

MITIGATING EARTHQUAKE EFFECTS ON
ELECTRIC POWER SYSTEMS

by

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SYNOPSIS

The background material and major recommendations concerning the response of electrical power systems to the San Fernando Valley earthquake of February 9, 1971 are presented. There exists the need for (a) methodologies to evaluate the impact of catastrophic disturbances to power networks, (b) more vibration testing and instrumentation to record earthquake excitation and the resulting equipment response, and (c) planning and performance standards. In addition, recommendations relative to the organization for structural design are made.

INTRODUCTION

The importance of electrical power to an urban community cannot be overemphasized. When the community is subjected to a severe earthquake, the disruption of electrical power can seriously impede rescue operations and other vital services which can cause more casualties and damage than the direct effects of the earthquake. The San Fernando Valley earthquake (SFVE) of February 9, 1971, served as a poignant reminder that existing specifications for earthquake design and construction of power systems are inadequate. The results of a post-SFVE study on the power systems are summarized in part. A more detailed development and specialized findings are given in the research report*. This paper is primarily concerned with the effects of an earthquake on power distribution networks, the failure of power system components and the loss of power to hospitals.

DESCRIPTION OF PREEARTHQUAKE SITUATION

1. Power Transmission Network--In a typical power system, the switching stations interconnect the high voltage transmission lines to form a grid-type network. The transmission stations are the first links in the sub-transmission network. The sub-transmission network in the United States

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can be described as a tree structure. Thus, the loss of any link in this network disrupts power distribution to lower branches of the tree.

2. Engineering for Power Systems--As a result of the 1933 Long Beach earthquake in which power systems experienced some damage, a West Coast industry standard of .2g equivalent static force to be applied laterally at the center of gravity of the electrical equipment was adopted. There was no requirement for vertical excitation. Verification was often based on sketchy tests or calculations performed by the suppliers. In addition, a large percentage of electrical power equipment must be mounted 8 to 25 feet above the ground to meet personnel safety requirements. Prior to the SFVE, dynamic analysis of the support structure was not required.

While the organization of each power system is unique, there are certain common characteristics, which, in the view of the authors, bear on the performance of electrical equipment. Typically, there is an electrical equipment group and a civil structures group, among others. The civil engineers are primarily responsible for the design of structures and can be called upon for assistance concerning structural design by other groups. Difficulties sometime arise when the electrical group attempts to do structural design for electrical equipment or its supports. Because seismic design has been a very narrow specialty, even within the area of structural engineering, it is not surprising that electrical equipment specialists were frequently not aware of potential problems and thus did not seek the assistance of earthquake engineering specialists. It should be noted that this was the situation prior to the SFVE. At present, as after the 1933 earthquake, there is a keen awareness of the seismic problem. Because the "service half life" of the design engineer is short relative to the time between destructive earthquakes, it would not be surprising to find that in 5 to 10 years the situation in regard to seismic design details reverts to that prior to the SFVE unless some organizational changes are made.

Another apparent weakness in the organization is associated with inspection and acceptance of completed construction. Typically, the inspection function is handled by a group of specialized technicians, who frequently inspect only outside contracted work and not the in-house construction. Another point which makes inspection difficult is that often there is a lack of details in the engineering design drawings. In some cases, suppliers do not provide the information, and in others, in-house designs are lacking. This is particularly true with respect to tie-down and mounting details.

3. Emergency Power--In the United States, standards for emergency power on the national level are embodied in the National Fire Prevention Code. For hospitals, the minimum required standards are well below what would be required to maintain more than the most vital life support systems. Even in California, which has one of the better codes, there is no specification for the security of emergency power equipment.

IMMEDIATE AND SUBSEQUENT RESPONSE OF POWER SYSTEMS TO THE SFVE

1. Power Transmission Network--Service on the Pacific interties were temporarily interrupted with the DC portion out of service for over one

year. Disturbance to the rest of the high voltage transmission network was minimal. There were extensive interruptions in the Los Angeles area although service to all but the most severely shaken areas was restored within an hour.

