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Interaction between the engineering seismologist and the structural engineer

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ABSTRACT: This paper describes some communication problems between consultants, offers suggestions how some improvements might be made, and then offers an example project where cooperative communications provided a successful outcome. There are often difficulties in communication between different disciplines involved in the development and application of seismic design parameters. These difficulties can be the result of different perceptions of the design requirements or different understanding of specific technical terms. Where communication between the different participants and consultants in the design process is limited, each consultant will be forced to provide independent design recommendations. Unnecessary and unknown conservatism can easily arise from such a situation.

INTRODUCTION

The authors have watched and participated in the field of earthquake engineering and its applications as it has progressed from its modest beginnings around the time of the First World Conference on Earthquake Engineering to the present more mature profession. The authors have separate professional expertise and practices in engineering seismology and structural engineering, respectively; they have cooperated on projects and have also worked individually with other engineering seismology consultants and structural design teams. From this broad background of experience, they have observed problems which often arise due to misunderstanding between groups consulting in these two disciplines. It is the purpose of this paper to address some of these problems and suggest constructive steps which might be taken to produce better understanding and cooperation between the two groups. To better describe the situation, we will first describe the role of the two different consulting groups and how the product of one may be used by the other.

SEISMIC DESIGN CRITERIA

The task of providing seismic design criteria has become the role of the geotechnical engineer largely by default. The geotechnical engineer has long held the responsibility of determining the external site environment and the methods that may be used to support the foundations of a structure. With the increased concern for seismic design, the earthquake hazard was simply added to the request for information to be supplied by the foundation consultant for use in design.

The defaulting of the responsibility for seismic design criteria led to many problems that are still only partly resolved. Much of the problem is due to the lack of formal education in engineering seismology and earthquake engineering even by graduates with advanced degrees in either geotechnical engineering or structural engineering. As a consequence, in many cases the only seismic recommendation offered in a report consists of an acceleration value given with no explanation. The measure of conservatism involved in the choice of the value and what type of earthquake it might be associated with are usually not discussed. In a more serious case, this lack of understanding of project requirements even extended to a situation where a geotechnical consultant performed complex computer analyses of multidimensional site response which the structural consultant did not require and then presented the results to the owner without any explanation. This type of exercise, which might be described as an attempt to over-analyze, is especially serious because such analyses yield a wide range of possible variations, even when carefully used with reasonable assumptions of parameters. The expected and justifiable reaction of many structural consultants to such extreme approaches has been to ignore the results of even responsible studies and use the seismic code exclusively. While satisfaction of the seismic design code is a separate legal requirement, this lack of communication means that any benefits which might accrue from the structural designer having a more complete understanding of the real earthquake hazard are prevented.

When a project has separate specifications for the work of individual consultants and consultants are chosen on the basis of the lowest bidder, there is often little inducement for cooperative interaction. The separate stages of a project may also be staggered in time. In many cases, there is little opportunity to respond knowledgeably to a request for proposal (RFP), a problem made more difficult when the designers are not known. An RFP might include a long list of items, almost like a shopping list. Several items on these long routine lists are rarely used in the design process and could profitably be omitted from most RFPs. The bidding process used to select a consultant mandates that the unnecessary items be included in the response to the RFP, or there is little chance of being selected. Knowing that the items are not directly used in the analyses, there is an inducement to provide a conservative response that is large enough to be non-controversial, as long as it will not impinge on either the design or the design schedule if the quantities are subject to review by a bureaucratic agency. One unfortunate result of such an approach may be a large series of reports establishing a precedent for a value with no rational basis. Studies of environmentally impaired sites require the preparation of an environmental impact report. Part of this report includes a description of geologic hazards, which may in turn include a description of the earthquake hazard. Following the 1989 Loma Prieta earthquake in California, many environmental reports prepared for sites in the epicentral region of the earthquake have listed a peak acceleration value of 0.8g, including reports prepared by several different consulting firms. Inquiries into the origin of the 0.8g value led to the finding that it was a value that was known to raise no objection by the review agencies. As long the value was sufficiently large there was no requirement that it be factually supported. The difficulties that may arise from the precedent established by the large number of reports using this value on a future design where ground motions are important are neither contemplated nor recognized.

