ELEVATOR EARTHQUAKE SAFETY CONTROL

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SYNOPSIS

The Public Health Building elevators at the University of California, Los Angeles, suffered severe damage from counterweight collision with the cars during the San Fernando Earthquake of February 9, 1971. The elevators are moderate speed, 500 fpm, gearless machines. They have been placed back in service with the addition of an Earthquake Safety Control. This is an active system which utilizes a vertical seismic trigger to initiate a controlled shutdown sequence. The system has been tested by a minor earthquake on November 16, 1973.

INTRODUCTION

The San Fernando Earthquake of February 9, 1971, raised concern over the safety of elevators during strong local earthquakes. It became evident that damage can be severe if automatic elevators are inadvertently operated before they are inspected adequately and necessary repairs made. A major concern for passenger safety in future earthquakes is the possibility of counterweights leaving their guide rails and colliding at high speed with the car.

Possible earthquake safety systems may be divided into two broad approaches, passive and active. The passive approach includes all steps taken to strengthen the total elevator system. The active approach is to bring the elevator system to an orderly halt as soon as possible before damage occurs.

A vertical seismic trigger makes possible an active approach. Compressional waves from a future earthquake will arrive at a building a few seconds before the slower traveling shear waves. The vertical acceleration component of the compressional wave excites the seismic trigger which begins the controlled elevator shutdown before the more damaging shear waves arrive at the building.

STRONG MOTION EARTHQUAKE

The term, "strong motion earthquake," describes ground motions experienced near the causative fault. As the fault rupture grows larger, ground surface dislocations may occur many miles from the epicenter. The vibrations transmitted through the earth travel through major and minor geological discontinuities and boundaries so that the ground motion experienced at a particular building is complex. Part of the seismic wave may be turned back (reflected) and part bent from its original direction of travel (refracted). Figure 1 indicates some of the possible transmission paths for the early seismic waves.

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Even though the details of the ground motion are complex, a useful simplification results by recognizing the characteristics of two predominant seismic wave types, compressional and shear. Compression waves are often called P-waves. They cause ground motion parallel to the direction of travel, a push-pull motion. The shear waves, called S-waves, cause ground motion transverse to the direction of travel. Approximate values of velocities in granite are 19,000 ft. per second and 10,000 ft. per second for P-waves and S-waves, respectively. Thus, P-waves will arrive at a building some seconds before the slower S-waves. This is an important fact because it allows action to be taken a short time before the more damaging S-waves arrive at the building.

EARTHQUAKE ACCELERATION IN BUILDINGS

Two accelerograms from the 1971 San Fernando earthquake are shown in Figure 2. They were recorded in a 12-story building located about 17 miles south of the epicenter. The lower accelerogram was recorded in the building basement and shows the ground accelerations which cause building motion. The upper accelerogram was recorded at the building roof and shows the building's response to the ground motion. Each accelerogram has four traces. The upper trace is Time, with a trace offset spaced at 0.5 second. The remaining three traces are two horizontal motions and one vertical (center trace).

Each accelerograph contained a seismic trigger responsive to only vertical acceleration. They were preset to trigger at 0.01 g. Figure 2 illustrates the following points:

1. The early arriving P-waves are largest in the vertical direction. The wave path illustrated in Figure 1 is directed upward at more than 45 degrees from the horizontal.

2. The pronounced change in character of the horizontal ground motion at 4.5 seconds is due to arrival of the S-waves.

3. The early vertical accelerations at the roof are more than twice the accelerations at the ground. The accelerographs were started by the seismic trigger at the roof location.

4. The amplitude of ground motion and building response is strongest in the N9°E direction, which is explained by the building location being south of the causative fault. The horizontal ground motion diminishes after about 15 seconds, whereas lateral vibration of the building is large for many seconds after the ground motion diminishes.

5. Equipment undergoes vibrations whose characteristics have been strongly influenced by the building's response to the earthquake. The earthquake experienced by the equipment corresponds to the motion at its point of attachment to the building. The peak lateral acceleration at the roof of the building of Figure 2 was 0.26 g. Equipment and fixtures whose natural vibration frequencies are near the building's natural vibration frequencies can experience absolute accelerations significantly larger than the peak building acceleration. Also, it is obvious that a larger earthquake will increase the acceleration of the equipment.

VIBRATIONS IN BUILDINGS

Seismic triggers sense acceleration. Before using such triggers to initiate earthquake safety actions, it is important to consider possible triggering due to non-earthquake vibrations. Figure 3 classifies vibration by acceleration and frequency. Three general classes of vibration sources are shown: earthquakes, micro-earthquakes, and industrial vibrations.

Vibrations normally experienced in a building differ from earthquakes primarily in frequency content. The perceptible vibrations which occur from time to time due to impact shocks, start-stop operation of equipment and steady operation of motors and compressors, is generally at relatively high frequencies of vibration (cycles per second). As the accelerations get larger, the frequency of vibration generally increases also. Earthquakes have substantial energy of low to intermediate frequency (0.1 to 10 cycles per second). Micro-earthquakes are simply very small earthquakes which occur many times a day. Figure 3 points out that a successful earthquake trigger should have little sensitivity to high-frequency vibrations.

