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GROUND MOTION STUDY FOR AN ESSENTIAL FACILITY

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ABSTRACT

The goal of earthquake-resistant design is to build a facility that can withstand a certain level of shaking without excessive damage. Essential facility buildings in California are being required to provide a higher level of seismic safety because of the nature of the critical functions they provide during and after natural and man-made disasters, especially earthquakes. Evaluation of the effects of earthquake requires quantitative way of describing the strong ground motion. Guidelines used in selecting and utilizing ground motion for essential facilities are presented. The specification of design ground motion parameters is one of the most challenging and most important problems in geotechnical earthquake engineering. One of the hospital sites in Southern California is used as a study site. Two levels of ground motions such as design basis earthquake (DBE) and upper bound earthquake (UBE) were considered per California Building Code 2001. Seven sets of time histories with three orthogonal components of translational motions were developed, reviewed by California Geological Survey and Office of Statewide Health Planning and Development and approved for two levels of ground motion. These time histories were used in dynamic analysis of the unbounded-brace frame structure.

Introduction

California have historically responded to major earthquakes and resultant loss of life by requiring stricter building codes to protect lives and property, with special requirements for critical buildings that need extra protection. Essential facilities must remain standing and functional during and after an earthquake for the safety of public and staff and to provide assistance to earthquake victims. During and immediately after a disaster, essential facilities are the beacon of life and hope for a community. In this paper a medical center from Southern California is used as an example.

This medical center is located just north of the Pomona Freeway (SR-60) at Vineyard Avenue in City of Ontario, California. Approximately 28-acre master-planned campus was developed in two phases. The first phase consisted of three buildings completed and operational since 2003:a four-story medical office building (MOB) with a basement and approximate building footprint of 26,000 square feet, a single-story surgical-center with a footprint of 55,000 square feet, and a single-story central utility plant(CUP) with a footprint of 30,000 square feet. The second phase consisted of four additional structures including a 186 million dollars 5-story In-Patient Tower and a 4-story Diagnostic and Treatment center with a basement, a five-story health services building (HSB), and eight-story parking structure and expansion to existing CUP.

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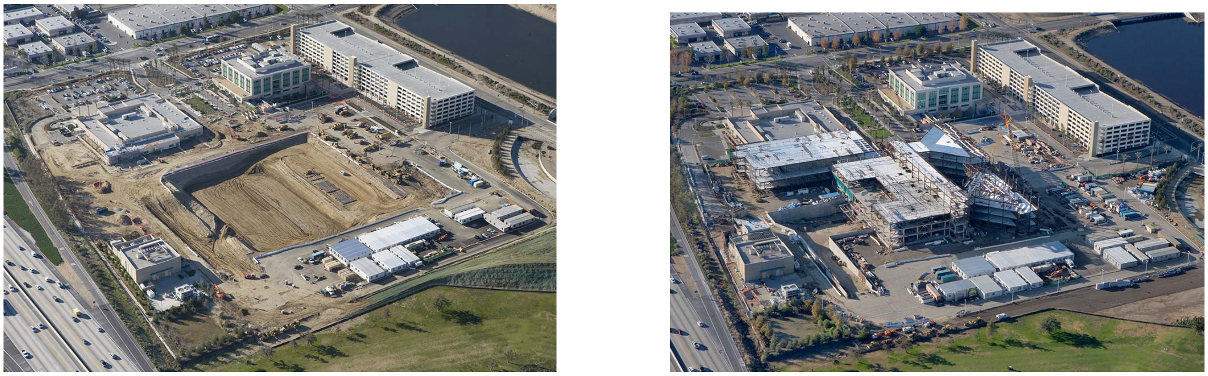