The timing of the earthquake was quite fortuitous in that most people were at home, expressways were relatively empty, and many severely damaged structures were unoccupied. At that time power loads were relatively low and major damage was restricted to a relatively small area adjacent to high population concentrations. Thus, extensive resources could be concentrated to recovery operations. The effects of the loss of power to recovery operations after a large earthquake affecting more extensive areas is difficult to estimate.

The very intense shaking accompanying this moderate magnitude earthquake emphasizes that the destruction of vital facilities such as transmission stations cannot be precluded. While power companies do run fault analyses of networks, vulnerability analysis to earthquake hazard has not been done. Such analysis would take into account the vulnerability of vital facilities potentially affected by a single event. Results of such an analysis would indicate the effectiveness of different strategies to improve system reliability to this type of disturbance.

2. Post SFVE Engineering Requirements for Power Systems--With respect to the design process, the most significant result of the SFVE has been the reevaluation of electrical equipment specifications. The revised specifications now typically call for equipment to resist a 0.5g horizontal acceleration and 0.4g vertical acceleration simultaneously. Moreover, natural frequencies, damping and mode shapes of equipment as mounted under service conditions must be determined. Several testing programs have also been initiated as a means to verify modeling efforts and obtain properties of electrical components. Currently, efforts are being continued to develop a unified set of equipment specifications for the West Coast.

3. Emergency Power--The situation of emergency power can best be illustrated by the circumstances at the Olive View Hospital, which was dedicated just a few months before the earthquake and had extensive emergency power facilities. The failure of the power system required evacuation to be carried out with flashlights. The all too familiar sight of emergency batteries strewn on the floor surrounding a collapsed stand was repeated.

CONCLUSIONS AND RECOMMENDATIONS

1. Power Transmission Network--While the response of the electrical power system to the SFVE was quite good as measured by extended disruptions, review of existing practice suggests some modifications. It is recommended that uniform, minimum standards of performance for the operation and planning and basic principles for reliability, adequacy, etc., of power transmission networks be established. Regional coordinating councils or other appropriate groups should be given the responsibility and authority to insure that these minimum standards are met. Improvements in network simulation methods should continue and monitoring instrumentation required for establishing model validity should be installed. Vital and costly facilities should have strong motion recording devices to accurately establish

those vibration levels at which the equipment fails under a strong earthquake. Special analytical methods should be developed for evaluating system security to catastrophic earthquakes. Results of these analyses would indicate "weak" links in the system so that they can be strengthened with improved design, system redundancy, or appropriate back-up equipment reserves.

2. Engineering for Power Systems--While the development of the new electrical equipment specifications represents a significant improvement, the experience following the 1933 Long Beach earthquake suggests a desirable change in the organization of power system design. Because earthquakes which adversely affect power systems are rare events, the long time intervals between these events tends to diminish any specialized experience and concern with the seismic problem. It is suggested that an individual position or a small group be created outside the traditional departments within the engineering division of each power system. This advisory person or group would be concerned solely with seismic problems of design, construction and inspection. This specialist group should have access to all phases of the engineering efforts and be expected to question and to make formal recommendation in writing to the various other departments. In this manner, seismic awareness can be constantly maintained. Furthermore, it is suggested that a "damage evaluation log" should be developed and maintained which would consist of a file of earthquake-induced power system damage. Emphasis would be on damage resulting from design, construction and inspection deficiencies. It would consist of pictures of the damage and results of analysis explaining the probable cause and suggested remedies. The file would be enlarged as data becomes available on a world-wide basis. Such a "damage evaluation log" should be readily available to those concerned with engineering of power systems in high and moderate seismic risk zones. The material presented in the log should be very brief and concise, thus encouraging its use by field personnel.

3. Emergency Power--The concept of emergency power must be reviewed. All vital facilities such as hospitals, communications systems, rescue and emergency coordination facilities, etc., should be provided with some emergency power. Other non-vital facilities such as tall buildings, large public facilities, etc., should also be considered. Equipment used to provide emergency power should carry special certification ensuring system reliability under extreme service environments. Installation and on-site facilities for emergency power should be subject to special specifications.

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