STRUCTURAL ENGINEERING

Few structural engineers are versed in seismology, structural dynamics, or the field of probability as it applies to earthquake engineering. Traditionally the structural engineer has designed structures using statics procedures to resist the maximum lateral design force specified in the applicable building code. The derivation of this lateral force is poorly explained and understood. Neither is the relationship between the lateral force coefficient and measured ground accelerations clearly explained. In present-day design, the use of a PSHA for a specific site and a specific building is becoming increasingly common. This is especially true for base-isolated structures where the use of site-specific anticipated ground motions to analyze the non-linear behavior is the practice. When a site-specific PSHA is completed, the structural engineer is presented with a report that probably contains response spectra at various levels of damping. The spectra may have been computed deterministically or for various levels of probability. The report may also include time histories based on actual or synthetic-acceleration time histories. Unless a diligent effort is made to explain the assumptions and processes used in performing the analyses and presenting the results, the engineer can be placed in a position of designing a structure for a seismic force input which he neither understands nor can justify. It is not surprising, then, that many engineers attempt to avoid such state-of-the-art approaches and retreat to the comfort of the code-specified force level, which may be inappropriate for the design of the structure in question.

The solution to this dilemma clearly lies in education. The more difficult consideration is how this education can be obtained and applied. Clearly, seismic design criteria should only be prepared by those in the geotechnical field who have expertise in engineering seismology. Education on the part of the engineering seismologist should be directed towards the importance of the skills needed to present the seismic recommendations. Unless academic schedules change in engineering education, the structural engineers' education in earthquake engineering will not come during formal academic training, but must be obtained either from continued education during their careers or from technical publications. Last, but not least, the owner of the proposed building must be made aware of the performance level that the engineer is striving to design the building to meet, and why this level was chosen. Unfortunately, this education process is woefully lacking. The paucity of reference material that deals with the topic of anticipated performance levels of structures is an example of the difficulties faced by the profession. The unfortunate result may well be that a building is designed without the engineering seismologist, the structural engineer and the owner understanding and agreeing on the anticipated performance and design rationale used to resist the ground motions.

Improved communication among the disciplines might be established if a review process such as one that already exists between some structural engineers and the geotechnical engineer were to be duplicated. This process occurs when a responsible structural engineer asks the geotechnical engineer to review the foundation designs to see that the geotechnical recommendations have been followed correctly. The structural engineer would explain to the engineering seismologist how the seismic recommendations have been incorporated in the design, to help establish that the recommendations were correctly understood and applied. The initial reaction of many engineers would be that this kind of requirement is invasive. Fortunately, the application of peer review has become much more acceptable in recent years, as engineers have gained experience with it and recognize its advantages in technical and other areas.

DESIGN EXAMPLE

It is prudent at this time to consider how seismic design requirements should be presented and what design parameters are necessary for different levels of study. Before considering the results that may be needed for a complete presentation, it should be noted that for the large majority of structures which are of modest size and have regular configurations, the only seismic design requirements which will ever be needed are those contained in the appropriate building code.

A complete development of seismic design requirements requires the combined effort of professionals in several different disciplines. Primary among these are the disciplines of seismology, geophysics, geology and geotechnical engineering, with the results presented and finalized in close cooperation with structural engineers. The cooperation of these disciplines is necessary for a complete seismic evaluation independent of whether the design requirements are to be considered purely from a deterministic basis or as the result of a probabilistic seismic hazard analysis (PSHA). Both methods require that the following three items be addressed in the order given: the seismic sources, which can be either faults or zones within which future earthquakes might occur; the potential sizes of future earthquakes within these zones and their rate of occurrence; and an attenuation function that allows estimation of the distribution of ground motions in terms of magnitude and distance. When the geology and tectonics of the area are well known, as they are in such locations as coastal California, the source model can be easily constructed. This is, perhaps, an uncommon situation overall, because in most regions the seismic geology is not well known. Where the seismic geology is not known, the source modeling becomes quite subjective and must be assumed on the basis of general tectonic regions whose boundaries and seismic mechanisms are not clearly defined. Geologic and seismic studies are continually adding to the overall seismic understanding, however. An example of the increasing recognition of seismic hazard brought by new knowledge is the realization that a large subduction zone probably extends from northern California to the Juan de Fuca Strait between the State of Washington and Vancouver Island.

