EARTHQUAKE PROTECTION OF COMMUNICATIONS FACILITIES

by

S. C. Liu[I]

SYNOPSIS

The continued reliable operation of telephone equipment in earthquake prone areas depends on the equipment's ability to survive quakes of a realitic magnitude. This paper describes procedures for developing regional earthquake protection practices of electronic, electromechanical and power systems based on cost and reliability. The following elements are included in this procedure: characterization of the earthquake environment, equipment vulnerability, and the cost of protection as opposed to potential losses.

INTRODUCTION

The development of reliable, yet cost-effective, earthquake protection practices for communications facilities requires a characterization of the earthquake environment, tests of equipment frameworks and assemblies, cost/loss considerations, as well as the interfacing of each of these elements. In this paper a general procedure is described, which includes all of these items to develop regional earthquake protection practices.

REGIONAL EARTHQUAKE ENVIRONMENT

The regional earthquake environment is determined via a microzonation analysis.[1] This analysis combines historical data, seismological and geological information, with a sound statistical model. The resulting contour map for the Rocky Mountain states, shown in Fig.1, depicts peak ground acceleration such that there is a 90% probability of not being exceeded during the 50-year service life of communications facilities.

BUILDING MOTION

Equipment located on upper floors is generally subjected to a more severe environment than equipment on ground floors since earthquake motion is amplified as the shock travels through the coupled ground-building-equipment system. An analysis[2] of the large collection of data gathered during the San Fernando earthquake has resulted in the upper-floor amplification factor shown in Fig. 2. In an analytical study of earthquake-induced building motion,[2] the motion time histories for the upper floors of representative multistory telephone buildings with different structural characteristics and soil conditions were calculated for earthquakes with Modified Mercalli Intensities of V to X. The results were expressed in terms of an envelope response spectra for different damping ratios as shown in Fig. 3. The average peak floor acceleration levels corresponding to such spectra is approximately 0.8 to 1.0 g, with the predominant frequency band of 2 to 6 Hz.

[I] Program Manager of Earthquake Engineering
National Science Foundation
Washington, D. C., U. S. A.

This frequency range includes most communications equipment and framework assemblies.

TIME HISTORY TEST ENVIRONMENT

Ideally, simulated earthquake motion for testing should resemble actual earthquake motion as closely as possible in peak accelerations, peak velocities, peak displacements, durations, and appearance of waveforms. A number of different test methods can be used to simulate an earthquake environment: the random waveform method, used here, satisfies more of the above requirements than any other.

The appropriate acceleration is generated on a digital computer using the techniques established earlier.[3] An envelope function is used to shape the initial, middle, and final phases of the simulated motion into a typical earthquake accelogram. The predominant frequencies are adjusted upper-bound earthquake environment is generated by matching, as closely as possible, the 2-percent spectrum of the synthesized earthquake to the in-building spectra shown in Fig. 2. The resulting acceleration history of this synthesized earthquake, shown in Fig. 4, qualifies as the upper-bound criterion, since it approzimately matches the upper-bound in-building response spectrum and has a peak acceleration close to 1 g. This peak acceleration value is consistent with the maximum building accelerations determined in Ref. 2.

A regional earthquake environment for equipment tests can now be generated for a specific location. As an example, consider a communications facility located geographically on the microzonation map (Fig. 1) such that the peak ground acceleration is 0.2 g. If the equipment is to be installed on the upper floors of the building, then the amplification factor in Fig. 2 is approximately 2.0, so that the peak upper floor acceleration will be 0.4g. The earthquake environment for a specific facility is determined by linearly scaling the accelogram of Fig. 4, which has peak acceleration approximately 1 g, down to 0.4 g. With equipment on the ground/first floor the test environment would be scaled to 0.2 g.

EQUIPMENT TESTING

The earthquake environment indicated above can now be used for testing various types of communications equipment. The basic concern is with the integrity of the equipment framework assemblies and their supports, such as holddown bolts and braces. If these supports fail, the entire system is vulnerable to catastrophic damage.

