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DESIGN OF ELECTRONIC DATA PROCESSING FACILITIES FOR EARTHQUAKE

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SUMMARY

Electronic data processing facilities have experienced damage in moderate size earthquakes that have a high probability of occurrence. The earthquake vulnerability or susceptibility to damage may be readily determined through simple engineering principles. Relatively inexpensive measures taken either beforehand in the design or as retrofit of a facility may significantly reduce, if not eliminate, the potential for earthquake loss and operational disruption.

INTRODUCTION

During the last 15 to 20 years, electronic data processing equipment and computer facilities have become an important part of our modern industrial and business world. Many of the major industrial giants use computers to monitor the day-to-day inventory and production cycles of their companies. Large business corporations maintain electronic data processing centers for daily business transactions, payroll, and credit verification.

These highly sophisticated computer systems with their extensive interdependency upon complex mechanical and electrical support systems such as HVAC, electric power, cooling water, telecommunications, etc., are far more vulnerable to natural disasters such as earthquake than their predecessors, the desktop calculator. Small earthquakes that have a relatively high probability of occurring during the life expectancy of these facilities have produced costly damage and disruption to data processing functions that have lasted for days. Damage to the buildings that house the data processing operations has generally been limited to nonstructural elements such as ceilings, partitions, and raised floors.

The economic impact from loss of data processing functions often far outweighs the dollar loss associated with equipment damage. It has been estimated by one of the major banking institutions in California that if their central data processing center in either Los Angeles or San Francisco were to be put out of operation for three days by a disaster such as earthquake, the business interruption would impact the economy of California. If the interruption extended to five days, the economy of the United States would be affected. And if it extended to seven days, it would start to impact the world economy. In a typical hour of electronic credit transaction, a major bank may exchange $12 million. Major manufacturing companies have estimated business interruption costs on the order of $5 to $10 million per day if computer facilities monitoring their manufacturing cycle were put out of operation. One aerospace company has estimated that 10 days of disruption in the main computer facility would put the corporation out of business.

EARTHQUAKE BEHAVIOR

Since the advent of electronic data processing on a major commercial scale, there has been limited opportunity to observe and assess the impact of earthquake upon the design and function of EDP facilities. The following is a brief summary of the observed and documented earthquake behavior of computer facilities in small-to-moderate size California earthquakes as well as several major events in Japan and Mexico. These events include: 1965 Seattle; 1971 San Fernando; 1978 Sendai, Japan; 1979 Imperial Valley; 1980 Livermore; 1984 Morgan Hill; 1985 Mexico City; 1987 Whittier Narrows (Los Angeles). All of these events ranged in magnitude from 5.5 to 6.5 with the exception of the Magnitude 7.5 Sendai event and the Magnitude 8.1 Mexico City event. These two larger events occurred at great epicentral distances from the sites investigated. Figures 1 and 2 illustrate typical earthquake damage.

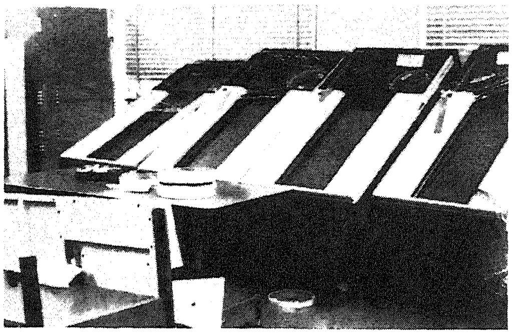

FIGURE 1 Sendai, Japan, 1978.
Tape Drive Units Tipped Over

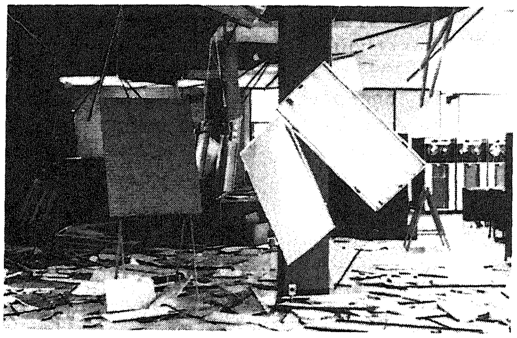

FIGURE 2 Seattle, Washington, 1965
Suspended Ceiling and Lighting
Fixture Collapsed

1. Peripheral equipment were observed to roll around on the floor, slide, catch casters or leveling pads in the floor penetrations and tip over. The tall slender cabinets used for communications tended to be more susceptible to overturning than other peripheral equipment. Vibration-sensitive disk drives and tape drives malfunctioned, heads crashed causing loss of data. Tape drives overturned as shown in Figures 1 from the Sendai, Japan earthquake.