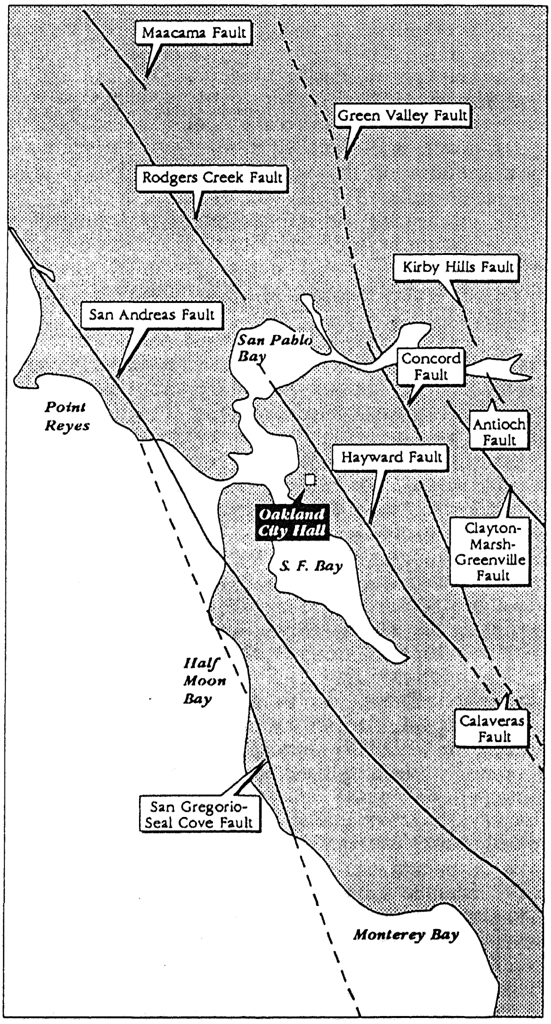


Figure 1. Location of Oakland City Hall

As an example showing the details of both probabilistic and deterministic seismic considerations and the close cooperation needed between the structural engineer, the engineering seismologist, and the building owners, we have chosen the project involving the rehabilitation and seismic upgrading of the City Hall in Oakland, California. A base isolation scheme is planned for this project. The choice of a design with a base isolation scheme as the example to show the results of a detailed seismic study was made because the new technology used for base isolation projects in California results in those projects being subjected to a critical peer review. The peer review of both the seismic criteria and the overall design mandates a close cooperative relationship between all members of the design team.

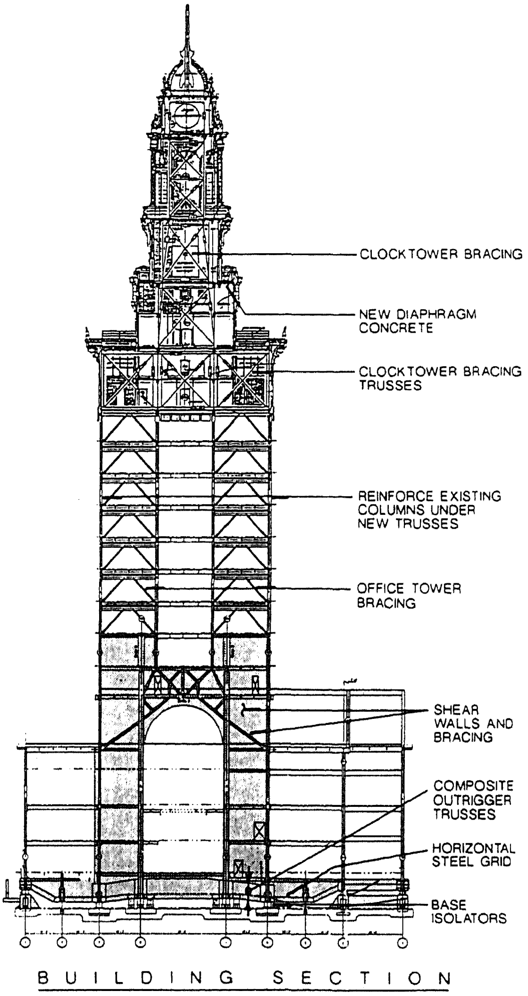


Figure 2. Section Showing Selective Upgrading

The location of Oakland City Hall is shown in Figure 1 and a schematic elevation of the structure and an outline of planned modifications are shown on Figure 2. Oakland City Hall was completed in 1914 after being designed following a national architectural competition in 1910. The building was damaged during the 1989 Loma Prieta earthquake and has not been used since the earthquake. The map location of the building is shown on Figure 1, together with the major faults. The building site is approximately 5 kilometers from the Hayward Fault, a strike slip fault associated with the San Andreas Fault system. The closeness of the Hayward fault totally dominates the deterministic study and is a major contributor to the probabilistic analysis. A United States Geologic Survey study group has examined the slip rate and recurrence rate estimates of the Hayward Fault following the 1989 Loma Prieta earthquake. From this study, they have estimated that there is a 28 percent probability that the segment of the Hayward Fault closest to Oakland will rupture in the next 30 years. A magnitude 7 event on this segment establishes the deterministic design earthquake. The response spectrum for the magnitude 7 event was computed using averaged results of spectral attenuations developed from western North American strong motion data. A series of PSHA using different attenuation functions and different rupture options on the Hayward Fault were performed to develop uniform hazard response spectra for different probability levels. Some of these spectra are shown on Figure 3. Spectra were developed for 50, 10, and 5 percent probabilities of exceedance in 50 years. These levels are frequently used in seismic design studies. 50 percent in 50 years represents motion to which a new building should respond almost entirely in the elastic range. 10 percent in 50 years approximates the motion levels given in the Uniform Building Code. 10 percent in 100 years is being considered as the level to be used for hospital design in California.

