SEISMIC RISK STUDY OF THE PALO ALTO CIVIC CENTER

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SUMMARY

This paper presents the results of the seismic risk study of the Civic Center of the City of Palo Alto in California. The main objective of the study was to determine the consequences to the building resulting from postulated earthquake motions occurring at the site. A scenario of potential damage to the building resulting from a range of earthquake motions of increasing intensities was also developed in the form of "Damage Curves." The potential seismic effects were investigated considering the existing condition of the building, which included significant cracks in floor slabs, concrete columns and shear walls resulting from creep and shrinkage effects of the prestressed concrete slabs.

INTRODUCTION

A seismic risk study of the Palo Alto Civic Center was conducted. Design modifications were developed, as a result of this study, to strengthen the building so that it can safely resist postulated seismic motions occurring at the site considering the existing condition of the building (Ref. 1).

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The seismic risk study consisted of the following major tasks:

- Development of the Earthquake Exposure
- Seismic Analysis and Evaluation of the Building
- Development of Conceptual Design Modifications
- Seismic Risk Evaluation

These tasks are described below.

DEVELOPMENT OF EARTHQUAKE EXPOSURE

The earthquake exposure at the building site was developed in the form of probabilistic site-dependent response spectra. This development was divided into two steps: 1) Estimation of probabilistic seismic hazard in terms of peak ground acceleration at the site, and 2) calculation of probabilistic response spectra. The following were the major factors considered in the development of these spectra:

- Site location with respect to seismotectonic region
- Seismic source geometry
- Seismicity and geology of the region
- Attenuation of earthquake ground motions from source to site
- Local soil conditions
- Amplification of ground motions as a function of frequency and damping ratio

The above factors were used in conjunction with a Bayesian probabilistic model (Ref. 2).

Five major seismic sources (earthquake faults) were considered in the development of earthquake exposure for the Palo Alto Civic Center site. The selected sources are the main contributors to overall seismicity of the Palo Alto area. These five sources (faults) are: San Andreas North, San Andreas Central, Sargent, Hayward, and Calaveras. Figure 1 shows these major faults in relation to the Palo Alto Civic Center site. Probabilistic site-specific response spectra were calculated for the following cases:

Economic Life of Building (Yr.)	Damping Ratio	Probability of Exceedance	Soil Condition
50	5%, 10%	10%, 50%	Intermediate, Soft
100	5%, 10%	10%, 50%	Intermediate, Soft

The response spectra for the above cases were developed by performing analyses of many earthquake accelerograms which were recorded at sites with soil conditions similar to those of the Palo Alto Civic Center site. The response spectra values were first obtained for each of the accelerograms, and were subsequently normalized with respect to the peak ground acceleration for each record. The normalized response spectra represent the dynamic amplification factors (DAF) associated with each accelerogram as a function of frequency and damping, and make it possible to compare the response spectra from the various earthquakes. Having obtained the statistics for the DAF's, the shape of the probability distributuion was developed. In this case, a truncated normal distribution was used. Further analysis lead to spectral values as functions of not only frequency and damping, but also as a function of the probablity of being exceeded during the economic life of the structure as well. Figure 2 shows the site-specific response spectra for an economic life of 50 years for values of 5 and 10 percent of critical damping. The spectrum with 5 percent damping was selected as the most realistic earthquake and was used for the analysis and evaluation of the Palo Alto Civic Center building.

SEISMIC ANALYSIS AND EVALUATION OF THE BUILDING

The Palo Alto Civic Center building consists of a podium at about the street level with an eight story tower placed at approximately the center of the podium and a three-story parking garage below ground. The building is constructed of cast-in-place concrete with prestressed post-tensioned beams and slabs. Figures 3 and 4 show a plan of structure at Level B and details of tower columns at the same level, respectively. As the figure shows, there is an expansion joint through the parking garage which separates the north part of the underground structure from the rest of the building. The north portion of the garage is 150 ft. by 202 ft. in plan, and has 10 to 12 inch thick concrete exterior walls. Concrete beams spaced at 20 ft. centers are continuous in the east-west direction with 5 1/2 in. reinforced and post-tensioned concrete slabs spanning in-between. The main portion of the building consists of the remainder of the facility south of the expansion joint. This portion of the underground garage is 202 ft. by 272 ft. and the concrete exterior walls are 12 inches thick.