2. Computer mainframes slid on the smooth raised floors, the cabinets warped and racked and settled unevenly, causing exterior doors to pop off and subfloor seismic bracing to rupture due to the heavy machine loads.

3. Tape storage racks tipped, rocked, dumping their contents, and some tipped over. The tapes were often damaged in falling and the magnetic data was lost when it could not be read from the tapes.

4. Three raised computer floors collapsed in the San Fernando earthquake. Raised floors under heavy mainframes listed as much as 1 inch, snapping subfloor bracing in the Livermore and Whittier Narrows earthquakes.

5. Suspended ceilings and lighting fixtures collapsed along perimeter walls of computer rooms in all of the earthquakes, as illustrated in Figure 2.

6. Power failures caused the facilities to shut down in all of the earthquakes.

7. Chilled water and fire water lines developed leaks, in some cases flooding the computer floor areas causing extensive shutdown and rewiring.

8. The halon fire suppression systems were triggered by the dust particles in the air from falling suspended ceilings in the Whittier Narrows earthquake. An automatic fire sprinkler head was shaken free from the ceiling over a mainframe in the Livermore earthquake.

Business interruption to computer facilities ranged from 6 to 12 hours in the small Magnitude 5.5 Livermore event, days to weeks in the Magnitude 6.5 San Fernando, Imperial Valley and Seattle events, and weeks to months in the 8.1 Mexico earthquake (in Mexico City). Much of the physical damage and most of the business interruption beyond the first few hours could have been eliminated with relatively simple cost effective mitigative measures. Only in the case of the Mexico City event, where the buildings housing the data processing operations were damaged as well, would more costly mitigative measures have been required.

VULNERABILITY ASSESSMENT

The methodology and procedures for Mitigating earthquake vulnerability to structures, nonstructural elements, support services and utilities are topics of other papers at the 9WCEE and have also been documented in Ref. 1. This paper focuses on the earthquake vulnerability of EDP equipment and the methodology for mitigating the risk.

Simplified Rigid Body Analysis Historic earthquake experience and experimental tests have shown that there are four basic modes of equipment response. Some of these lead directly to equipment failure, while in other cases the equipment will continue to function without damage. These basic modes of equipment motion are:

- Rocking about one edge without sliding;
- Sliding on the floor without rocking;
- Rocking and sliding; and
- Movement with the floor, without sliding or rocking.

In the simplified rigid body dynamic analysis method for assessing equipment vulnerability, the typical peripheral equipment and computer mainframes are idealized as rigid rectangular boxes supported on a rigid floor. Motion of the equipment is treated two-dimensionally with one horizontal and vertical component of floor motion combined in the analysis. The resilience of the floor and the flexibility of the equipment frame and its support system are neglected. These simplifying assumptions lead to a direct set of dynamic equations for the equipment motions that are solved using three basic parameters:

- The aspect ratio (height to the center of gravity of the equipment divided by one-half the base width of the equipment);
- Peak horizontal and vertical floor accelerations; and
- The coefficient of friction between equipment base and floor surface.

Peak horizontal and vertical floor accelerations are usually determined through dynamic analysis of the building structure. The coefficient of friction between equipment base and the floor depends on the type of equipment support system that is used (e.g., leveling pads, casters, skids, bolted holddowns or tethers, etc.) and the surface characteristics of the floor (e.g., smooth tile versus a rough rug).

