THE FACILITY MANAGER'S ROLE IN EARTHQUAKE SAFETY

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SUMMARY

The Author has collaborated with others to write a comprehensive "Seismic Safety Guide" (Reference 1) to assist managers of the Department of Energy facilities to administer an effective earthquake safety program without falling into common pitfalls and prolonged diagnosis. Most managers are unfamiliar with earthquake engineering and tend to look for answers in techniques more sophisticated than required to solve the actual problems in earthquake safety. This paper offers advice to facility managers and calls upon the earthquake engineering profession to provide practical and responsible support to improve earthquake safety in an economical and timely way.

INTRODUCTION

In 1971, following the destructive San Fernando earthquake in Southern California, the Lawrence Berkeley Laboratory (LBL) embarked upon a comprehensive earthquake safety program. Since then over 32 buildings have been strengthened; many natural hazards have been mitigated; lifelines and emergency facilities have been hardened; seismic designs for new facilities have been upgraded; and seismic risk management has been systematically applied to maintenance, operations and emergency services. A great deal was accomplished within a tight budget in a relatively short time, primarily due to wise counsel by Karl Steinbrugge and the late Harold Engle, internationally known experts in earthquake engineering.

In contrast, a number of seismic safety investigations at other locations, both in government and private enterprise, have been stalled in the process of investigation. Most facility managers, unfamiliar with earthquake engineering, tend to look for answers in techniques more sophisticated than required to solve the actual problems in earthquake safety. Often the approach to solutions of these problems is so academic, legalistic and financially overwhelming that mitigation of actual seismic hazards simply does not get done in a timely, cost effective way. Sometimes, more time and money has been expended analyzing problems in earthquake safety than needed to accomplish practical solutions to these same problems.

Out of these observations came the idea for a "Seismic Safety Guide" for the Department of Energy (DOE). The Guide has been written to provide practical advice about earthquake safety and engineering to managers of DOE facilities so that they can get the job done without falling into common pitfalls and prolonged diagnosis.

The Guide is comprehensive with respect to earthquakes in that it covers natural hazards, site planning, evaluation and rehabilitation of existing buildings, design of new facilities, operational safety, emergency planning, building contents, and risk management. Each chapter is written by a professional with solid design and field experience including earthquake damage investigation. Comment and advice from the facility manager's point of view is provided in the Foreword of each chapter by the author, who compiled and

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edited the "Seismic Safety Guide." Contributing authors are Jack R. Benjamin, Wendell S. Bril, John J. Earle, Harold M. Engle, Jr., Stephen R. Korbay, Lyle E. Lewis, Roland L. Sharpe and James L. Stratta. The Preface is written by Karl V. Steinbrugge.

SEISMIC REVIEW OF LBL FACILITIES

Lawrence Berkeley Laboratory (LBL) is a multipurpose DOE facility operated by the University of California, engaged in large-scale fundamental research and applied science. It is located in the San Francisco Bay Area in "earthquake country" in close proximity to the Hayward Fault. In February 1971, following the destructive San Fernando earthquake in Southern California, LBL initiated a comprehensive review of its existing facilities and operations to improve earthquake safety.

The review experience was enlightening. At LBL, all except a few old buildings were designed by professional architects and engineers, licensed in California using the Uniform Building Code (Reference 2) applicable at the time. All construction received inspection. In spite of these procedures, the investigation revealed that significant structural deficiencies existed in over 50% of the buildings reviewed. Several old buildings had no formal lateral force-resisting system. In other buildings, deficiencies were related to modifications after construction that altered the lateral force-resisting system. Design deficiencies, relatively few in number, were usually due to the lack of a clear and comprehensive design philosophy rather than to design error. Most problems stemmed from defective lateral force-resisting systems which had missing links, brittle members or connections, or simply did not comprise a comprehensive and predictable system. Generally, not enough consideration was given for nonstructural elements or lifeline services. Seismic "plan checks" or "third-party" design reviews were not performed prior to 1971.