During overexcavation During hospital building construction

Figure1. Vineyard Hospital Site

The Ontario Vineyard Medical Center 5-story in-patient tower and 4-story diagnostic and treatment center (as shown in Fig. 1) is the fourth template hospital designed in California as an Unbounded Braced-frame structure. This advanced structural design required close coordination with design team, reviewing agencies: Office of Statewide Health Planning and Development (OSHPD) and California Geological Survey (CGS) and hospital team members. Leighton provided digital synthetic seismic time-histories to the project structural engineer for dynamic analyses of the hospital structure, reviewed by CGS and OSHPD. Dynamic analyses of the hospital structure required seven sets of earthquake time histories in accordance of California Building Code 2001 (CBC 2001) for two levels of earthquakes. Each set of earthquake time histories had two horizontal components and one vertical component. Actual earthquake records with compatible geologic and seismic/tectonic environment as same as this site were selected and were scaled to match the target spectrum for the site.

Unbonded Braced Frame

During an earthquake, a large amount of kinetic energy is fed into a structure. The manner in which this energy is dissipated determines the level of damage. In Japan, Professor Wada and his team developed the unbounded braced Euler buckling of the central steel core is prevented by encasing it over its length in a steel tube filled with mortar. The term Unbounded Brace came from the need to provide a slip surface or unbonding layer between the steel core and the surrounding concrete, so that axial loads are taken only by the steel core. The unbonded braced frame has been used on nearly 300 buildings in Japan since 1987.

On January 17th, 2000 the first unbonded braced frame was installed in the United States at UC Davis Plant and Environmental Science Facility. The first unbonded braced building was introduced for Kaiser Santa Clara Medical Center project. Following OSHPD approval, the first hospital project to incorporate the unboneded braced frame system began construction on June 17th, 2002 in Santa Clara, California.

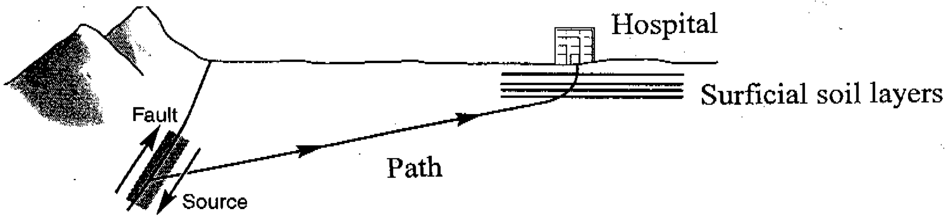

Figure2. Source of Earthquake and Path of Energy in Relation to Hospital Building

The ground motions generated by earthquakes can be quite complicated. At a given point on earth, they can be described by three components of translation and three components of rotation. In practice, the rotational components are usually neglected and three orthogonal components of translational motion are most commonly measured. For engineering purposes, three characteristics of earthquake motion are important namely 1) duration of motion 2) amplitude 3) frequency content. Although written descriptions of earthquakes date back to 780 B. C., the first accurate measurements ground motions were made in early 1930s. Measurement of ground motion has advanced considerably since then. A selected set of ground motions from this data base is used in this study.

The goal of earthquake-resistant design is to produce a structure that can withstand a certain level of shaking without excessive damage. The specification of design ground motion parameters is one of the most difficult and most important problems in geotechnical earthquake engineering. Seismic hazard analyses involve the quantitative estimation of ground-shaking hazards at a particular site. Seismic hazards may be analyzed deterministically, as when a particular earthquake scenario is used or probabilistically, uncertainties in earthquake size, location and time of occurrence are explicitly considered. In this study, probabilistic seismic hazard analysis is used. Faults (sources) in the vicinity of the subject site are shown in the Fig. 3 below.