Figure 4 is a portion of a continuous recording of vibrations in the Public Health Building elevator machine room. The vibrations were recorded over a 5-day period on a rotating drum recorder making one revolution each 15 minutes. The record is very long. For convenience, only a typical portion is shown. Figure 4 shows a 2-minute slice from a 24-hour recording, starting at 8:16 a.m. on Tuesday and ending at 8:18 a.m. on Wednesday. The start-stop of each car shows as an increased vibration of about 10 seconds duration. The number of elevator operations is greatest between 8:00 a.m. and 6:00 p.m., with the time period 10:00 p.m. to 7:00 a.m. relatively quiet. The amplitude of vibration is considerably smaller than 0.01 g. It is on the order of 0.001 g. The frequency of the vibration is about 30 cycles per second. The amplitude-frequency relationship in this particular elevator machine room is shown as a point on Figure 3, for reference.

CHARACTERISTICS OF THE SEISMIC TRIGGER

After examining the characteristics of earthquakes and the vibrations of buildings, it is apparent the opportunity exists to utilize a seismic trigger to increase elevator safety during earthquakes. Because there is time to initiate and complete safety steps before the building lateral vibrations become excessive, the approach is active, contrasted to passive. The seismic trigger must be carefully designed to trigger at the onset of an earthquake and to not trigger when non-earthquake vibrations occur.

The seismic trigger installed at the Public Health Building is the Kinemetrics, Model EST-1. It has the following characteristics:

1. It is anchored to the machine room concrete floor adjacent to a column which is continuous to the foundation.

2. The trigger is normally preset to provide a switch closure at 0.03 g vertical acceleration. The trigger level is field adjustable between 0.005 g to 0.05 g.

3. The acceleration required to trigger must occur in the frequency range of 1.0 Hz to 10 Hz. The trigger's ability to respond to high frequency acceleration is sharply attenuated above 10 Hz.

The solid line on Figure 3 designated Trigger Sensitivity illustrates points 2 and 3. The normal vibrations in the machine room are significantly below the trigger level. Thus, spurious triggering has not been a problem.

SAFETY CONTROL

The safety control is a series of relays activated by the seismic trigger preset to trigger at 0.03 g of vertical acceleration. Upon receiving the seismic trigger signal, the Earthquake Safety Control instantly programs the elevator controls to respond:

1. Prevent idle elevators from running, open the doors, and shut down the motor generator set.

2. Slow down elevators in motion, stop level at the next floor in the direction of travel, open the doors to allow passengers to leave the car, and then shut down the motor generator set.

3. Allow elevators in express zones to continue at reduced speed to the next available landing in the direction of travel, stop at floor level, open the doors, and shut down the motor generator set.

INSPECTION AND RESET

The Control is reset with a special key. An electrically interlocked reset sequence assures that the elevator mechanic must put each car on INSPECTION before resetting the Earthquake Safety Control and subsequently inspecting for possible earthquake damage. It is important that the building owner/manager coordinate the elevator earthquake safety planning with all other emergency uses of the elevators. For example, fire department access to upper floors must be included. It may be most economical to strengthen one elevator designed for emergency use. The strengthened elevator may be programmed to run at reduced speed only.

The sequence of actions by the elevator mechanic for returning elevators to service is:

1. Go to machine room and switch each car to INSPECTION.

2. Visually inspect all elevator equipment in the machine room and secondary for obvious movement of supports, misalignment, and other earthquake damage.

3. Insert key into Control, turn to RESET, resetting main latching relay for entire bank of elevators.

4. Reset elevator No. 1 using RESET pushbutton on Control. At this point, power is back and the POSITION INDICATOR will show where car is parked.

5. Mechanic goes to car and rides on top of car at inspection speed to inspect complete hoistway.

6. If there is no visual damage to the elevator equipment, switch car to AUTOMATIC and return to service.

At regular intervals, the Earthquake Safety Control is tested. This is accomplished by inserting a key into the Control and turning to the TEST position. The entire bank of elevators instantly undergo shutdown response.

EXPERIENCE WITH UCLA PUBLIC HEALTH BUILDING ELEVATORS

The Earthquake Safety Control system was installed on three elevators during March 1972. The level of the vertical acceleration component of the compressional wave set to trigger the acceleration sensor was originally 0.01 g. In 1973 it was lowered to 0.005 g. No false triggers of the system have been experienced since its original installation and until today (12/1/75).

In 1973, an additional Counterweight Derailment Device was installed on one of the three elevators (car No. 3). This device operates in conjunction with the acceleration sensor of the Earthquake Safety Control system in the following manner. A controlled elevator shutdown will take place if the device determines that the counterweights have been derailed. An inspection, repair, and manual resetting are needed to reactivate the elevator. If the acceleration sensor is triggered, a controlled elevator shutdown also takes place. However, if after three minutes the counterweights are still on their guide rails, the elevator comes back to service at a reduced speed of 150 fpm.