Significantly, most deficiencies were relatively simple to diagnose. They were quickly found by practical techniques used by structural engineers specializing in earthquake safety. Sophisticated analyses were not required and if used would have complicated and slowed the entire process of detection and, consequently, correction.

Sixty buildings, as well as critical site utilities and emergency facilities, were reviewed. The site was studied to identify natural hazards such as possible fault displacement and earthquake-triggered subsidence and landslides. Special facilities such as concrete shielding blocks, storage for hazardous materials, communications centers, medical services and emergency generators received careful attention. The order of inspection was based on a priority system which considered life safety, emergency recovery capacity, off-site consequences, program continuity and property value. The order of subsequent projects to abate hazards and improve earthquake safety was based on consideration for the probability of earthquake occurrence, the structural response, human exposure, property damage, and the possibility of off-site consequences.

These priority systems were simplistic and judgmental. Although due process was followed, the level of sophistication and complexity was minimized in favor of decisiveness and practicality. Structural deficiencies and operational hazards which could be easily corrected were promptly abated. When more complex hazards were identified interim action was undertaken to reduce risks until the process of full abatement could take place. Over 32 buildings were strengthened; four were evacuated and demolished. Projects to repair or strengthen structural systems, nonstructural elements and lifelines were carried out on a priority basis over several years and will continue for some time.

Among the lessons learned is the importance of detailing and the need for the responsible engineer to ensure that constructed details actually carry out the design philosophy. The experience again established the need for and effectiveness of the "plan check" or "third-party review" which has been a vital factor in the excellent performance of modern California public school buildings designed and constructed under the Field Act.

The cost of the earthquake safety survey by LBL's specialized consultants amounted to 0.06% of the replacement value of all buildings surveyed, not including contents. Costs for all building corrections totaled about 1.0% of replacement value.

The earthquake safety survey and improvement program at LBL has been a comprehensive experience in practical risk management. From this perspective it has been our observation that some earthquake safety programs elsewhere have tended to become too sophisticated, complex, and expensive for expeditious achievement of desired results. Often the process of studying the seismology of an area, selecting "design" earthquakes, and developing priorities and analysis techniques, becomes an end unto itself rather than the program's practical objectives (Reference 3).

Fortunately, the consultants who assisted LBL counseled a practical course which achieved early results and minimized costs. It was with their advice and support that the concept for the Seismic Safety Guide was developed. Its emphasis, then, is on the practical application of earthquake engineering rather than the state-of-the-art.

ADVICE FOR THE FACILITY MANAGER

A comprehensive earthquake safety program can cover a lot of territory. The scope, depth and focus required to carry out an effective program will vary considerably with the age of a facility, the risk involved and the quality of design which was applied during its construction history. For a new and growing facility the focus will be on design and construction. For an older facility the need to evaluate existing conditions and abate seismic hazards will receive the most attention. For the majority of sites, however, a balanced program will be most effective in preventing further development of new hazards while reducing the backlog of old ones.

Those structural engineers who have reviewed a number of facilities, both in government and private enterprise, have found a wide variety of serious seismic deficiencies that the facility managers were unaware existed. This is par for the course, even in areas of the country where seismic design provisions have been part of the building code for many years.

East of California few conventional buildings in the United States have been designed for earthquakes, even where there has been a history of earthquakes of sufficient intensity to damage buildings. At those sites where the potential for seismic destruction exists along with a legacy of hazardous buildings and contents, the prospect of carrying out a comprehensive earthquake safety program is indeed challenging.

The facility manager, usually unfamiliar with earthquake engineering, may be easily led into a quagmire of sophisticated and costly studies which are both time consuming and unnecessary to solve the actual problems in earthquake safety. In recent years, the state-of-the-art in seismology, geotechnical theory, and dynamic analysis has progressed tremendously. Spurred on by the need to resolve questions in seismic safety for nuclear power plants, the field has become very specialized. The great strides made in these specialties have contributed significantly to the field of earthquake engineering and public safety. Unfortunately, it is easy for the responsible manager to "fall into a crack" between experts who quite naturally tend to resolve seismic questions in compartmentalized, complex solutions based on their own specialties.

