EARTHQUAKE SAFETY FOR NEW STRUCTURES: A COMPREHENSIVE APPROACH

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ABSTRACT

The seismic resistance of new facilities not yet built can be reasonably assured by paying careful attention to each of several key steps in the process of designing, constructing and maintaining the structures. By following recognized guidelines and standards of performance at each step in the process, all participants can promote achievement of quality end results, including production of seismically resistant structures. Except for critical and high-hazard facilities, this should not add significantly to the overall cost. By monitoring and asking pertinent questions about performance at each step, and providing for a system of gathering intelligence and feeding corrective information into California's comprehensive earthquake preparedness planning process, in the future it should be possible to assure higher levels of seismic resistance in new structures than has been consistently achieved in the past.

INTRODUCTION

[Author's note: This paper was written from a California perspective, and is based mostly on California experience. On the other hand, with only a little adaptation and interpretation, most of the conclusions are also relevant to other regions that may experience earthquakes, including much of the rest of the United States.]

Recently much well-deserved attention has been directed to existing hazardous buildings. The subject of this paper, however, is ensuring the earthquake safety of structures yet to be built, by focusing on potential weaknesses in their design and construction. Except for high-hazard or critical facilities--such as nuclear reactors, dams, plants processing toxics, emergency facilities, and hospitals--most new structures can be made seismically resistant for little additional cost, through good designs, proper construction methods, and careful inspection by qualified personnel. To put up first-rate structures in earthquake country, owners and builders need to secure the help of qualified designers, obtain independent expert reviews of earthquake resistance in the case of major structures, and use experienced and reliable contractors and inspectors to ensure the quality of workmanship. When backed by the code-compliance reviews of a competent

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local building department, the process should yield buildings that are resistant to earthquakes.

Unsafe or seismically questionable structures already in existence can be another matter altogether. It can be costly and disruptive to mitigate or eliminate an existing earthquake hazard. The potentially high cost of dealing with existing hazards and the folly of needlessly creating new ones underlines the crucial importance of doing things right the first time, when structures are designed and built. This paper suggests some ways of trying to achieve that goal.

MITIGATING MAN-MADE HAZARDS

Most earthquake hazards are man-made, consisting of buildings or other structures that may collapse or be damaged. Such structures may cause death or injury, as well as loss of homes, workplaces and businesses. While the creation of new earthquake hazards cannot be eliminated entirely, it can be greatly reduced by using available state-of-the-art knowledge in siting, designing and building structures. We who live in earthquake country have not gone the final mile until all reasonable and prudent measures have been taken to reduce to an acceptable level the seismic hazard in any significant structure that is put up in the future. Many years of effort have brought substantial progress in California, but we are still a long way from having finished the job.

SIMPLIFYING THE QUEST AND CONCENTRATING ATTENTION

Preparing for a chaotically devastating event like a major earthquake may seem an insuperably complex affair. While earthquake preparedness is indeed a complicated business, there are ways of simplifying the quest. Priorities can be fixed and attention concentrated where it will do the most good. Due diligence can identify and strengthen weak links in the process.

The California Earthquake Hazard Reduction Act of 1986 is a particularly valuable vehicle for improving earthquake hazard reduction and emergency response. This landmark legislation set up a comprehensive system of earthquake safety planning and plan implementation. Individual program elements are carried out on a voluntary basis by state agencies, local governments, and the private sector. The California Seismic Safety Commission orchestrates the program and updates it annually, in a series of publications under the general title, "California at Risk." Implementation of the recommendations in this paper can be facilitated by their inclusion in the comprehensive plan.

FOCUSBING ON IMPORTANT DECISIONS

Focusing attention on important decisions will help ensure that reasonable and prudent measures have been taken in siting, designing and building new structures. Concentrating on successive steps in the process, and on the participants and their responsibilities, helps us identify critical decisions. If things go well at each step, and available state-of-the-art methods and judgment are used, the result should be good-quality structures likely to perform satisfactorily in future earthquakes.
Alternatively, however, a failure at any critical point—i.e., lack of attention to seismic resistance, or inadequate plan checking and construction inspection, or use of improper materials, or sloppy workmanship—increases the risk of seismically questionable results. The decisions to watch are those in: (1) the design process, (2) plan checking and code enforcement, (3) construction and inspection, and (4) operation, maintenance, and modification of structures while in use.

