

Seismic Analysis and Design

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Architects have a critical and expanding role to play in reducing earthquake damage. Across the country, an increasing number of jurisdictions are adopting seismic provisions in building codes for the first time, and this trend will accelerate. Many clients want to go beyond the code requirements to limit potential property damage or increase the chances of continued operations after an earthquake.

Seismic analysis and design services address the resistance of buildings and their contents to earthquakes. Until recently, research and design approaches to improving the seismic performance of structures had focused principally on new buildings. Over the past ten years there has been a growing concern about the seismic performance of older buildings, which represent the far greater hazard in major, damaging earthquakes.

Traditionally the structural engineer was regarded as the professional with the primary responsibility for the seismic performance of a building. While this is still true, architects are now recognized as having a critical and expanding role to play in improving seismic performance. Architectural decisions concerning site planning, building form and configuration, coordination of structural and mechanical system layouts, construction details, and support and bracing of nonstructural components are crucial determinants of overall building performance during an earthquake.

In addition, code changes, technical advances, and increasing concern about loss prevention are driving an expansion in the market for broad seismic-related services.

CLIENT NEEDS

Architects outside the Pacific Coast region are—and increasingly will be—faced with explaining seismic requirements to clients who may never have had to consider such issues before. Even in areas that have had seismic requirements in the past, clients may be surprised to learn that more complex code requirements are in place that may require additional investment from the owner. This can be a difficult discussion. Clients may not want to hear that they should spend more money for seismic analyses. They generally assume that proper structural engineering and adherence to building codes will satisfy their needs, and they do not want to discuss investment in seismic protection that goes beyond code requirements. Yet this situation creates opportunity for the architect who excels at client communication. The knowledgeable architect who can explain the issues involved can capture an emerging market by generating the client's confidence that the architect can develop an integrated solution to provide appropriate seismic protection.

The architect can start by explaining the different levels of earthquake performance that now can be achieved. Hospitals, fire and police stations, utility companies, and central operations centers are examples of the types of facilities that must attain the highest levels of

Summary

SEISMIC ANALYSIS AND DESIGN SERVICES

Why a Client May Need These Services

- ▶ To meet mandated seismic requirements in new buildings
- ▶ To enhance seismic resistance in existing facilities
- ▶ To provide seismic protection beyond code requirements

Knowledge and Skills Required

- ▶ Knowledge of structural theory and concepts
- ▶ Knowledge of construction methods
- ▶ Understanding of seismic forces on building structures
- ▶ Ability to collaborate with engineering consultants
- ▶ Knowledge of applicable seismic codes and standards

Representative Process Tasks

- ▶ Assemble project team
- ▶ Identify seismic-related issues
- ▶ Determine expected level of seismic performance
- ▶ Develop seismic design strategies
- ▶ Develop cost/performance analyses of design options
- ▶ If required, obtain modeling analysis or laboratory performance tests
- ▶ Prepare construction drawings and specifications

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Code Changes Drive the Seismic Market Outside California

While California has had seismic provisions in its building codes for many years, it was not until the 1990s that the need to protect against earthquake hazards outside of California became widely recognized. One major concern is the New Madrid fault, which extends to Wisconsin and Michigan in the north, to Louisiana, Mississippi, Alabama, and Georgia in the south, as far east as Pennsylvania and South Carolina, and to Kansas in the west. A major earthquake near the epicenter of the New Madrid fault in Missouri would rock the entire Midwest, causing damaging intensities as far away as Ohio. The last time this fault was active, in 1811–1812, it made the Mississippi River run upstream.

As a result of the increased awareness of the hazards from both the New Madrid and other faults throughout the country, seismic provisions were added to all three of the model building codes (the Uniform Building Code [UBC] and the Building Officials and Code Administrators [BOCA] and Southern Building Code Congress International [SBCCI] codes). The International Building Code (IBC), which replaces the three separate model codes, marks another leap forward. The IBC seismic provisions address hazard-resistant design and construction issues more comprehensively and uniformly than the three existing codes and places increasing emphasis on reducing property damage through performance objectives. Many jurisdictions outside California have new seismic provisions based on the model codes, and more are implementing them every day. In the 1990s, for example, New York City, Boston, and St. Louis adopted significant seismic provisions for the first time.