The most important thing the facility manager can do to initiate an effective and economical earthquake safety program is to hire an experienced earthquake engineer who is strong on design and tends to keep analysis straightforward and simple. Occasionally, there is good reason to apply structural dynamics to gain better understanding of a complex problem, but not very often. The facility manager should be wary of the potential consultant who sells professional services primarily on the basis of dynamic analysis.

A similar warning should be issued about one's choice of geotechnical consultants. The level of sophistication in state-of-the-art techniques for predicting the intensity of ground shaking is intimidating. There is a strong tendency for both consultants and clients to believe the predictions to be more accurate than history shows they are. This tendency may lead participants to spend more money and time than the exercise is worth. The illusion of security thus developed is apt to be in direct proportion to the degree of sophistication applied.

It should be the responsibility of the project manager of the design team to ensure that the client is not victimized by specialized consultants. Too often, however, in their search for highly qualified consultants to compete for Architect/Engineer appointments, project design managers themselves become overwhelmed by the sophistication of the specialists jargon.

During a recent conference on seismic safety a geotechnical expert was describing the sophisticated techniques his firm had used to estimate a site-specific earthquake ground motion for his client. His study had been the last of a series by various consultants and agencies covering the same geographical area. These analyses had absorbed almost ten years. A well known earthquake engineer asked, "Haven't we analyzed this site enough? Isn't it time to design corrective measures to strengthen the unsafe buildings at this site?" The consultant's answer was, "Well, no, not really. The state-of-the-art is changing all the time." Obviously, the specialist was more interested in analysis for its own sake than he was in solving the problem of earthquake safety.

The extent to which a site should be investigated will vary with the degree of natural hazard present and the probable consequences of damage. It will also vary with the complexity of the geology or the difficulty of the diagnosis. One important point to keep in mind is that it is easy to dissipate funds in site investigation work before the problems, priorities and direction of the broader earthquake safety program are fully understood. Detailed work should always be carried out after the other facets of earthquake safety have also been considered and the objectives of further work are more clearly defined. Implementation of the seismic safety program, however, should not be delayed by prolonged investigation of all problems.

It is important to identify potential natural hazards such as unstable slopes and existing landslides, areas subject to dynamic subsidence, liquefaction or strength loss under ground shaking and of course, fault movement. The object of the investigation is to avoid the hazard if possible and to mitigate it if it is not practical to avoid it.

Even when structural dynamics is to be employed, the selection of ground motion input can be a relatively simple matter. There is no sense in making a "federal case" over the input because the record shows that the prediction of ground motion is indeed an inaccurate science. The inaccuracies of input often can be accommodated in good structural design.

The development of site-specific criteria for seismic design is one of the more sensitive processes that must be carefully managed to avoid technical and political pitfalls. Usually, the pressure to develop site-specific criteria relates to dynamic analysis rather than equivalent elastic static lateral force analysis. Unfortunately, there is persistent misunderstanding and confusion about the meaning and use of ground acceleration as a measure of the earthquake resistance of buildings. This applies not only to public perception but also to most facility managers and engineers who do not have the technical insight and experience of the earthquake engineer. This confusion is amplified through continued miscommunication of the issue by the public media. They usually equate estimated peak ground acceleration with elastic static design base shear leaving the implication that "Code" buildings are grossly underdesigned for potential earthquakes. In reality, a low-rise building with a ductile lateral force-resisting system analyzed for a 0.2g elastic static lateral force, and having been well-designed and constructed to Code, should resist actual ground accelerations of 0.8g without collapse (Reference 4). The media do not explain that the static base shear force must be fully resisted within allowable Code stresses in the members of the lateral force-resisting system. Nor do they point out that a proper analysis using structural dynamics must consider that all forms of structural work energy will act to resist forces induced by the earthquake such as kinetic energy vibrating the building mass, strain energy causing elastic and inelastic deflections, and damping energy required to overcome friction between moving parts and internal molecular friction within the materials of construction. In effect, a comprehensive earthquake-resistant design using dynamic analysis balances the energy absorption and ultimate resistance of the building against the earthquake input forces (Reference 5).