THE DESIGN PHASE

The Early Decisions

The first set of decisions involve the designers and the owner or builder. They jointly make early decisions on siting and design that can do much to determine a structure's ultimate fate. If a site is suspected to have geologic problems, these should be investigated before matters proceed. Early formative decisions on a structure's basic design are also of great importance, and the quality of a building and its cost tend to be established in the initial design stages. If unwise decisions are made then, they may be difficult and expensive to change later.

In seismic design it is of course essential to observe the prevailing code requirements. California jurisdictions use the Uniform Building Code, whose seismic standards are considered stronger than the codes followed in parts of the Midwest, East and South. Even a good seismic code is only a minimum standard, and code compliance alone may be far from sufficient to ensure acceptable earthquake resistance for many buildings. In general, however, adherence to seismic code standards, along with prudent design decisions and good construction, should result in acceptable performance for most buildings.

Beyond code compliance, good design decisions are basically a matter of using informed architectural and engineering judgment. To be effective in earthquake country, designers must understand the fundamental philosophy of seismic design, and know the characteristics of earthquake-resistant structures. For proper seismic strength, a structure's lateral-force-resisting system must be constructed with careful attention to the details of its design. All key components should be securely tied together so they will resist being pulled apart by earthquake forces. James L. Stratta comments:

The most important aspect of earthquake engineering is the development of the construction details to transfer the loads along the intended continuous path of...lateral resistance.... The advanced technology of earthquake-resistant design makes it necessary for all involved with construction to be aware of structural requirements that heretofore may have been overlooked.

Because the early design decisions are so critical, it is imperative that the members of a design team work closely with each other and with the owner from the outset. As things stand now, all-too-often the structural engineer member of the design team is not brought into the process until after formative design decisions are made. If not guided by seismically
sophisticated judgment, such early decisions can predispose a structure to
seismic weakness. A committee of the Seismic Safety Commission noted in a
recent report:

Initial decisions on a project's structural concepts can do much to
determine its ultimate seismic resistance, for better or worse.
Thus decisions early in the design period may commit a project to a
building configuration or design concept that makes effective
lateral-force resistance difficult to achieve. Accordingly, close
collaboration from the outset between the architect and structural
engineer—as well as the mechanical and electrical engineers—is
highly desirable.4

Professional Qualifications: Education. Testing. Experience. Performance

In addition to early collaboration, architects and engineers also need
an informed understanding of the essential seismic design principles that
are pertinent to their respective professions. Architectural and
engineering education for all who are likely to practice in earthquake
country should include substantial exposure to seismic design basics.
Moreover it is also important to require persons entering the design
professions to pass rigorous examinations, including seismically related
questions that can eliminate applicants who do not understand seismic design
fundamentals.

These are the first steps. Next, to learn the ropes on designing for
earthquake resistance, new professionals need to go through a kind of
internship. They need to work closely with one or more seasoned colleagues
who are proficient in seismic design. They also need to gain experience in
the realities of construction. In addition, to maintain competence and keep
up with the state-of-the-art, all practicing professionals need to continue
their educations throughout their careers. In many states and for a number
of professions there are mandatory provisions requiring regular partici-
pation in continuing education programs as a condition for renewing
eligibility to practice. While this is not true of the design professions,
the high stakes in earthquake country suggest that it would be a very good
idea to require mandatory continuing education for architects and engineers,
with special attention to earthquake-resistant design.

Since some unqualified or poorly performing practitioners are likely to
be found in any profession, the design professions need to be policed, to
ensure high levels of competence. In part this can be done by professional
self-policing. A good example is peer review of design firms. Ultimately,
however, policing is a responsibility of the public licensing agencies. In
California these are the Board of Registration for Professional Engineers
and Land Surveyors, and the Board of Architectural Examiners. This subject
probably deserves more attention than it is currently getting.

Independent peer review of project designs should be done in the case of
all major structures, and certainly should be done for any facility whose
failure would endanger or adversely affect substantial numbers of people.
The value of independent peer review is already well established for many
types of critical facilities, such as nuclear reactors, dams, public
schools, hospitals, and emergency response facilities. In the case of major projects, independent review is also justified for non-seismic reasons, as a quality-control and cost-control measure, reviewing project management as well as project design.5

PLAN CHECKING, INSPECTION, AND CODE ENFORCEMENT

Local Building Departments: A Weak Link?

Another major step in the process is plan checking of designs for code compliance, and on-the-job inspection of construction. Local building departments carry out these important duties with widely varying effectiveness. Structural engineers often point to the City of Los Angeles as one of California's ablest in handling code enforcement and plan checking. Also widely recognized for thorough work is California's Office of the State Architect, which plan checks and inspects public schools under the 57-year-old Field Act, and has similar responsibilities under the 18-year-old Hospital Act.