Three-dimensional analytical models of the Palo Alto Civic Center building were developed for use with the computer program EDAC/TABS. This is a modified version of the program TABS 80 developed at the University of California, Berkeley. Separate models were developed for the two portions of the building on each side of the expansion joint. A typical frame of the model at Line D is shown in Figure 5.

A damping value of 5 percent of critical was selected as a realistic value for the structural analysis. Soil-structure interaction effects were included. A modal analysis procedure was then used for computing the dynamic response of the building. Maximas of nodal displacements and member forces were then computed.

The seismic adequacy of the various members of the building, including beams, columns, and shear walls was evaluated for overstress and potential failure. The maximum displacements were also determined. It was found that the columns in the garage and the shear walls in the tower would be significantly overstressed, with potential for local or overall failures.

DEVELOPMENT OF CONCEPTUAL DESIGN MODIFICATIONS

The following conceptual design modifications were recommended on the basis of the above analyses and evaluations.

- Strengthen perimeter columns under the tower for all levels in the garage
- Strengthen the shear walls of the elevator core for the complete height of the tower
- Provide shear walls between columns on lines C, E, and 12A for all levels in the garage
- Provide extra support for the slab at the expansion joint at all three levels in the garage in case it has a tendency to slip off the existing supports
- Fix all minor cracks in the building using epoxy

SEISMIC RISK EVALUATION

The analyses and evaluations described in the previous sections were performed for a postulated earthquake with 50 percent probability of exceedance for a 50 year economic life of the structure. This was construed to be a realistic earthquake at the site. In addition, a risk study was also performed which took into account a scenario for increasing levels of earthquakes and the resulting damage to the structure for such earthquakes. Expected levels of damage were expressed in the form of damage curves.

Several different procedures, including procedures developed at EDAC, were used for damage analysis. They included the following:

- A simplified empirical approach based on statistical analysis of available damage data on similar buildings
- Detailed damage analyses based on drift index and ductility ratio (Ref. 3)
- Detailed damage analysis based on ductility up to failure (Ref. 4)
- Detailed damage analysis based on Yield and Ultimate Capacities (Ref. 5)
- Damage analysis procedures, developed at EDAC (Ref. 6)

The above methods are based on different assumptions. All these methods were used to get a comprehensive picture of possible damage to the building and to develop estimates of damage for various levels of earthquake motions. Detailed descriptions of the above methods are available in the appropriate references.

Figures 6 and 7 present, respectively, the damage curves for the building in existing ("as is") condition and after all the proposed conceptual design modifications are completed. These damage curves were developed by assessing seismic scenarios on the basis of analyses and evaluations described previously, field investigations, and engineering experience.

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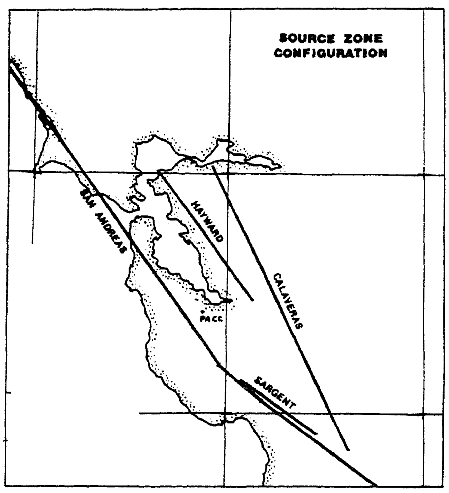