The only time that the system operated, since its installation, was during a minor earthquake on November 16, 1973. The system operated successfully as designed. The acceleration sensor triggered and brought the elevators to a controlled shutdown. Since the counterweights did not leave their guide rails, the one elevator with the counterweight derailment device restored the elevator automatically to service, after three minutes, at a reduced speed. The other two elevators were restored to service manually after proper inspection.

It is believed there may be occasions when the counterweight derailment device may automatically restore to service elevators which are still in an unsafe state. For example, controllers may collapse affecting the safety switch and the elevator could still be able to operate, if the counterweights have not derailed. Also, a hoist cable could partly jump off, and again the elevator may operate but be unsafe. Thus, the Earthquake Safety Control system, operated by the acceleration sensors, and requiring inspection and manual resetting, is seen to provide a more comprehensive system of safety.

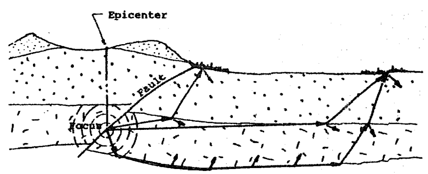

Figure 1. POSSIBLE TRANSMISSION PATHS FOR SEISMIC WAVES OF EARLY GROUND MOTION

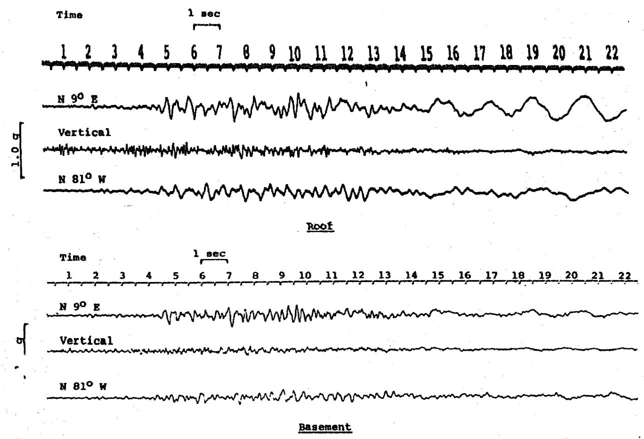

Figure 2. EARTHQUAKE ACCELERATIONS RECORDED IN A 12 STORY BUILDING, LOS ANGELES, FEBRUARY 9, 1971

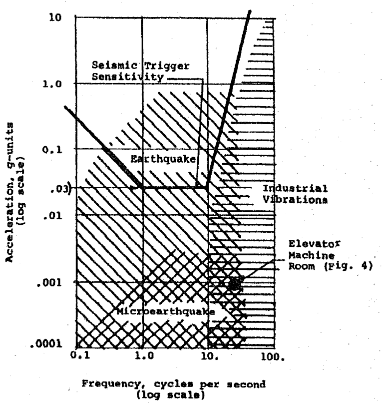

Figure 3. CLASSIFICATION OF VIBRATIONS BY ACCELERATION AND FREQUENCY

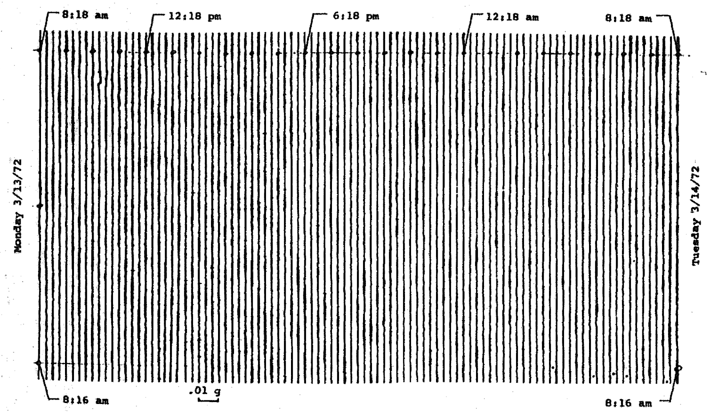

Figure 4. A PORTION OF THE CONTINUOUS RECORDING OF VIBRATIONS IN THE PUBLIC HEALTH BUILDING ELEVATOR MACHINE ROOM

DISCUSSION

A.R. Chandrasekaran (India)

As seismic triggers, the discussor would prefer a device based on peak velocity rather than peak acceleration, as velocities are more indicative of damage potential. Would the author like to comment on the relative merits of acceleration and velocity triggers ?

Author's Closure

With regard to the question of Mr. Chandrasekaran, we wish to state that the relative merits of acceleration and velocity to indicate damage potential of ground motion misses the point of the vertical seismic trigger.

The seismic trigger used in the elevator earthquake safety control is designed to actuate on early arriving P-waves of 0.03 g vertical acceleration in the frequency range 1.0 to 10.0 Hz. This is a relatively low acceleration to allow rapid elevator shutdown before the damaging horizontal motions are realized. However, when limited to less than 10 Hz, 0.03 g is a high acceleration compared to non-seismic vibrations in a building, thus eliminating false triggering.

For general application of seismic triggers to initiate protective measures for moving equipment, we feel acceleration is most appropriate. The structural engineer has most often expressed the design levels for the building in acceleration units. As a practical matter, seismic trigger settings to protect equipment attached to the building should be in acceleration units also.