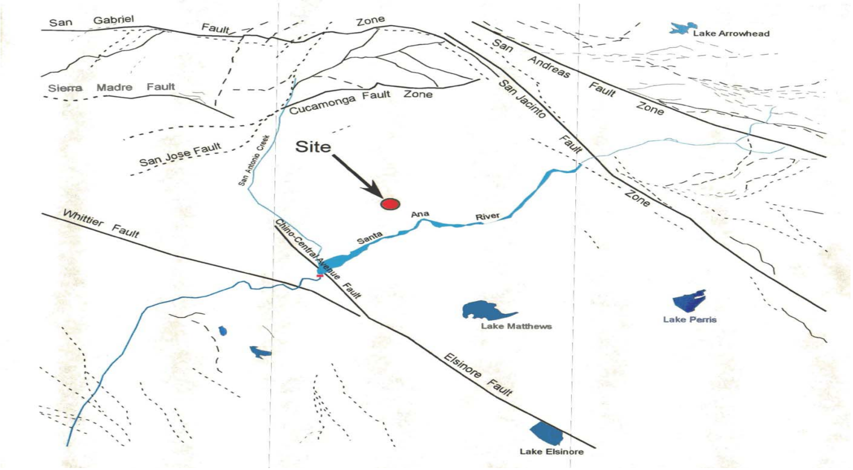

Figure3. Active Faults in the Vicinity of the Hospital Site

Target Response Spectrum

We have used the site-specific probabilistic response spectra for 5percent damping developed for earthquake event with 10 percent probability of exceedance in 50 years (or 475-year average return period) and earthquake event with 10percent probability of exceedance in 100 years (or 975-year average return period) as the target response spectra. The target response spectra were developed using EZ-FRISK program based on the average of four attenuation relationships, namely, Boore et al. 1997, Campbell and Bozorgnia 2003, Sadigh et al. 1997 and Abrahamson and Silva 1997. These four attenuation relationships were selected for this study based on the local experience. For the Boore and Campbell models, an average shear wave velocity of 300 meters per second was utilized in the upper 100 feet based on analysis of existing subsurface data. The relationship by Boore and Campbell allow for consideration of the site shear wave velocity.

As requested by the project Structural Engineer, Acceleration Response Spectra (ARS) for 2- and 10-percent damping ratios were determined based on the 5-percent damped ARSs, utilizing recommended procedures by Newmark and Hall 1982. Fig. 4 illustrates the 2-, 5- and 10-percent damped design ARSs associated with the two probability of exceedance levels for DBE and UBE events.

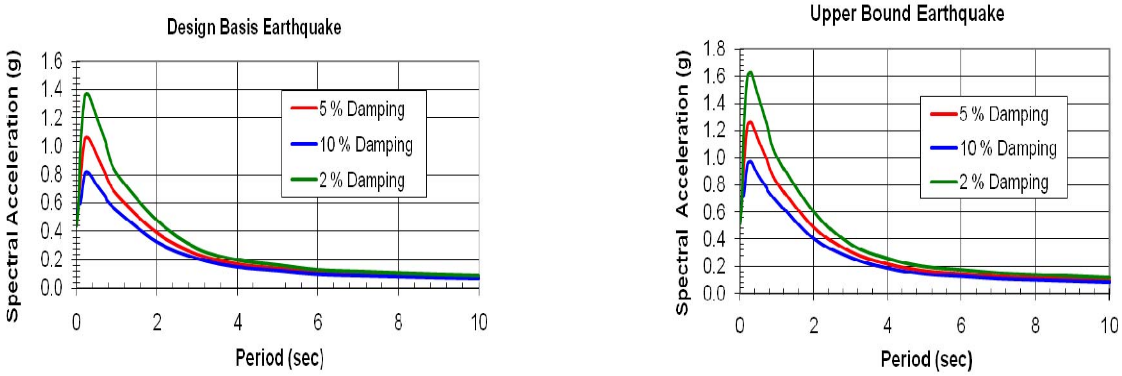

Figure4. Target Response Spectra for DBE and UBE

Selected Earthquake Records

The results of the hazard de-aggregation indicate that the total hazard is dominated by earthquakes with a magnitude between 6.5 and 7.0 at distances ranging from 10 to 20 kilometers. We searched the Pacific Earthquake Engineering Research (PEER) strong-motion database website (http://peer.berkeley.edu/smcat/search.html) and Consortium of Organizations for Strong-Motion Observation Systems (COSMOS) to obtain actual earthquake records from sites with compatible geologic (soil profile type) and seismic/tectonic environment (type of fault, magnitude, and seismic source distance) as the subject site. We have selected the following earthquake records, summarized in Table1 below. These processed motions were obtained from PEER strong motion data base.