FIGURE 1 FAULT SOURCES USED IN THE STUDY

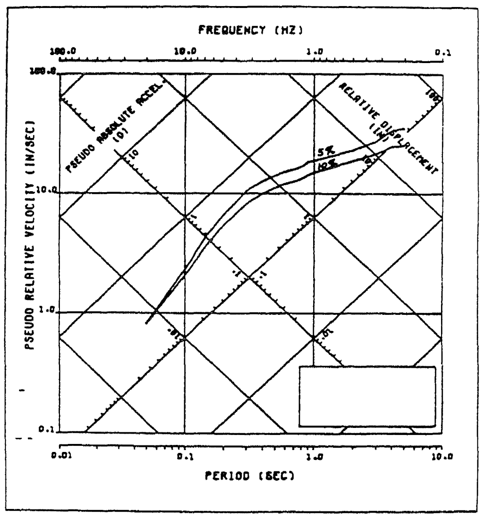

FIGURE 2 PROBABILISTIC SITE-SPECIFIC RESPONSE SPECTRA USED IN THE EVALUATIONS

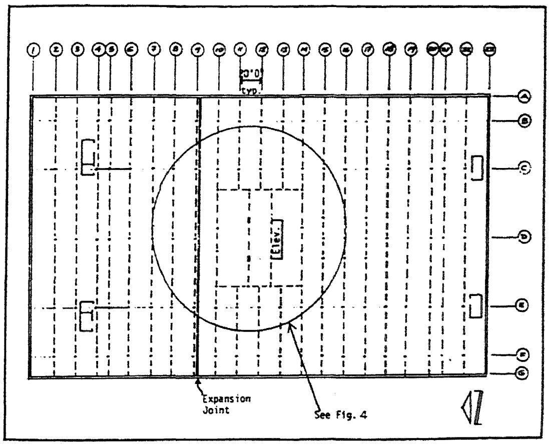

FIGURE 3 BUILDING PLAN AT LEVEL B

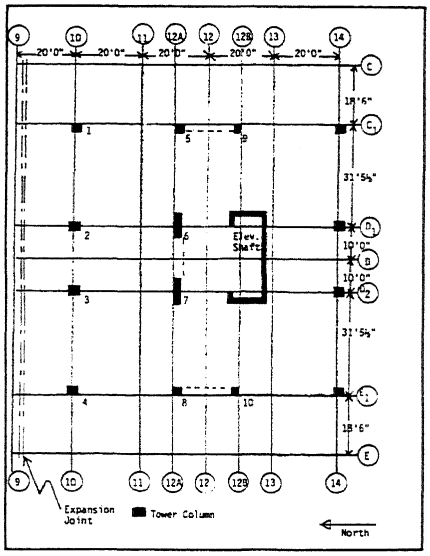

FIGURE 4 TOWER COLUMNS AT LEVEL B

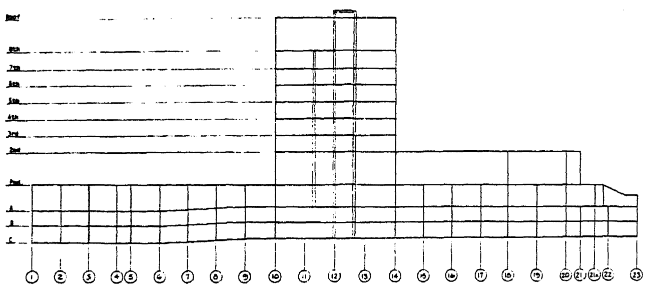

FIGURE 5 FRAME AT LINE D OF THE ANALYTICAL MODEL

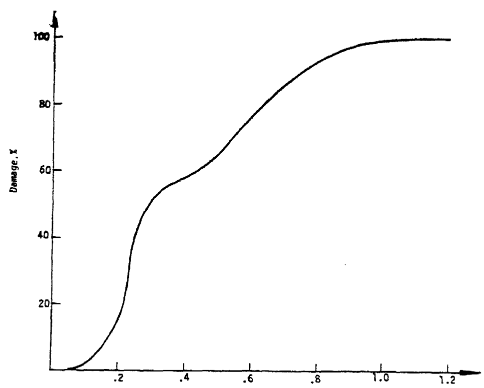

FIGURE 6 DAMAGE CURVE FOR THE BUILDING IN "AS IS" CONDITION

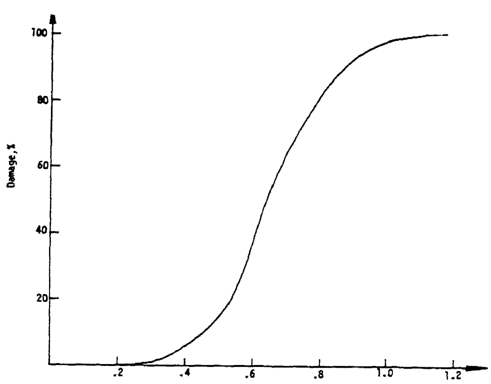

FIGURE 7 DAMAGE CURVE FOR THE BUILDING WITH ALL MODIFICATIONS