There is, however, justifiable concern about many city and county building departments, some of which are weak links in the process.6 Yet these are the agencies the general public relies on for safeguards against constructing seismically hazardous structures. One structural engineer experienced in forensic engineering and cases involving litigation assesses the true situation as follows:

Unfortunately, in many areas, inexperienced designers and building officials allow construction of structures that do not meet the intent of the code. A severe earthquake in a heavily built up area will no doubt bring this out.7 [emphasis supplied]

How should plan checking and inspection be handled? The local building department should check all plans for code compliance, and should inspect construction for the same purpose. To assure adequate on-the-job enforcement, most building departments need stronger support from local decisionmakers, and more funding. Often fees collected for building department plan checking and inspection are put in the general fund and used for other activities. This can deprive the public--and building owners--of service they deserve and expect. The situation calls for some education of local officials.

Review of Local Performance

Since there are enormous stakes at risk in earthquake country, it is not enough to rely only on local initiative. Perhaps this is a case where the state should play a stronger role. Full-fledged preemption of local plan checking and inspection may seem like overly strong medicine, but the success of state regulation of public schools and hospitals suggests the value of some kind of state oversight for local building departments. One possibility, of course, would be a regular state-level review of local performance. There is some precedent for this in the work of the California Energy Commission. The results of such monitoring could guide local action, as well as state action when warranted.
Perhaps better still, or at least not as bureaucratic, would be peer review of local building departments by some of the ablest among local building department administrators, working through the good offices of the California Association of Building Officials (CALBO). CALBO is already taking a greater interest in ways to improve local building departments and their staff, having co-sponsored a series of seismic seminars for local personnel (jointly with the Seismic Safety Commission).

Reexamining the Codes

In California and the West--where earthquake awareness is higher--most local jurisdictions adopt versions of the Uniform Building Code. As noted earlier, the UBC is believed--at least by many westerners--to be stronger in its seismic provisions than the codes typically followed in the Midwest, East and South. There is particular cause for concern with the seismic requirements actually adopted and enforced by local jurisdictions in much of the nation, where the public has tended to view earthquakes as happening somewhere else. In fact, the historic record shows that damaging earthquakes have occurred in many parts of the United States, and must be expected to recur. In any event, in California and elsewhere, continuing attention to the codes, their seismic adequacy, and their enforcement, are important to the quest for earthquake safety.

CONSTRUCTION: COMPLIANCE, CARE, AND WORKMANSHIP

Construction is another critical phase. Even the best of designs cannot assure first-rate results unless construction is of high quality, with close attention to the execution of details called for in the building plans and specifications, and in full compliance with the code.

Experience, Qualifications and Reliability

It is important at the outset to select an experienced, reliable contractor who can muster a qualified work force. A contractor who understands seismic design requirements, and who has previous experience with projects emphasizing seismic resistance, will be more likely to do the job right.

With regard to the work force, it should be noted that organized labor offers apprentice training programs to teach beginning construction personnel the techniques of quality workmanship. Exposing young workers to good practice early in their careers is an effective way to improve future performance. To a limited extent this training already includes some attention to seismic concerns, and strengthening this aspect was already under consideration before the October 17, 1989 earthquake.

At the very least, the contractor and his personnel should carry out all aspects of structural design with diligence and care, and in earthquake county they should have a special regard for seismic safety. Contractors and workers who do things wrong can undermine a designer's intent in a multitude of ways.
Inspection/Observation

During construction it is important that the work be observed, reviewed and inspected to ensure compliance with the plans and the code. Construction observation or review by the design engineer involves periodic on-site touring of construction work to see that it basically follows the intent of the plans and specifications. Inspection is more detailed, and may be performed by licensed inspectors employed by the owner or contractor. In addition, of course, the local building department should inspect for code compliance.

Often this observation and inspection work is not done, or not done thoroughly, in a "penny wise, pound foolish" economy. The cost of proper on-the-job inspection and observation is far outweighed by the assurance that the construction will be of good quality, and that the designers' and owners' intent will be met. Careful inspection may also avert costly and dangerous mistakes or omissions. Some spectacular and deadly structural failures in the past few years are examples of disasters that competent inspection could have prevented.

A thorough kind of plan review and inspection, such as is done for public schools and hospitals, would give assurance that a project's design is being carried out satisfactorily. To approximate this kind of care in private-sector work, project contracts and budgets should provide for construction review and observation by the design engineer, and for appropriate inspection by qualified personnel.