In spite of the fact that site-specific earthquake ground motions are not predictable in an engineering sense, there seems to be a compulsion to study and attempt to predict accurately the maximum credible earthquake and the maximum ground acceleration a site might experience. Possibly this is influenced by technical "spin-off" from the nuclear power industry, where the determination of a maximum credible earthquake for each reactor site is a regulatory requirement. For whatever reason - political, academic or psychological - a lot of time and money goes into estimating and predicting the size of the earthquake and the maximum ground acceleration, even though it may be an unrewarding and impractical exercise.

The process of setting seismic criteria for a given site is an inexact science. Earthquakes, being unpredictable in nature, continue to bring surprises to engineers and seismologists alike. The 1971 San Fernando and 1979 Imperial Valley earthquakes in California produced ground accelerations which were recorded at higher levels than most researchers believed reasonable for "moderate" earthquakes. The startling effects in San Fernando stimulated many changes in seismic codes. On the other hand, the damage in Imperial Valley was relatively light considering peak ground accelerations exceeded 0.8g.

In 1980, three relatively small earthquakes near Livermore, California took place in approximately one minute producing a duration of heavy shaking previously associated only with major earthquakes. Although the effects were very localized, the surprisingly long duration caused considerably more damage than one would expect from the instrumental magnitude of the events. This unpredictable nature is an important characteristic of earthquakes.

If one looks at actual experience with damaging earthquakes, it is indeed rare to find that the predicted size of the earthquake was the major deficiency revealed by the damage. The reality is that most problems are found to be the result of common structural deficiencies, such as a missing or brittle link in the lateral force-resisting system, or simply the lack of a formal, predictable lateral force-resisting system per se. These problems are the result of not implementing what has been known about earthquake resistant design and observed about earthquake damage for many years. Excessive time and money should not be spent on guessing the size of a future earthquake and its ground motion. For the facility manager this is an important pitfall to be avoided. The money can be more wisely spent on fixing buildings before the earthquake strikes.

When site-specific seismic criteria must be specified, the work should be carried out by an experienced geotechnical specialist working in close coordination with the structural engineer who will use the results. Generally, seismologists and geologists have limited understanding and little control over how the site-specific criteria will be utilized for structural design. It is impossible for them to take this into account if they must set criteria in a structural vacuum. Worse, when this happens, the structural engineer may be saddled with unrealistic criteria that will make the analysis unrealistic or the resulting design solution impractical if not unusable.

Public arguments over seismic criteria are commonplace with respect to facilities that house hazardous materials. Because the estimate of earthquake size is at best an educated guess, these arguments make an ideal battleground for political forces. It's a poor place to take a stand. The cost to provide extra strength and ductility for an earthquake-resistant structure to resist a major earthquake versus that required for a moderate earthquake, is usually small; perhaps 2 or 3% of the cost of most buildings. It is not worth arguing about if this cost is balanced against the high costs that are usually required to develop data to support site-specific criteria for an event smaller than a major earthquake. As a practical matter, the cost of inflation due to several month's delay is apt to be more than the cost of providing extra strength for the larger earthquake.

Politically, the costs of prolonged public debate are significant and damaging. It does not make economic or technical sense to undertake extensive studies that have the object or possibility of establishing less stringent site criteria in an area where potentially damaging earthquakes have been part of recent geological past and can be anticipated in the future.

THE BALANCED EARTHQUAKE SAFETY PROGRAM

An effective earthquake safety program is analogous to an effective lateral force-resisting system; it should have no weak links.