Existing seismic codes throughout the country have the stated goal of maintaining life safety, and are prescriptive in nature. Only California has special requirements that respond to a higher performance goal of damage control to maintain postearthquake

function in hospitals. The Building Seismic Safety Council has developed guidelines for performance levels that ultimately will be embodied in codes. The three basic performance levels defined in the guidelines are “collapse prevention,” “life safety,” and “immediate occupancy.” The ultimate level of seismic performance is “continued operations.”

Collapse prevention means what it says—it provides only that the structure will continue to bear gravity loads, but there may be significant risk of injury. It is a level seldom desired by owners of structures that require architectural involvement, and it does not meet seismic building code requirements. An owner might elect to protect a building from collapse in a location where seismic codes are not in effect.

Life safety is the basic level of protection now required by seismic building codes. It means that some damage to the structure may occur, but there is little overall risk of life-threatening injury. There may be considerable nonstructural damage. It should be possible to repair the structure, but it may not be economically practical to do so. Structural repairs may be necessary before the building can be occupied again.

Immediate occupancy means that it is safe to go back in the building immediately after the earthquake, and only limited structural damage has occurred.

Continued operations is the highest level of seismic performance. Some books may have fallen off the shelves, but all building systems will remain operational if the public services to the building are operational.

Ultimately, codes may require different performance levels for different building types. For now, different performance objectives are a subject of discussion between the architect and client in the programming phase.

seismic protection in order to remain operational during an earthquake. seismic codes have more stringent requirements for most of these facilities. Clients whose buildings contain very expensive or irreplaceable contents, such as high-tech manufacturing companies, laboratories, historical buildings, and museums, will probably want to invest in a higher level of protection than the code minimum. For a school, the most relevant question is whether the community’s emergency plan designates the building as an emergency shelter. Of course, one of the client’s key questions will be the cost, which is difficult to determine in the pre-design phase, but knowledgeable cooperation between the architect and structural engineer from the outset of design can greatly reduce costs. The architect can explain to the client that cost-benefit analyses will be developed for various design options that could produce performance within the client’s desired range. The architect’s job is to explain the available alternatives as clearly and accurately as possible, and let the client make the decision.

Clients who are planning to build or who already own facilities in areas with high seismic activity (as opposed to high seismic potential) generally are aware of earthquake threat and are more interested in investing in protection above code requirements. The 1994 Northridge, California, earthquake was one of the most costly disasters in U.S. history, with \$25 billion in estimated property damage and approximately 60 deaths. California building owners have learned firsthand about the losses that accompany the destruction of building contents and about building repairs that may take years. As a result, designs in California often go far beyond code requirements.

As noted above, there is growing recognition of the need to address seismic rehabilitation of existing structures. Retrofit of existing buildings in regions of high seismic activity is a growing market. These seismic rehab projects may be done in conjunction with damage repair or overall rehabilitation. Many government agencies, institutions, and businesses are doing seismic surveys of all their facilities. Although engineers may take the lead in facility survey or seismic evaluation work, architects often are involved in developing rehabilitation or repair strategies in conjunction with project implementation and capital investment plans. Project scheduling can be demanding when the client needs to keep the building operating during the rehabilitation or repair work or wants to minimize downtime. Seismic retrofit of historic structures is particularly challenging, and careful coordination between architect and engineer is required to maintain the historic characteristics of the building.

The federal government has taken a leadership role in earthquake hazard mitigation by requiring that its own buildings, whether owned, leased, or assisted, meet appropriate seismic standards. Federal buildings and federally assisted or regulated buildings must adhere to a 1990 executive order requiring “cost-effective investments” in seismic protection of “public investments.” This order includes new construction financed with federal grants or loans or federally insured or guaranteed loans or mortgages. It has generated considerable work in seismic facility surveys and seismic analysis and design.