(A note on redundancy: Some readers may question whether it is necessary to have inspection by inspectors employed by the owner, as well as inspection by local building departments. In fact, activities as important as building long-lasting structures call for applying the well-established principle of redundancy, both in the process by which a structure is designed and constructed, and in the structural elements that provide seismic resistance. Redundancy in the design, construction and review processes provides "fail-safe" assurance, greatly reducing the likelihood of design errors and construction mistakes. Structural redundancy provides back-up strength in case a building's primary system of seismic resistance is threatened by strong earthquake forces.)

OPERATION, RENOVATION AND MAINTENANCE

Once a building is finished and occupied, the way it is operated, maintained, and renovated or modified can significantly affect its structural integrity and earthquake resistance. Obviously a building should not be used for purposes that make demands unanticipated by the original designer. It should not be overloaded unless strength is also added. A structure intended for low human occupancy--a warehouse, for example--should not be converted to a higher-occupancy use without due attention to possible increases in the threat to life, limb, and property.

Similarly, when a structure is modified, changes that could reduce earthquake resistance or otherwise increase the threat should be avoided. If not done with careful attention to seismic safety, ill-advised modifi-
cations--such as removing structural walls or putting large openings in them--can adversely affect a building's performance in an earthquake. Good maintenance and upkeep are also essential if a structure is to retain its strength. Poor maintenance can allow deterioration and corrosion, significantly reducing a structure's life, usability, and safety.

A NEW APPROACH

Much of what has been said so far will probably not be news to those who have followed seismic design and construction issues closely. What may be new is the recommendation for comprehensive, across-the-board monitoring of performance in all key steps of the design and construction process. Needed is an "intelligence" system that can provide for informational feedback, collecting and evaluating evidence as to the performance of designers, local building departments, contractors, and builder-owners--focusing particularly on how well they appear to handle the seismic aspects of their responsibilities.

Simple and relatively non-bureaucratic procedures can be used to gather information on the whole process. One good way would be periodic hearings by the Seismic Safety Commission or some other appropriate body. Evidence on performance could be heard, and perhaps also gathered on a case-study basis. The information obtained should be invaluable, and the continuing public attention to the issues should have a salutary effect. It would keep the public from simply assuming that they are being protected. It would help keep the various participants on their toes between earthquakes, and better prepared for the next one. Also, the evidence would suggest where improvement is needed, and what ought to be done. It would lay the groundwork for needed policy change, and for appropriate administrative or legislative action.

One important use for the information would be in annual program revisions under California's comprehensive system of earthquake safety planning, noted earlier. While implementation is largely voluntary, evidence of a clear need would probably be persuasive to the participating organizations, given the new climate of public awareness and sensitivity to earthquake safety. The information could also be used in formulating stronger measures, where necessary.

A CHECKLIST OF QUESTIONS TO ASK

The quest for information can be guided by asking specific questions. Candid answers would tell informed observers a great deal about what is going on, and how well the system is taking seismic safety into account. The following kinds of questions ought to be revealing.

The Design Phase

1. How well is undergraduate and graduate education preparing architects and engineers to grasp the basic needs of seismically resistant design?

2. Do informed observers believe that the educational programs can be improved? How?
3. Do the licensing examinations for the design professions adequately probe candidates' knowledge of seismic concerns, and the fundamentals of seismic design?

4. Does the seismic design content of the examinations need strengthening? If so, what is the likely effect of strengthening on the pass-fail rate, and what are the implications of this?

5. Do the licensing boards appear to be policing the professions with a view to disciplining or eliminating members whose performance is consistently inadequate?

6. On entering practice, do new professionals work with seasoned colleagues who have had previous experience with seismic design? If not, what changes in the practice of design firms could facilitate such mentoring early in a new employee's career?

7. Do new professionals have enough exposure to the construction process to grasp its limitations, and work effectively within them? Should apprenticeship for professionals include experience at construction sites?

8. Are good continuing education programs regularly given by the professional associations and educational institutions, on the needs of design practice in earthquake country? Do the programs adequately present and interpret the latest state-of-the-art knowledge for use in professional design practice?

9. How well do practicing design professionals participate in such continuing education programs? Is there evidence that substantial numbers do not participate? If so, what measures can be taken to encourage participation, including mandatory continuing education requirements?

10. Do structural engineers and architects jointly participate in early design decisions for all significant projects they work on, and are the seismic design questions given adequate consideration?

11. How diligently are architects and engineers making use of seismic design aids (such as those recently prepared for architects by a committee of the Seismic Safety Commission)?