When this portion of the seismic analyses was complete and some preliminary structural studies were completed, meetings were arranged between representatives of the City of Oakland, the restoration architect, structural engineers and the engineering seismologist. After lengthy discussions of the various design alternatives and the performance levels anticipated for the alternatives, the following seismic design criteria were selected. The Seismic Isolation Appendix to Chapter 23 of the 1991 Uniform Building Code requires that the isolation system be stable against a "maximum credible" earthquake. In this context, a magnitude 7 event on the nearby Hayward Fault constitutes this event. Also developed for the site from the PSHA was an event with 10 percent probability of exceedance in 50 years. This spectrum, which represents the design basis spectrum, is slightly larger than the spectrum of the maximum credible event. To comply with paragraph 2375(d) of the UBC Seismic Isolation Appendix, the isolator system stability is checked against the spectrum represented by 1.25 times the design basis spectrum. Some of the site-specific spectra which were developed for the project and used in the design are shown in Figure 3.

In addition to base isolation, the building upgrade also includes a new grid of trusses to support the clock tower bracing, a new steel-braced frame in the office tower, new shear walls in the core of the podium level and outrigger trusses and a steel diaphragm over the isolators in the basement. Computer analyses of the structure suggest that the base shear experienced by the building during the Loma Prieta earthquake is close to the base shear expected for the isolated building during the design earthquake. This was not apparent at earlier design group meetings, but now allows a much clearer estimate of the probable performance of the repaired building during the design level earthquake than could be made otherwise. Included in the set of performance criteria is some non-damaging yielding of the steel in the braced frames in the office tower, translation of the building on the isolators of up to 15 inches near the corners, some repairable cracking of the masonry in the clock tower, and localized cracking in the piers and near corners of the windows of the office tower perimeter walls. The estimate of future damage to the brick and bearing tile infill materials is dependent on the cyclic shear strain capacity of the materials based on in-situ tests, including the effects of the event duration, which is expected to be between 20 and 40 seconds.

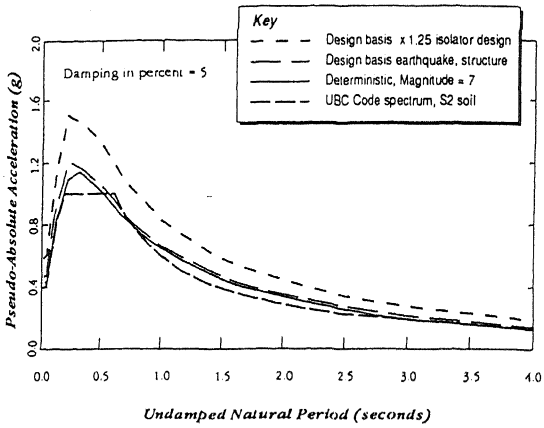
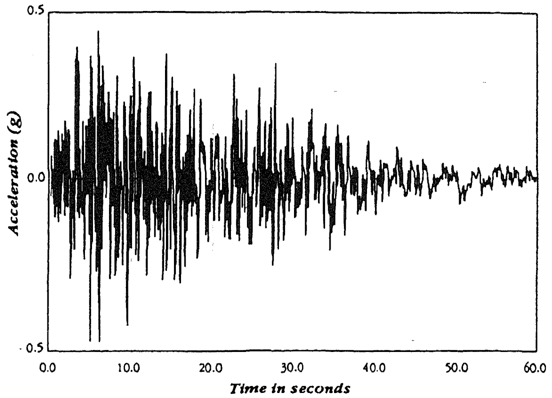