The facility manager should make certain that new buildings are not being inadequately designed while the process of reviewing existing buildings for earthquake resistance is underway. This is a profound admonition, but it has happened and will happen again. To avoid this pitfall, a plan-check or third-party review, prior to start of construction, will ensure that new structures and rehabilitation projects are indeed properly designed to resist earthquakes. It is embarrassing to find that a newly designed and constructed building is worse than an old one.

Design criteria should be formalized, clearly defined and simple to use. Complex approaches should not be applied unless the need is clearly established. At most sites many minor modifications and equipment installations are routinely designed by architects, mechanical or electrical engineers and others who do not have experience with seismic design. If the seismic criteria are simple and easy to use, these minor projects will usually be built with adequate earthquake resistance. Significant structural design should be carried out by registered structural engineers with a clear responsibility for review of construction as well as implementation of design.

The site should be reviewed for likely seismic hazards. Potential conditions that are inherently hazardous in ground shaking should be identified. The investigation need not be rigorous unless the potential hazards pose a high risk for new or existing facilities. If a new project is planned, the specific siting should of course be examined in more detail. The main thing is to flag potential hazards and take them into account. For example, it would be folly to permit the typical one-third increase in allowable bearing capacity for seismic loading in sensitive soils subject to strength loss under ground shaking. The initial investigation should be quite broad and superficial in character but it is important that it be carried out by an engineering geologist or soils engineer who understands the nature of soil dynamics, preferably from a perspective of practical experience with earthquakes and design.

Existing structures should be evaluated to determine their earthquake resistance. A structural engineer experienced in earthquake investigation should do the job. The assessment should be kept simple. The basic concept is to ensure that each building has a predictable lateral force-resisting system. The job of rehabilitation should be started one step at a time, reducing liability on a priority basis. Given a limited budget it is important to determine which buildings will have the greatest payoffs per dollar spent for improvements in life safety and property protection.

Operations, equipment, hazardous materials storage, and nonstructural building elements such as light fixtures should be surveyed for earthquake safety. Obvious falling hazards, such as loose overhead storage, should be corrected immediately. Most operational hazards are obvious to one simply observing the scene and imagining an earthquake taking place. The relationship of work stations to tipping hazards, such as storage cabinets, should be considered. The close storage of chemicals which can become very dangerous or explosive when mixed should be reconsidered. Tie-downs should be installed on plant equipment such as transformers, emergency generators, tanks, elevator drives, fans, motors and similar units. A simple and judgmental priority system should be applied to use limited resources economically.

Finally, an emergency plan to recover from a destructive earthquake should be developed. The scenario technique can be applied to develop a realistic idea of problems to anticipate in the aftermath of an earthquake. Those who will have to handle the recovery should spearhead the planning. Recovery plans should be kept very simple so that they can be easily used in an emergency situation. Checklists and regular drills are most effective. Obstacles to recovery should be reduced by eliminating obvious hazards and ensuring that supplies and equipment that will be needed will in fact be available.

Lifelines, such as water supply lines, power systems, storm and sanitary sewers, transportation and communications systems should be surveyed with earthquakes in mind. The consequences of possible facility losses can be mitigated by careful emergency planning, and the potential for loss of a given facility reduced by "hardening" the lifelines that would likely be in jeopardy during an earthquake. Self-help planning, preparation and training should be key elements in any emergency response plan for earthquake safety.

The manager who is charged with the responsibility for a major facility obviously needs professional advice to carry out a cost effective earthquake safety program and manage the associated risks that become evident in that process. In the end the responsibility for decision must lie with the facility manager, but good communication and mutual trust with a practical earthquake engineering consultant is essential to provide the manager with an extension of expertise in this specialized field.

As well, the earthquake engineering profession has a public obligation to see that these goals are achieved and not lost in the process of lengthy investigation and voluminous reports.

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