12. Do architectural and engineering firms have their office processes and procedures independently peer reviewed, with special attention to their seismic design performance?

13. Are architects and engineers employing structural measures such as ductility and redundancy in all significant structures on which they work?

Plan Checking, Inspection, Code Enforcement

1. Are designs of all structures of major consequence independently peer reviewed? Is the construction of all structures of major consequence being adequately observed by the design professionals, and inspected by qualified inspectors?
2. How well are local building departments discharging their plan checking and inspection responsibilities, particularly with respect to seismic concerns?

3. Is there evidence that plan checking or inspection are not sufficiently thorough for significant numbers or kinds of projects?

4. Are building department personnel properly trained and thoroughly qualified for their plan checking and inspection duties?

5. Are continuing education programs on seismic plan checking and inspection regularly offered, and are they geographically accessible to building department staff?

6. Do building department personnel regularly participate in continuing education programs, especially those on seismic design, plan checking and inspection?

7. Do city and county governments and their administrative personnel give adequate financial and moral support to their building departments, and encourage them to do a thorough and responsible job?

8. Do the local codes appear to take adequate account of seismic design needs, and do they appear to be well enforced?

9. Are any significant concerns voiced about the local codes, or about the Uniform Building Code? Are these concerns being appropriately dealt with by the code-drafting agencies?

10. Is the public aware of the earthquake-performance objectives set forth in the codes?

**Construction and Workmanship**

1. Are owners and builders sufficiently sensitive to the importance of good-quality construction and workmanship to a structure's seismic resistance?

2. Is on-the-job observation and inspection done regularly during construction, either by the design engineer or a qualified inspector employed by the owner, or both? Are adequate funds being allocated in building project budgets for thorough observation and inspection?

3. If observation and inspection are not regularly done in some circumstances, what are the principal reasons why not? How can any impediments, such as liability concerns, be reduced or eliminated?

4. Are contractors and their supervisory personnel alert to the importance of their work to the future seismic safety of structures built in California? If so, are they also well informed on the precautions they can take to ensure adequate attention to the seismic aspects of construction?
5. Are continuing education programs offered on seismic concerns in the construction process? If not, what are some practical ways to make such continuing education offerings available, and to encourage participation?

6. Are apprentice training programs for construction workers giving adequate attention to seismic concerns?

7. What proportion of construction workers appear to be well-informed on the important things they should watch for on a job, in the interest of maximizing seismic safety?

8. How are the Association of General Contractors and the building industry associations using their organizational resources to promote seismic safety awareness on the part of members?

Operation, Renovation and Maintenance

1. Are owners and builders sufficiently aware of the need for care in operating and maintaining structures, and for caution in remodeling them?

2. In cases of persistent poor maintenance, are there ways--such as inspections by local building, fire or health departments--to call attention to lax maintenance and initiate remedial measures?

3. Are tenants and users of structures sufficiently aware of the issues regarding operation, renovation and maintenance? Are there ways of increasing their awareness?

4. Are publicly owned facilities being maintained the way they should? If not, why not, and what countermeasures ought to be taken?

5. When owners undertake significant reinvestments in a building, such as additions or alterations, are seismic safety concerns high on their list of priorities?

CONCLUSION

The approach outlined in this paper lends itself to implementation through the comprehensive earthquake preparedness program established by the Earthquake Hazard Reduction Act of 1986. Responsibilities of the various participants could be included as recommended initiatives under the "California at Risk" master plan. Implementation could be pursued in a variety of ways, including performance monitoring and case-study evaluations conducted or sponsored by the Seismic Safety Commission. Such an intelligence-gathering system could feed advisory information into the comprehensive earthquake preparedness planning effort. With luck, most of the recommendations would be carried out voluntarily by the responsible agencies and organizations. Other measures could be considered where justified by apparent lack of progress.
REFERENCES


5. A thorough discussion of peer review in its several forms is found in American Society of Civil Engineers, Quality in the Constructed Project: A Guideline for Owners, Designers and Contractors, v. 1, 1988. (Preliminary edition for trial use and comment.)


7. Stratta, op.cit., p. 263.

8. For a recent comparison of several seismic codes, see Rene W. Luft, "Comparisons Among Earthquake Codes," Earthquake Spectra, v. 5, no. 4, November 1989, pp. 767-789. See also the long list of publications on seismic guidelines and related matters in the Earthquake Hazard Reduction Series (EHRS), issued by the Federal Emergency Management Agency.
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