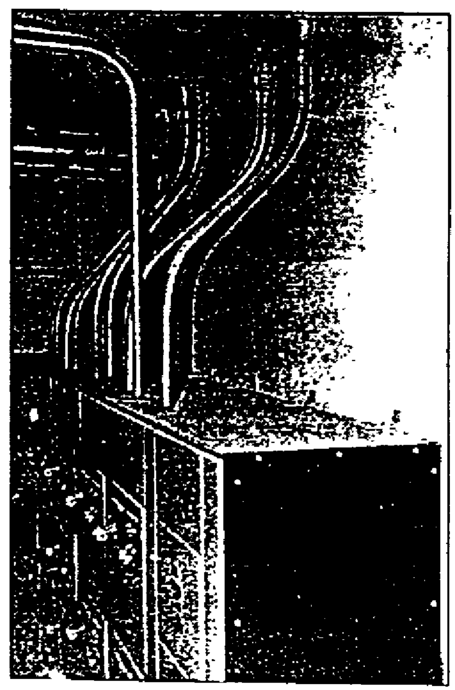


Photograph 3-62. Anchored transformer at East Bay Municipality Utility District treatment plant.

Unanchored electrical cabinets may topple or slide. Anchor them to floor; attach them to the wall with angle clips.



Photograph 3-63. 'Cabinet with no anchorage vulnerable to overturning.



Photograph 3-64 Cabinet installed with angle brackets tieing it back to the wall.