Table1. Selected Earthquake Records for the Study

Earthquake Name and Recording Station (Date)	Type of Fault	Moment Magnitude	Seismic Source Distance (km)	Soil Profile Type (USGS)*
Landers Earthquake, 22074 Yermo Fire Station (06/28/1992)	Strike-slip	7.4	25	C
Loma Prieta Earthquake, 47524 Hollister – South St. and Pine Dr. (10/18/1989)	Reverse-Oblique	7.1	17	C
Cape Mendocino Earthquake, 89156 Petrolia (04/25/1992)	Reverse-Normal	7.1	16	C
Imperial Valley Earthquake, 955 El Centro Array #4 (10/15/1979)	Strike-slip	6.9	8	C
Imperial Valley Earthquake, 952 El Centro Array #5 (10/15/1979)	Strike-slip	6.9	5	C
Imperial Valley Earthquake, 5165 El Centro Differential Array (10/15/1979)	Strike-slip	6.9	6	C
Northridge, 24279 Newhall Fire Station (01/17/1994)	Reverse-Normal	6.8	11	C

*- USGS soil profile C has shear wave velocity in between 180- to 360-meter per second.

Spectral Matching Analysis

Spectral matching analysis consists of taking actual earthquake accelerograms and adjusting them to match a target response spectrum obtained from probabilistic response spectrum. Vertical-to-horizontal reponse spectral ratio of 2/3 was used in our analysis. Spectral matching analysis was implemented using the EZ-FRISK computer program (Risk Engineering 2006) which utilizes Dr. Norman Abahamson's time-dependent spectral matching algorithm RSPMatch99. The original, target and matched response spectra are presented in Figs. 5 and 7 for horizontal components and in Fig. 9 for vertical component for UBE. The spectrally-matched and original time histories from selected earthquakes are presented in Figs. 6, 7 and 9.

