EARTHQUAKE RESPONSE OF ELEVATOR COUNTERWEIGHTS

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SUMMARY

Damage to elevators from recent earthquakes is reviewed. To address these problems seismic regulations for the U.S National Elevator Code have been drafted which provides for: a) improved anchoring of equipment, b) addition of rope retainer guards for sheaves and drums, c) stronger counterweight guide rails or the use of tie brackets, and d) seismic switches and counterweight derail detectors to shut down elevators should earthquake or counterweight damage occur. The counterweight-counterweight frame-guide rail system has been modeled to determine its dynamic response. Nonlinear effects of clearances within the system have been included. Methods of incorporating damping to improve system response are being evaluated as well as the effects of rope dynamics on system response.

INTRODUCTION

The 1971 San Fernando earthquake and the 1978 off-Miyagi Prefecture earthquake have demonstrated the vulnerability of elevators to earthquake damage from moderate earthquakes. In the San Fernando earthquake 640 counterweights used to balance the weight of elevator cars in traction elevators came out of their guide rails. In the off-Miyagi Prefecture earthquake, it is estimated that 25 percent of the elevators experienced damage. When it is realized that the vast majority of the structures which were served by the elevators experienced no structural damage, the high vulnerability of the elevators can be appreciated.

While there is no record of an elevator falling as a result of earthquake damage, the fact that the car and derailed counterweight will hit each other if they try to pass, poses a direct life-safety problem. The loss of elevator function also has the secondary effect of hindering building evacuation and the entry of emergency personnel. In addition, there are the direct financial losses and the economic and social impact of the loss of use of the structure while the elevators are inoperable. In major cities the impact can be particularly severe because of the large number of commercial and residential buildings which utilize elevators.

A second element which makes it difficult to improve elevators' earthquake performance is that many of the affected cities are located in regions in which the return period for major earthquakes is very long, in excess of 200 years. Therefore it is difficult to justify the cost of improved earthquake resistance.

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This paper will discuss the types of failures observed in recent earthquakes followed by the approach taken in the draft U.S. National Elevator Code to address these problems. Finally, research directed at technical solutions to improve elevator earthquake response is discussed.

EARTHQUAKE DAMAGE TO ELEVATORS

Recent earthquakes have provided valuable information on the vulnerability of elevator systems. Observations have indicated the following deficiencies. Machine-room equipment including motors, traction machines, support beams and control cabinets are inadequately anchored allowing loss of function due to their motion. In the hoistway protrusions, damaged or snagged ropes and cables set in motion by the earthquake. In some cases vibrations caused ropes to jump a sheave or drum. Counterweights would come out of their guide rails due to failure of the guides or rail deflections would be larger than the penetration of the guides thus freeing the counterweights. Guide rails, often unsupported between floors, can experience large midspan deflections. When subjected to motion in the plane of the guide rails, only one rail supports the counterweights at a time. If its deflection is larger than the penetration of the guide with respect to the rail as shown in Fig. 1, the counterweights can swing clear of the guide rail. When the counterweights are out of their guide rails there is inadequate clearance for the elevator cab to clear the counterweight and impact will occur if they attempt to pass each other.

CODE APPROACH

The American National Standard Safety Code for Elevators, Dumbwaiters, Escalators, and Moving Walks (ANSI A17.1) is a model code. That is, the code, when it is adopted by state or local agencies, may be modified to fit local conditions. Usually the code is adopted in toto. The proposed seismic regulations, Appendix F, will, if adopted as planned, initially appear as an elective Appendix to the Code. Its provisions are keyed to the seismic risk map used in the American National Standard Building Code (ANSI A58.1) and is to be applied to zones 3 and 4. The primary thrust of the Code is to reduce life-safety hazards rather than to prevent damage. Since many of the regions for which the seismic provisions are applicable have earthquake return periods which are very long, provisions have been adopted to keep cost of implementation low but consistent with the goal of providing safe systems. The major changes to improve earthquake safety can be divided into four major groups:

1. <u>Securing Equipment</u>. Equipment including machines, control panels, motor-generator units, machine beams, and sheaves must be adequately secured to withstand seismic forces produced by an acceleration of 1 g horizontally and 0.5 g vertically acting simultaneously.

2. <u>Preventing the Fouling of Ropes</u>. These measures fall into two categories: eliminating features in the hoistway that would snag or cut suspension ropes, governor ropes or traveling cables; and providing rope retainer guards for sheaves and drums.