The general test procedure is as follows: (1) Program a shaker table motion using the upper-bound earthquakes shown in Fig. 4. (2) Test the equipment-framework with linearly scaled inputs of 0.1 g to 1.0 g. (3) During each test record peak table acceleration a_i, corresponding to initial damage, and a_f, corresponding to total failure, to obtain a damage profile as shown in Fig. 5.

By keying the damage profiles for the different types of equipment to the microzonation map, regional earthquake protection practices are developed.

Electronic Switching Systems (ESS) - This equipment, termed Nos. 1,2,3, and 4 ESS, is the latest vintage of telephone switching facilities. It is replacing the electromechanical equipment, which presently comprises the bulk of the existing telephone plant. The frameworks supporting the equipment are 7 ft. tall and are generally self-supported, i.e., they are anchored to the floor. As a result of this support system the configuration is basically an inverted pendulum with a fundamental frequency which varies between 2 and 6 Hz depending on the specific type of equipment.

The electronic equipment tests are performed for three frameworks and for three different weight categories, for a total of nine cases. The initial failure level, which is defined as the input acceleration level that causes a permanent frame distortion (as measured by strain gauges) or loosening of the floor anchor bolts; and the total failure level, which corresponds to frame upright buckling or pull-out of the anchor bolts, are determined.

The test results are used to construct the damage profile in terms of base equipment acceleration. It is found that in general electronic equipment with light weight and located on ground floor is less vulnerable than heavy equipment located on upper floor. Most electronic equipment can sustain as ground acceleration up to 0.25g without significant damage. The damage profile for various cases considered are used in conjunction with regional contours to determine the regional floor anchor bolt requirement for equipment on ground/first floor and on upper floors of telephone buildings. In some cases, i.e., heavy equipment in the high risk areas of Fig. 1, it is necessary to include overhead bracing to insure the safety protection equipment.

Electromechanical Equipment. - This equipment, which consists primarily of crossbar switching facilities, is mounted on 11-1/2 ft. frameworks anchored to the floor and braced to the ceiling. This configuration results in an equipment-framework-bracing fundamental frequency of 4 to 8 Hz, depending on the specific mix of equipment weights and frameworks. Tests are performed in the same manner as the electronic equipment, i.e., varying the weight, framework, and input environment. In addition, a special structure is built to simulate overhead bracing on the shaker table. The results of the electromechanical equipment tests are also expressed in terms of damage profiles. By keying these damage profiles to the microzonation map, regional earthquake protection practices are developed. Namely, it is determined that a special earthquake designed overhead bracing configuration should be used in the high risk areas, while a less expensive nonearthquake ceiling bracing configuration could be used elsewhere.

COST AND LOSS CONSIDERATIONS

The procedures developed previously will result in earthquake protection practices which increase equipment reliability. The cost of this protection as well as the avoidance of potential losses must also be considered to insure that the practices are cost-effective as well as reliable.

Consider a situation with one communications system located within a given isoacceleration contour. Assume that regional earthquake protection is incorporated to ensure survival of the system for the environment indicated by its location on a contour map. The specific earthquake protection installed is determined by the damage profile (e.g., Fig. 5) of the equipment-framework system. Without earthquake protection, expected losses over the 50-year facility service life would be equal to the value of the equipment, c_i. With earthquake protection, this loss is reduced to $L_e = p_f c_i$, where p_f^i is the probability that the design environment will be exceeded during the facility service life, i.e., the exceedance probability is 0.10.

Thus, the expected loss is $L_e = 0.10\ c_i$. The earthquake protection cost ratio δ (protection cost divided by equipment replacement value) for communications facilities is typically 0.0004 to 0.02, depending on the type of equipment and its protection level. Therefore, an expenditure $P = 0.004\ c_i$ to $0.02\ c_i$ results in a reduction of expected losses, L_e from c_i down to $0.10\ c_i$.