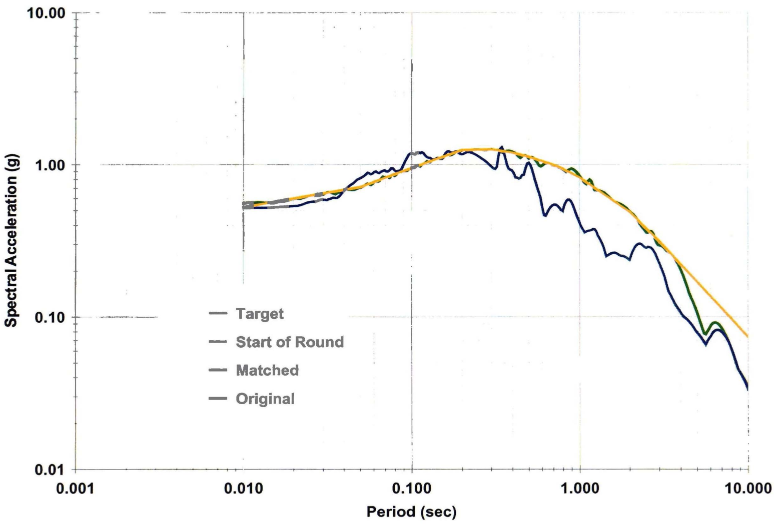

Figure5. UBE 140 degrees Spectra for 1979 Imperial Valley Array# 5

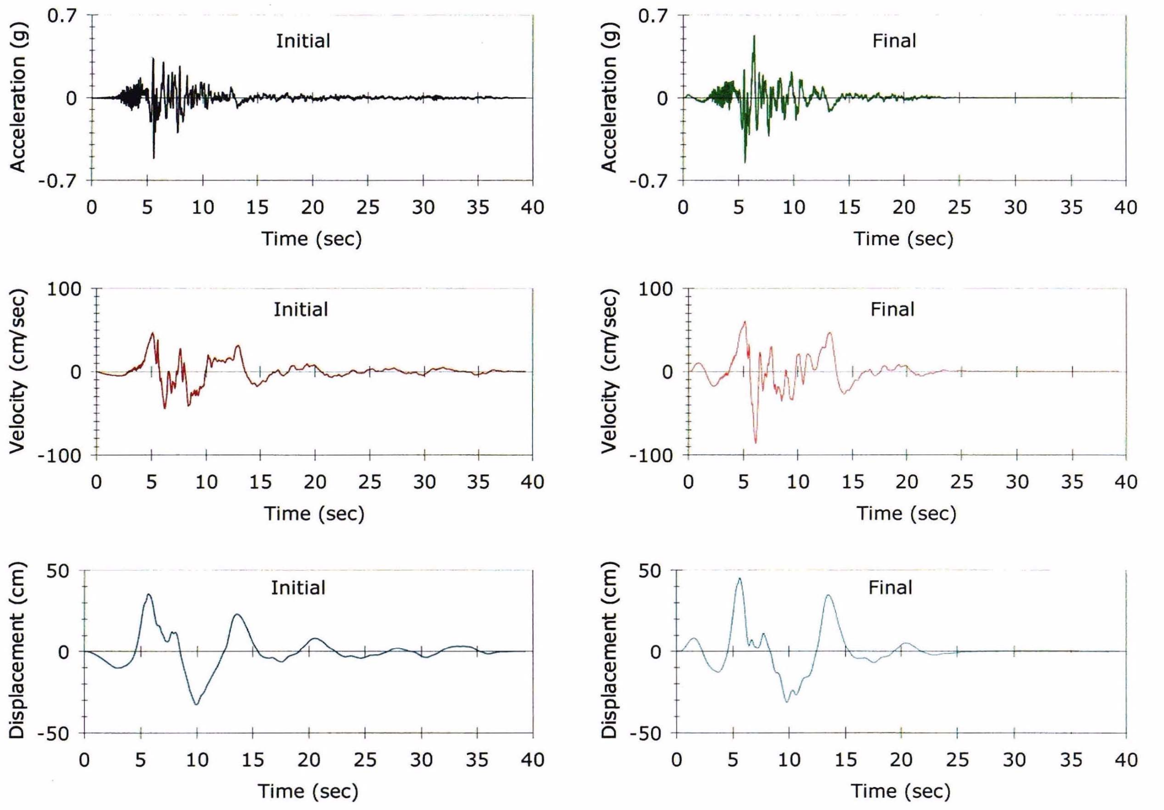

Figure6. Initial and Matched Acceleration, Velocity and Displacement Time Histories for UBE140