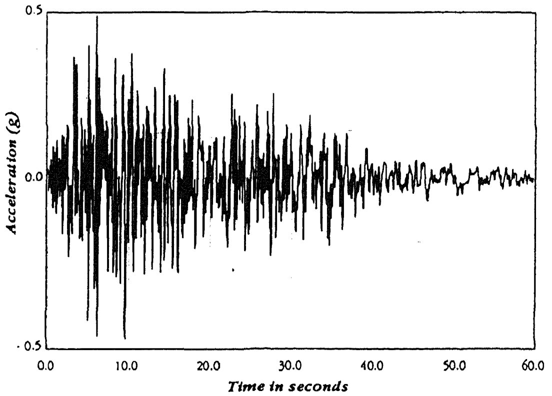
Figure 3. Spectra Considered in the Design Process

Because the satisfactory dynamic performance of a base isolation system relies on the non-linear response of the isolator, the behavior of the entire system must be subject to a non-linear analysis. This analysis uses acceleration time histories as input motions to the system. The selection of what form of motion record should be used has been the subject of discussion for many years. There are three principal sources of these records: synthetic motions, recorded motions used without scaling, and recorded motions subjected to some form of scaling. There are proponents of each of these procedures and arguments may be raised for and against each. The procedure used for the Oakland City Hall was to select records obtained at stations where the appropriate near field characteristics had been observed. These near field records often include a single large displacement cycle. The chosen records were then scaled to approximately match the design spectra by adjusting their spectral amplitudes without changing the phase relationships between different frequency components of the motion. Three pairs of time histories were prepared for the design phase of the project, in accordance with paragraph 2375(d) of the UBC Seismic Isolation Appendix. These were in addition to time histories for the different probability level events developed for the preliminary feasibility studies that were completed prior to the meetings between the complete design team and the owners.

One record of a pair of records is shown on Figure 4 before and after the spectral scaling to match the design



Design basis earthquake after fitting



Design basis earthquake before fitting

Figure 4.

basis response spectrum at a damping level of 5 percent. The starting record was constructed by combining the first 6.56 seconds of the S16E component of the 1971 Pacoima Dam record with the latter portion of the 1952 Hollywood Storage Parking Lot record. Both portions were scaled to have peak acceleration values of 0.47g before they were combined. The starting acceleration time history and the same record after completion of the spectral fitting are shown on Figure 4. Although there are readily apparent differences between the two records on Figure 4, the differences are subtle enough that they can only be seen when both curves are inspected together. Figure 5 shows the spectra computed using the time histories on Figure 4 together with the design basis spectrum used both for the analysis and as the target spectrum for the fitting process.

The dynamic analyses of the structure used for the design process were made using the commercially available program ETABS. Although the analysis with isolators requires the assumption of a very high damping, the first mode is widely separated from the other responses and permits the analysis to be made in this way. Final checks on the analyses were completed using the non-linear program ANSR which can include the correct hysteretic characteristics of the isolators together with a modest 5 percent damping of the strengthened structure above the isolators.

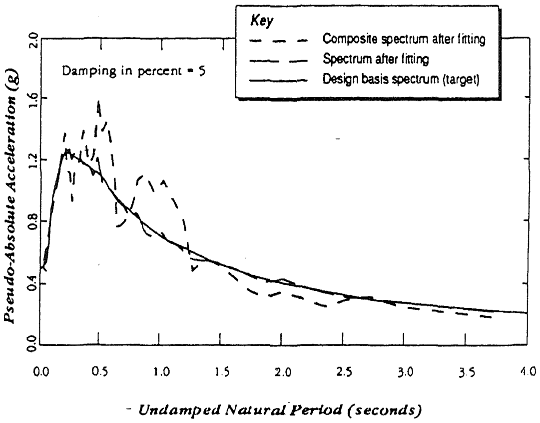


Figure 5. Example of Spectral Fitting Procedures

The design recommendations and the scheme proposed and adopted for restoring the building have been subjected to a detailed peer review. This peer review has covered the basic design assumptions and extends to the static and dynamic geotechnical properties, as well as the development of and the choices made to obtain the design level spectra and associated design ground motions.

CONCLUSIONS

When knowledgeable and experienced consultants are involved in a design team, excellent cooperation between the engineering seismologist and the structural engineer can result. After examining experiences on many projects, we have reached several conclusions: 1. Consultants on a project must be able to communicate freely. This is a patently obvious conclusion, but in many projects controlled by large developers and government bodies this can be difficult, especially when the investigative phase precedes the design phase by a considerable time. 2. The extent of technical education in the field of earthquake engineering is grossly deficient. There is little opportunity for obtaining even a basic understanding of earthquake behavior and certainly almost none for the understanding of the importance of displacements in addition to resistance to forces. 3. Probably the most effective method of providing for active and positive understanding and application of earthquake engineering design comes from a complete interactive peer review on projects.