For n systems within a given contour, each system, a,b,c,...,n, is equally vulnerable and has a likelihood of failure, $p_f(a)$, $p_f(b)$,...,$p_f(n)$, with joint failure probability $p_f(bc)$,...,$p_f(mn)$, etc. If each system has earthquake protection commensurate with its contour location and these systems are geographically separated so that their failures can be treated as independent events, the expected loss can be expressed as

$$L_e = c_i[np_f + 2\binom{n}{2}p_f^2 + 3\binom{n}{3}p_f^3 + \dots + n\binom{n}{n}p_f^n].$$

Note that higher-order terms contribute very little to the total loss because therse terms correspond to higher-order joint failures, which are extremely small. Neglecting these terms for $n \geq 2$ a lower bound estimate of the earthquake loss is $L_e \geq nc_ip_f = 0.10\ nc_i$. Since the protection cost for n systems is $P = n\delta c_i$, where δ is typically 0.004 to 0.02 for telephone equipment, it can be conxluded that earthquake protection can be very cost-effective.

CONCLUSIONS

This paper has described procedures developed to ensure telephone equipment reliability in various earthquake-risk regions. For a given system the following elements must be determined: the nature of the earthquake environment, equipment vulnerability, and the cost of the protection as opposed to the possible system losses. Earthquake protection practices designed according to these prerequisites will increase system reliability in a cost-effective manner.

ACKNOWLEDGMENTS

All of the work described in this paper was performed while the author was at Bell Laboratories. I wish, specifically, to acknowledge N. J. DeCapua for his major contributions to these studies.

REFERENCES

1. Liu, S. C. and DeCapua, N. J., "Microzonation of Rocky Mountain States," Procedures of the U. S. National Conference on Earthquake Engineering, University of Michigan, June 1975, pp. 128-35.

2. Liu, S. C. Fagel, L. W. Dougherty, M. D. , "Synthesis of Earthquake Motion in Multistory Buildings," to be published in the ASCE Journal of Structural Division, 1976.

3. Liu, S. C. and Fagel, L. W., "Earthquake Environment for Physical Design," Bell System Technical Journal, Vol. 51, No. 9, November 1972, pp. 1957-82.

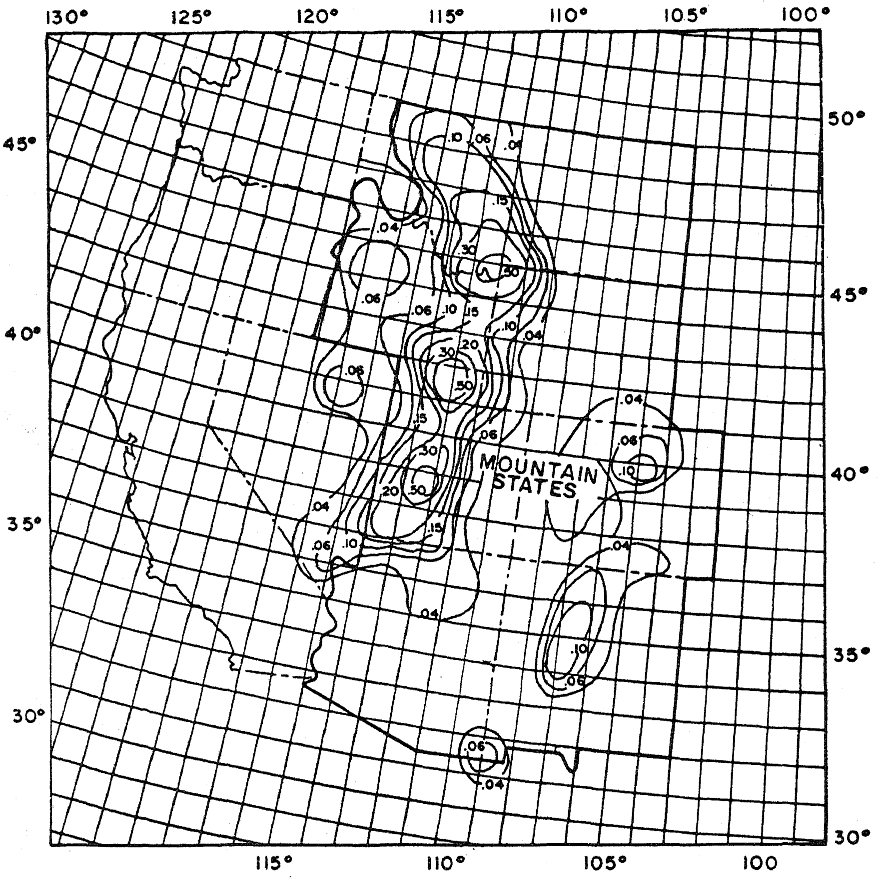

Figure 1 Peak Earthquake Ground Acceleration "g" Contours with a 90-Percent Probability of Not Being Exceeded in 50 Years.