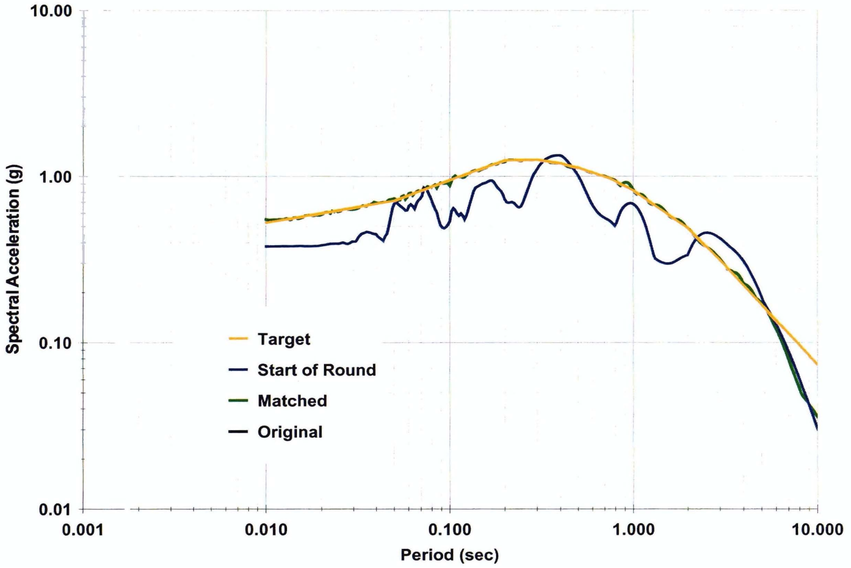

Figure7. UBE 230 degrees Spectra for 1979 Imperial Valley Array#5

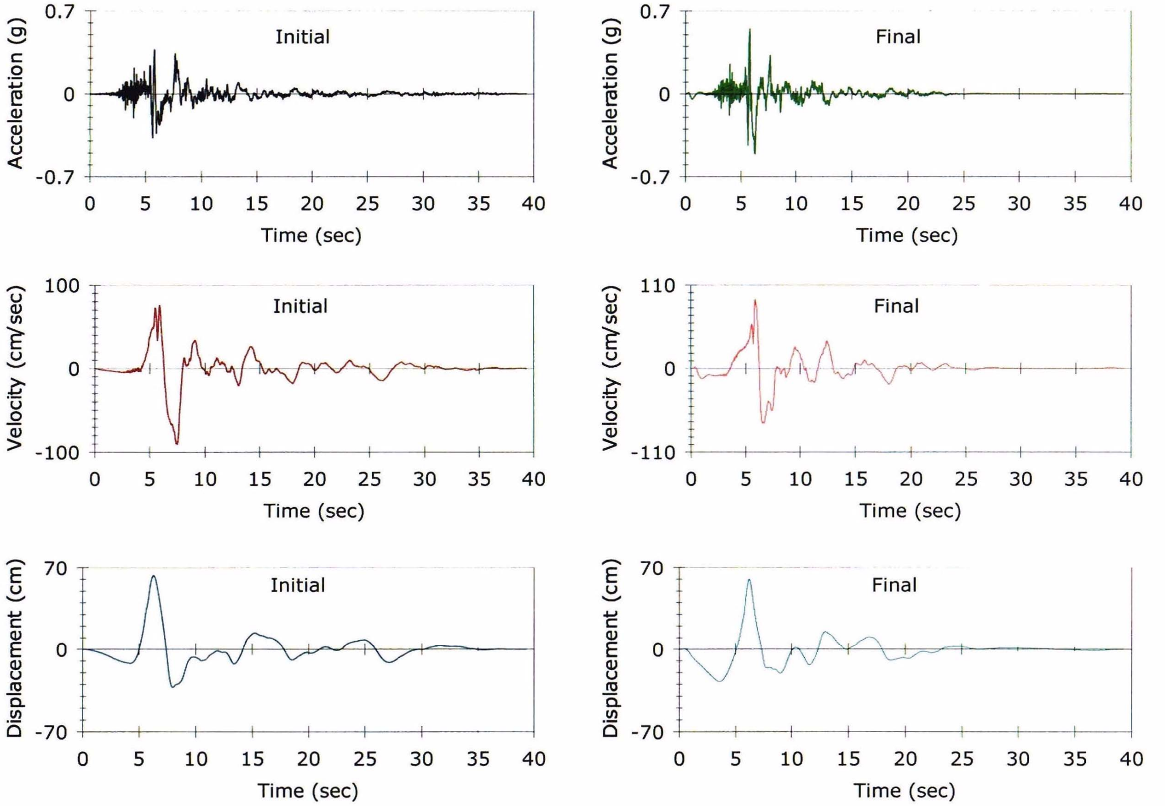

Figure8. Initial and Matched Acceleration, Velocity and Displacement Time Histories for UBE230

