USE OF NONLINEAR ANALYSIS TO INTERPRET EARTHQUAKE RESPONSE OF PENDULAR SUPPORTED HIGH VOLTAGE ELECTRICAL EQUIPMENT

by

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SYNOPSIS

During the 1971 San Fernando Earthquake extensive damage occurred to a high voltage DC Converter Station. The greatest damage was sustained by current divider equipment which was supported with tension hangers as a three-dimensional pendular system. An analysis of this complex system was performed during a study for the Bonneville Power Administration to increase the earthquake resistance level of electrical facilities. The pendular system was first analyzed, by a computer code, using a linear three-dimensional model and subjected to earthquake time-history input motion. The results of this analysis indicated that the tension hangers unloaded which invalidated the assumption of linear behavior. Therefore, a non-linear model was developed using a state-of-the-art nonlinear three-dimensional dynamic computer code. The nonlinear behavior included were (1) hangers which carry tension loads only and (2) pendular restoring forces which are a function of the hanger forces. The results of the three-dimensional nonlinear analysis are presented.

INTRODUCTION

The current dividers and anode reactors are suspended from the valve hall roof at the Celilo DC converter station with insulator hangers to form a three-dimensional pendular system which can experience large displacements during seismic excitation. During the 1971 San Fernando earthquake, the same type of suspension system failed on all 42 current dividers at the Sylmar DC converter station. A general view of a damaged current divider is shown in Figure 1. The damage to the valves caused by the falling dividers resulted in the highest cost and longest downtime for repairs of all electrical equipment damaged by the earthquake. Assurance of the satisfactory performance of this suspension system was, therefore, a very important part of the design modification study performed for the Bonneville Power Administration by Agbabian Associates (AA).

MODIFIED LINEAR MODEL

An analysis was provided of the current divider and anode reactor support system in an initial Assessment Study (Ref. 1) which was based upon the assumption that the suspension insulator hangers had been replaced with post insulators which could resist both tensile and compressive loads.

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The results of this linear analysis was used to point out that both tensile and compressive forces could result from the earthquake motions, and since the hangers in reality could not resist compression but would go slack, the current dividers could impact on the hangers resulting in forces larger than those computed by this analysis.

As a result of the review of the model used in the Assessment Study, it was decided that this model should be separated into two models for the design modification study: (1) a model of the building without the current divider; (2) a model which included a roof segment (1 bay) and a current divider and anode reactor. This separation was possible due to the low frequency of the pendular system compared to the building frequency (i.e., the effective horizontal isolation of the current divider). The partition of the model into two separate models made it possible to expand the model of the roof segment, see Figure 3, to provide a more precise definition of the hanger geometry.

The initial stiffness of the model of the building was modified from that initially used to provide an experimentally measured fundamental frequency of the building. The second model, the expanded model of the roof and current divider and anode support system, was also checked to make certain that the frequencies of the support system were in agreement with test results. The modified building model, see Figure 2, was then analyzed for a new earthquake ground motion consistent with the new response spectra developed for the modification study. Three components of the Helena 1935 earthquake ground motion were used as input. The computed lateral response of the building roof was then used as input motion to the expanded roof/current divider model. The vertical input motion for the model was assumed to be the ground vertical motion. Thus, the building acted as a filter for the horizontal motion but not the vertical input motion. The force time history in a linear insulator hanger resulting from the analysis is shown in Figure 4. The current divider response was such that the hangers did not quite go into compression, varying plus and minus 2000 lbs. Thus, the analysis indicated that the hanger would unload completely when given a slight increase in excitation.

THREE-DIMENSIONAL NONLINEAR MODEL

Under vertical excitation, any statically stable pendular system can still be dynamically unstable so that oscillation amplitudes grow to unexpectedly large values as the result of a transient disturbance. Such a system is said to be parametrically excited, and thus the dynamic instability is a potential problem of any pendular system. This fact underscores the necessity of including the nonlinear effects of a pendular system in any model in addition to the suspension hanger nonlinearity. The AA GENSAP computer code is fully capable of including both nonlinear effects and therefore a three-dimensional model with full nonlinear capability was developed and subjected to the filtered seismic input. One result of the analysis, the force time history in a suspension insulator hanger, is shown in Figure 5. It should be noted that several periods of hanger unloading occur, resulting in a peak hanger force of about 5000 lbs. Impacting did not occur with the input considered. The displacement time history of a point on the current divider near a valve connection link is shown in Figure 6. The displacements shown are relative to the roof motion which is $\pm$ 0.5 in. relative to the ground.

RECOMMENDATIONS

Since the present insulator hangers have a 15,000 lb rating, the factor of safety for the input considered is a value of 3.0. Thus, the existing system has a reasonable factor of safety against failure for the input considered and no revision of the support system is apparently required at the converter station. However, the current divider valve connecting links should be modified to allow for about 5 in. of extension.

Because of the nonlinearities of the system, the following factors should be noted:

(1) Only one unique ground motion input has been considered in the analyses. Although the input used is typical of the site considered, slightly different input motions could produce peak hanger forces which differ from those presented due to the nonlinearities of the problem.

(2) The factor of safety quoted above must be considered with the input motion used and must not be viewed as equivalent to a load factor. Because of the nonlinear behavior, it cannot be stated that the system would survive an input motion three times stronger than that considered.

Additional analysis using other earthquake ground motions would also provide additional insight on the relationship between strength of earthquake ground motion and insulator hanger stress.

REFERENCES

1. "Assessment of Earthquake Resistant Design of AC-DC Converter Stations," R-7119-1984, Agbabian Associates, August 1971.

2. Kobrinsky, A. Ye., "Mechanisms with Elastic Couplings: Dynamics and Stability," NASA TT F-534, National Aeronautics and Space Administration, Washington, D.C., June 1969.