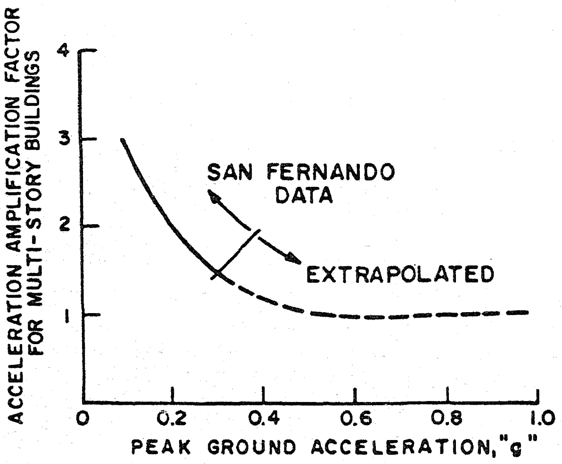

Figure 2 Building Amplification vs. Earthquake Ground Acceleration.

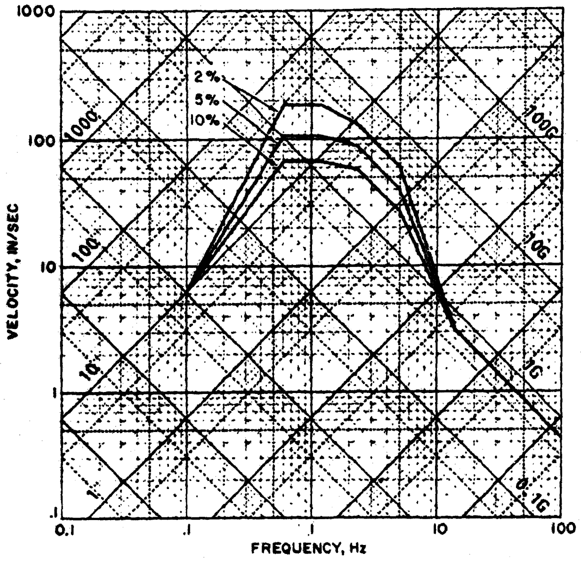

Figure 3

Envelope of In-Building Damped Response Spectra

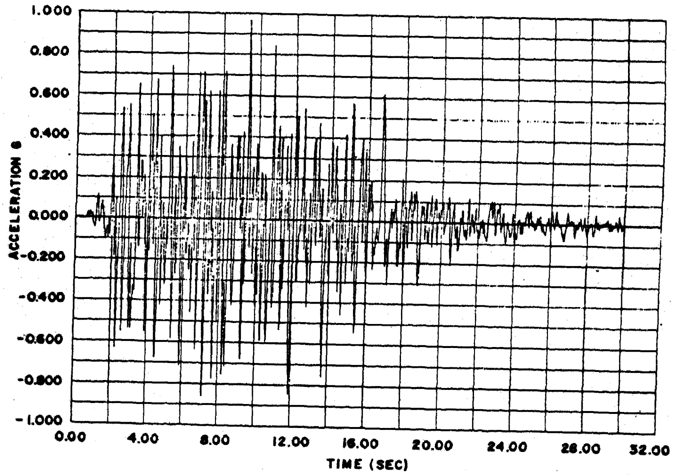

Figure 4

Analytically Developed Artificial Earthquake Accelogram

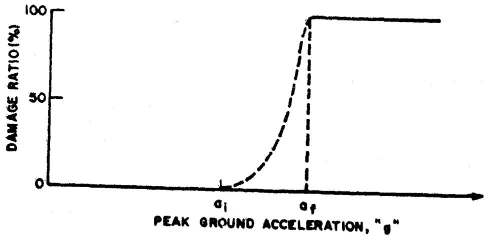

Figure 5

Typical Profile of Damage to Communications Equipment