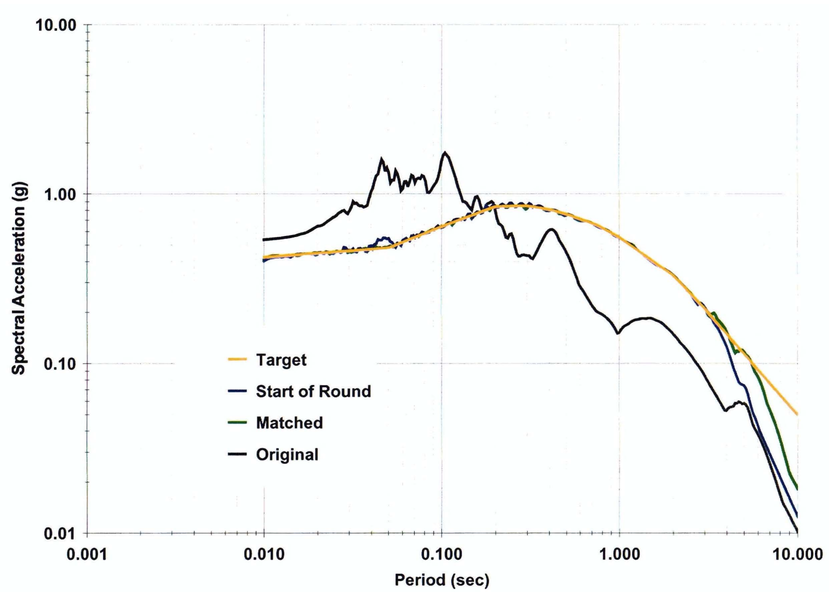

Figure9. UBE Vertical for 1979 Imperial Valley Array#5

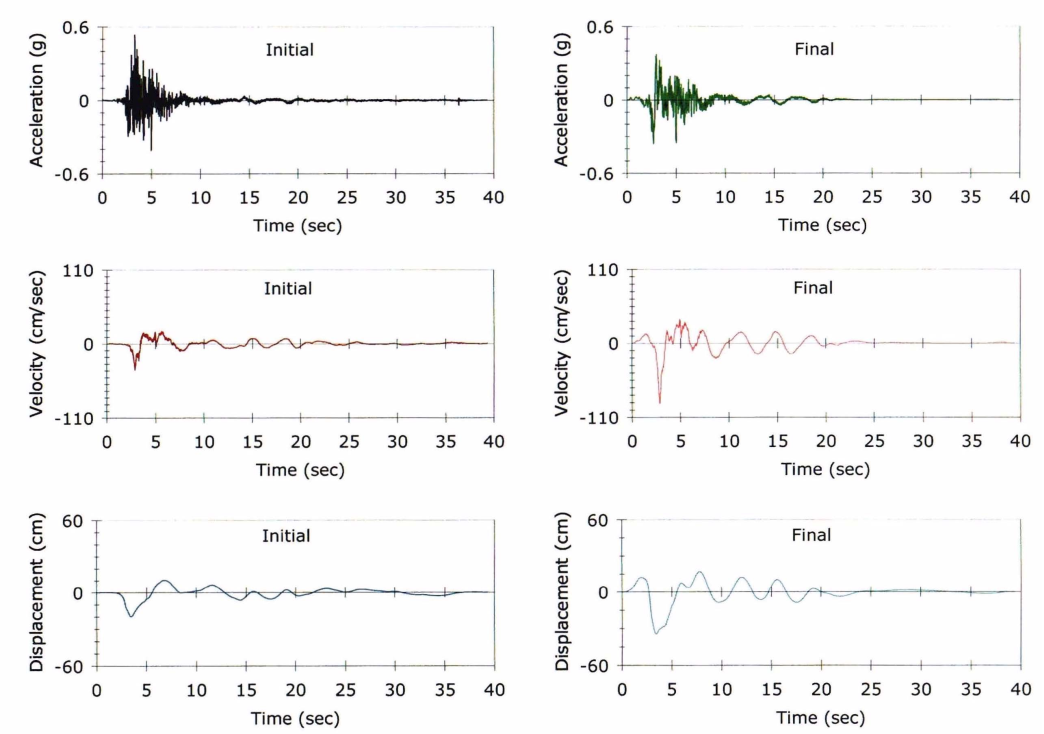

Figure10. Initial and Matched Acceleration, Velocity and Displacement Time Histories for UBE UP

These time histories were developed in accordance with section 1631A.6 of the 2001 CBC, Title 24, Part 2. As part of the process of satisfying code requirement, the square root of the sum of the squares (SRSS) of the 5 percent-damped site specific spectrum of the scaled horizontal components were constructed for each pair of horizontal ground motion. The motions were scaled such that the average value of the SRSS spectra did not fall below 1.4 times the 5 percent damped spectrum of the design-basis earthquake for periods from 0.2T second to 1.5T seconds. Project structural engineer provided the fundamental period (T) of the first-mode of vibration for the hospital building as 0.73 seconds. SRSS and 1.4 times the 5 percent damped spectrum for a selected motion are shown in Fig. 11.

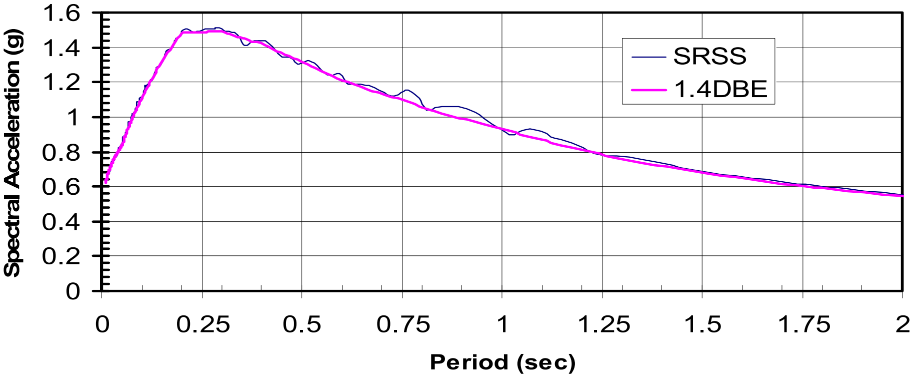

Figure11. SRSS and 1.4DBE Spectra for 1979 Imperial Valley Array #5

The spectral matching analysis results for the fourteen set of time histories derived from the seven selected earthquakes were reviewed and approved by CGS and OSHPD. Due to the page limitation of this paper, only selected results from the study are presented here in. Non-linear dynamic time history analyses were conducted by the project structural engineer of record to verify inelastic response displacements, brace strains, frame column design and column anchorage design. These analyses were conducted at UBE level, except that permanent drift was checked at the DBE level. This hospital is under construction now and expected to serve the public in early part of 2011.

Conclusions

This paper presents the overall process of formulating the seismic design parameters including time histories for essential facilities in California. During this study certain critical challenges were encountered and those challenges were resolved through extensive coordination amongst the team which included the Architect, Structural Engineer, Owner, and Reviewers (CGS and OSHPD). The lesson learned was to have effective communication with team and get them engaged and involved right from the begging of the project (planning stage).

This paper comprehensively addresses steps involved in formulating the seismic design parameters including time histories: 1) selection of attenuation relationships 2) selection of target design spectra 3) selection of time histories for matching 4) selection of guide lines for spectral matching. In summary, with thoughtful analysis, careful planning, and effective coordination, a reliable time history analysis with multiple sets can be completed with great quality with limited time allocated.

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