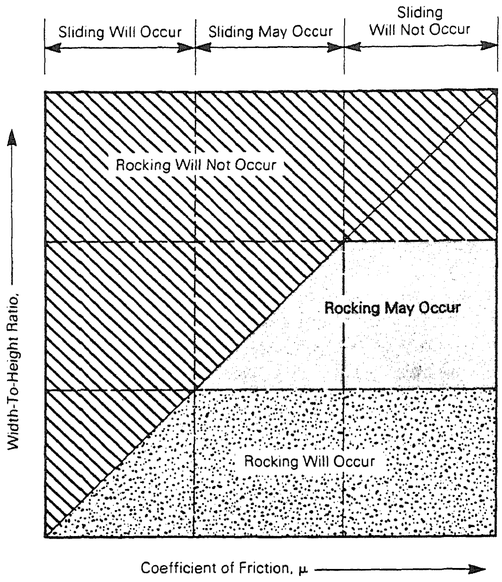

FIGURE 3 Modes of Possible Equipment Motion

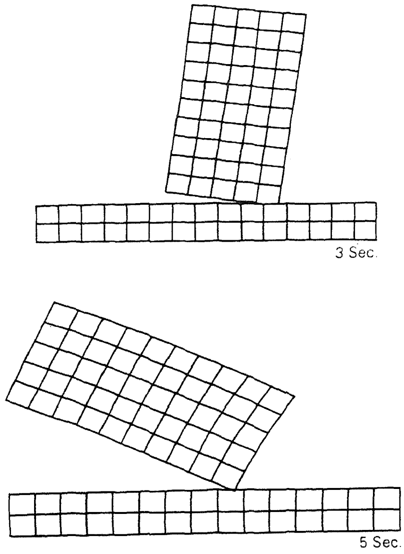

FIGURE 4 Computed Earthquake Response of Equipment

Figure 3 illustrates the possible modes of equipment response in terms of the width-to-height ratio (reciprocal of the aspect ratio) and the coefficient of friction between the equipment base and the raised floor. An example of this method of analysis has been documented for three types of computer equipment in Ref. 2. This method of analysis provides a direct relatively simple assessment of the probable modes of equipment movement and the potential for sliding into other objects, impacting them, or tipping over, resulting in heavy internal damage to the equipment.

Elastic and Nonlinear Dynamic Analysis A more rigorous form of analysis may be performed to assess the equipment vulnerability using two-dimensional linear elastic and nonlinear finite element models capable of representing large deformation behavior of the equipment as it slides and rocks or bounces on the floor. Recorded or computed earthquake motions of the building floor response are used in this analysis. The sliding and rocking response of equipment considering flexibility of the equipment and floor is shown in Figure 4 from such an analysis.

Dynamic Testing As an alternative to the analytical methods of vulnerability assessment, dynamic tests may be conducted to assess earthquake behavior of the equipment cabinet frame, internal components, and support systems or attachment. Both IBM (Ref. 3) and Bell Laboratories (Ref. 4) have conducted experimental studies on the various means of anchoring and supporting computer equipment to reduce its vulnerability to earthquake. Even though this test data is limited to a few pieces of equipment and a few earthquake motions, it has provided valuable insights into the methodology for seismic risk reduction to EDP equipment.

MITIGATIVE SOLUTIONS

The most cost-effective forms of earthquake risk mitigation for EDP equipment are associated with the methods of anchorage or support of the equipment. There are three basic alternative methods of support: anchor; isolate on low-friction leveling pads; and leave as is. There are certain restrictions and assumptions that are implicit in each of these strategies.

Strategy A -- Fixed Anchorage or Bracing Figures 5 and 6 illustrate through-floor anchorage and vertical bracing schemes that may be used to attach tall narrow equipment to the structure to prevent it from tipping over. These schemes provide the greatest assurance that the equipment will stay in place following an earthquake. This strategy should be used when the equipment is closely spaced and may impact if not restrained. The internal components of the cabinet must have a low vulnerability to vibratory motion since restraint of the cabinet at the base only may result in amplified motions in the cabinet. If the cabinet itself does not have sufficient strength to resist the earthquake loads, then a floor-to-ceiling brace such as shown in Figure 5 must be used as a strengthening element.