3. <u>Retaining Counterweights Within Their Guide Rails</u>. Two major changes

have been made to improve the ability of counterweights to be retained within their guide rails. The selection of guide rail size has been upgraded and the use of intermediate tie brackets has been encouraged. The effect of these requirements is to reduce the separation of guide rails due to seismic loads so that counterweight guides will remain engaged.

4. Operation of Elevators Under Earthquake Emergency Conditions. Protective devices consisting of a seismic switch and a displacement switch are required. The seismic switch senses vertical accelerations which will be activated by acceleration of .15 g. The displacement switch is activated by the displacement of the counterweights outside of their normal plane of travel or if they have left the guide rails. The signals from these devices cause the elevator control system to go into an emergency mode of operation. A detailed flow chart which defines the sequence of operations under an earthquake emergency has been developed. The importance of integrating system operation for earthquakes with other special situations such as fire or emergency services cannot be over-emphasized.

RESEARCH

Research has been undertaken to evaluate methods of improving seismic response of elevator systems in a cost-effective manner. The counterweight-guide rail system has been modeled using physical and computer models to investigate the nonlinear response introduced by clearances normally provided between the counterweight frame and the guide rail and between the counterweights and their frame. Fig. 2 shows five counterweights, the counterweight frame, and rails which are supported in four locations. The frame which is supported on linear bearings can be attached to a vibration table which can be operated under computer control. Fig. 3 shows the system with instrumentation to measure the input acceleration and the deflections of the rails and counterweight frame. The model is designed so that clearance between the counterweights and their frame can be changed. For moderate level excitations, a bistable response can be observed. That is, if the counterweights are centered within the guide rails, the rails can vibrate without effecting the counterweights. However, if the counterweights come in contact with the guide rails a large amplitude impacting between guide rails results. For identical excitations, the magnitude of the counterweight deflection increases by 94 percent and the differential motion, that is rotation, of the counterweight frame increases by 125 percent. A second effect which is being investigated is that associated with the variable contact area between the counterweight frame and the guide rail which introduces a nonlinear restoring force when the counterweight moves relative to the guide rails. Methods of introducing damping into the system are being evaluated.

In addition, the influence of the dynamic response of ropes on system performance is being evaluated as well as the effect of different building systems on elevator response.

RECOMMENDATIONS

While statistical summaries of elevator damage from recent earthquakes have been useful in formulating improvements in the elevator code, two important types of information are lacking. The first need is for more detailed information on the particular parts which failed and on their mode of failure. This information would facilitate improved component and system design. Knowledge of the vertical position of the elevator when failure occurs would better enable the damaging forces to be determined. It would also be useful to know the type of structural system used to resist lateral forces.

Several problems are encountered in attempting to obtain the above types of information. The task of collecting failure information must be done by repair service personnel at the time repairs are made. In the rush to restore service it is not surprising that failure data is not recorded. Also, service personnel are not engineers and they lack the training required to assess damage. Also, damage reports could be subpoenaed for use in litigation and thus, it may not be in the best interests of the elevator companies to collect the data.

The collection of damage data could be improved by incorporating appropriate provisions in the elevator code. First, a sample one page damage report form could be included in the code so that it could be copied and used to document damage. The code could require that damaged parts be submitted to the agency responsible for enforcing the elevator code so that they could be analyzed by engineers to assess failure mechanisms. Finally, damage reports could be classified as privileged information which could not be used as evidence in litigation.

ACKNOWLEDGEMENTS

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Figure 1 Top View (section) of Counterweight-Rail System

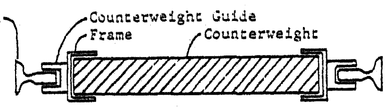

Figure 2

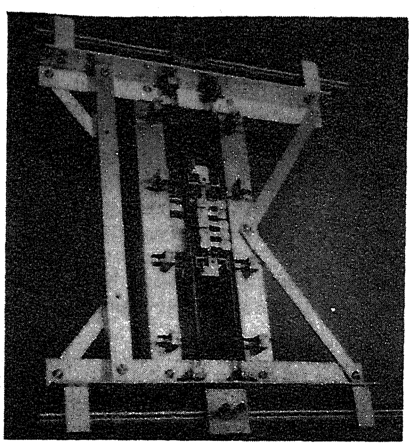

Figure 3