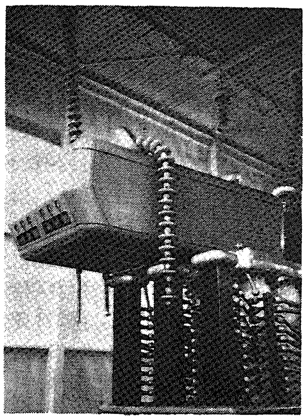
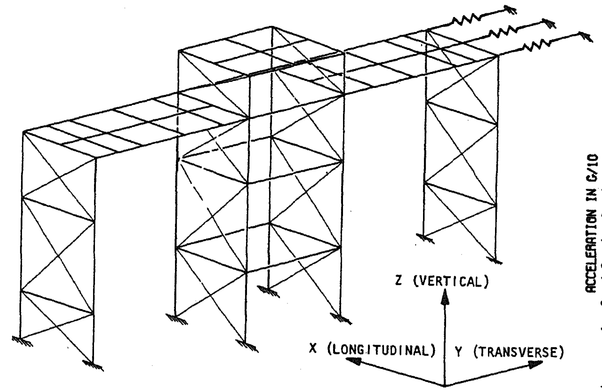
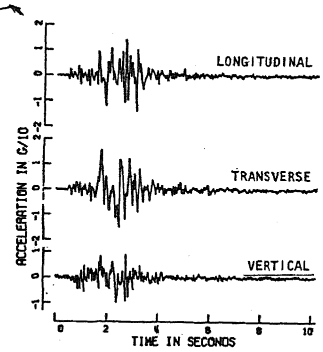


FIGURE 1. GENERAL VIEW OF DAMAGED CURRENT DIVIDER AND VALVE





THREE DIMENSIONAL GROUND MOTION INPUT

FIGURE 2. MODIFIED BUILDING MODEL

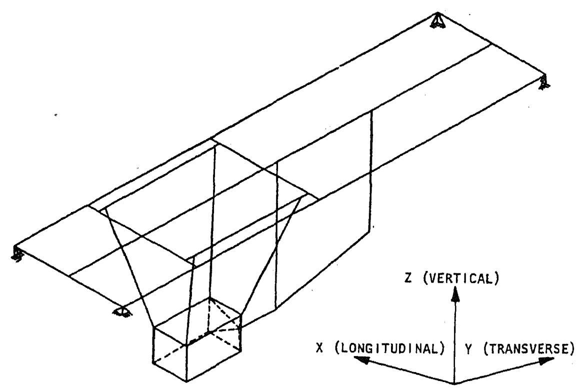


FIGURE 3. EXPANDED CURRENT DIVIDER COMPUTER MODEL

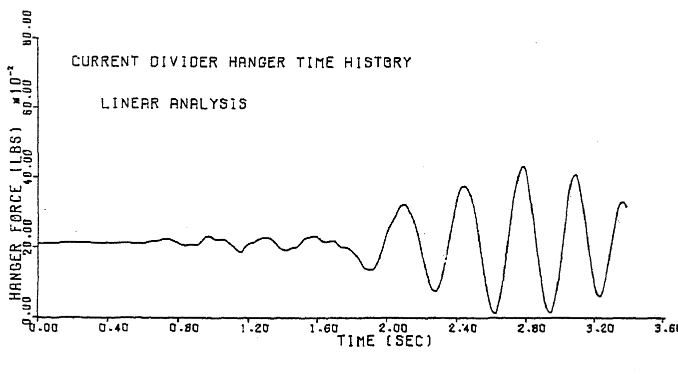


FIGURE 4. CURRENT DIVIDER HANGER TIME HISTORY, LINEAR ANALYSIS

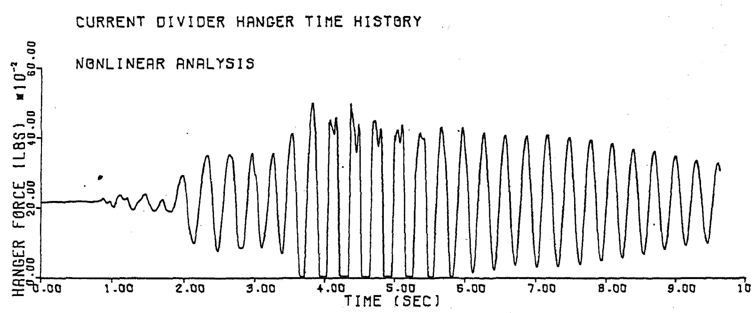


FIGURE 5. CURRENT DIVIDER HANGER TIME HISTORY, NONLINEAR ANALYSIS

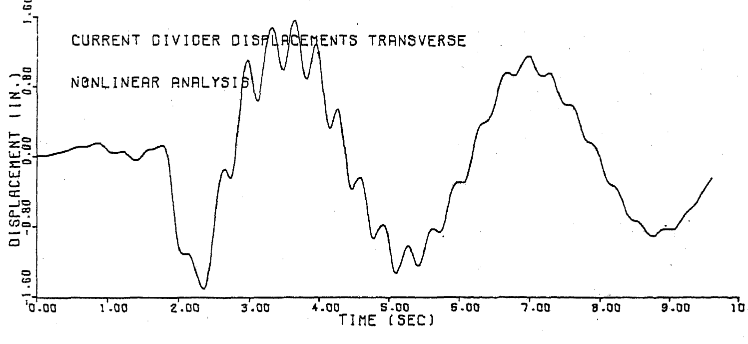


FIGURE 6. CURRENT DIVIDER DISPLACEMENT TRANSVERSE, NONLINEAR ANALYSIS