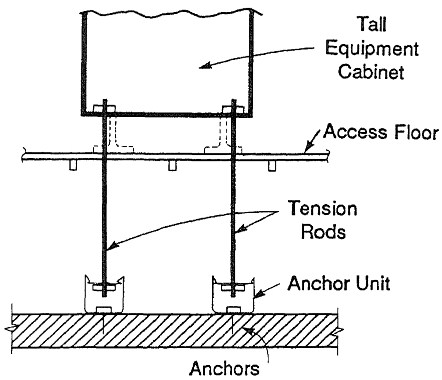

FIGURE 5 Through Floor Anchorage

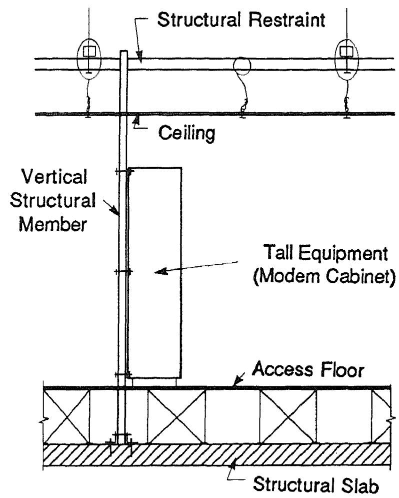

FIGURE 6 Vertical Seismic Bracing

Strategy B -- Isolate from Horizontal Floor Motion In this strategy, equipment is supported on low-friction seismic leveling pads or casters, that permitted the equipment to move relative to the floor. This system isolates the cabinets from most of the horizontal floor motions. It is the best system to use with weak, flexible equipment cabinets with internal components that have a high vulnerability to horizontal floor motions.

When using this strategy, special precautions must be taken to prevent the casters or leveling pads from rolling or sliding into floor penetrations. This could result in equipment overturning that may damage vibration-sensitive internal components. Furthermore, adequate space must be provided between the equipment and surrounding walls or other equipment to prevent impact during the earthquake. If the equipment is tethered to limit its lateral excursion on the floor, the transfer of tether forces into the raised floor becomes a design consideration and the effect of an abrupt tether force applied to the base of the equipment may result in overturning of the equipment. Thus, tethering should not be used except for very low profile equipment. Furthermore, low friction horizontal isolation should be limited to equipment with fairly low aspect ratios (e.g., 1-1/2 to 2-to-1).

Strategy C -- Support on High Friction Skids and Leveling Pads Most of the computer equipment currently used is supported on high friction rubber-based leveling pads or metal skids. The equipment may be left on this form of support system if the dynamic stability analysis indicates that the equipment will not tip or slide; the support system will not fail due to collapse or disengagement of the leveling pads; the cabinet is strong enough and stiff enough to resist the motions without failure or excessive distortion; and the internal components have a low vulnerability to vibration effects.

DISCUSSION

Earthquake mitigation costs for a typical computer facility may range from 1/2 percent to 2 percent of the replacement value of the computer equipment. These costs are generally a very small fraction of the potential business interruption losses that may range into the millions of dollars per day.

There are many elements of the modern data processing facility that are equally as vulnerable to earthquake damage as the computer equipment. Of particular concern is the raised access floors. Often designed and constructed without seismic safety in mind, such floor systems have proven susceptible to collapse in earthquake.

Suspended ceiling systems and overhead fire sprinkler systems have performed poorly in past earthquakes. Ceiling tiles, lighting fixtures and sprinkler heads have dropped to the floor around computer equipment. Downtime following earthquake has generally been found to be significantly higher than before. This has been attributed to the dust and fiber particles entering the computer room with the collapsed ceiling. Spring-mounted mechanical and electrical systems, such as fans, motor generators, and emergency diesel generators, are particularly susceptible to malfunction in earthquake. If the vibration isolation system on the equipment is not constrained by specially designed seismic snubbers, the equipment will bounce violently during the earthquake and may rupture piping, conduit, and support anchorage, often resulting in loss of function.

CONCLUSION

In conclusion, modern electronic data processing facilities are vulnerable to earthquake effects, along with the supporting equipment and surrounding environmental building system. There are simple methods for assessing the probable forms of earthquake behavior of the equipment as well as the basic building support services. Knowing the earthquake behavior and vulnerability of the systems permits mitigative solutions to be developed that are usually simple and cost effective.

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