Most seismic analysis and design services for buildings are provided by teams that include architects and structural or civil engineering firms to handle technical evaluations. Related services include site analysis, which may require geological and soils consultants; facility surveys and evaluations; and construction documents when programs are implemented.

SKILLS

Seismic design involves a close collaboration between the architect and structural engineer, with careful coordination of mechanical and electrical engineering. To ensure that consideration of seismic issues is assigned the right priority—and occurs at the right time in the design process—the architect needs to have a clear conceptual understanding of seismic design issues.

For the architect, the basic knowledge required for seismic design includes familiarity with the fundamentals of structures and structural design, construction methods and practices, mechanical and electrical systems, and nonstructural architectural components such as bracing and support methods for exterior cladding. In addition, the architect must understand the effects of ground motion on buildings and the effects of building configuration on seismic performance. The architect will need to be familiar with the relative seismic performance of various structural systems and building materials. General conceptual knowledge of the applicable seismic codes is important, as is the ability to explain code requirements and cost/performance trade-offs. The architect must keep abreast of rapidly advancing technical progress in the field.

PROCESS

The scope of services for seismic analysis and design varies from project to project, but a structural engineer must be part of the design team from the outset of the design process.

Factors that could affect the scope of service. The scope of work for seismic analysis and design projects varies widely. For simpler buildings, seismic services may add no cost to the building design; they are simply part of routine structural engineering. More complex

Seismic Design Technology Is Advancing Rapidly

Technical knowledge in the seismic field has advanced rapidly in the past 25 years. Beginning in the mid-1970s, the federal government initiated a building seismic research program. This program has produced (among other things) excellent technical engineering resource documents that read much like building codes and are used as a basis for code development. Known as the NEHRP Provisions (National Earthquake Reduction Program: Recommended Provisions for the Development of Seismic Regulations), the document is updated every three years by the Building Seismic Safety Council in Washington. The NEHRP Provisions include sets of maps of the United States indicating the relative risk of earthquake damage for different regions of the country. (The NEHRP maps published in the late 1980s were what caused the codes groups to become concerned about expanding seismic provisions outside California.) While the NEHRP provisions themselves are written for structural engineers, a nontechnical version is being published for use by architects.

Powerful new performance analysis tools and technologies are revolutionizing seismic design. Today emphasis is on tailoring buildings to perform to the level a particular client needs. Engineers can now design sophisticated structural systems that will perform quite predictably in seismic events and that can be adjusted to vary the response of the structure to seismic forces. It is now possible to evaluate a variety of seismic structural systems with different capacities and predict their performance relative to a variety of earthquake intensities.

▶ **Other seismic factors beyond those required by code may be considered in the programming phase.**

SEISMIC EXPECTATIONS CHECKLIST

A. Earthquake performance of structure

Earthquake*	DAMAGE			
LEVEL OF SEVERITY	NO LIFE THREAT, COLLAPSE	REPAIRABLE DAMAGE, EVACUATION	REPAIRABLE DAMAGE, NO EVACUATION	NO SIGNIFICANT DAMAGE
Low to moderate				
Moderate to large				
Large				

B. Earthquake performance of nonstructural components

Earthquake*	DAMAGE			
LEVEL OF SEVERITY	NO LIFE THREAT, FAILURES	REPAIRABLE DAMAGE, EVACUATION	REPAIRABLE DAMAGE, NO EVACUATION	NO SIGNIFICANT DAMAGE
Low to moderate				
Moderate to large				
Large				

C. Function continuance: structural/nonstructural

Earthquake*	TIME TO REOCCUPY			
LEVEL OF SEVERITY	6 MONTHS+	TO 3 MONTHS	TO 2 WEEKS	IMMEDIATE
Low to moderate				
Moderate to large				
Large				

*The levels of severity used in this chart are defined just below. Classification may be modified by poor soil conditions or specific seismological forecasts.

Low to moderate: <6.5 magnitude on the Richter scale

Moderate to large: 6.5-7.5 magnitude on the Richter scale

Large: >7.5 magnitude on the Richter scale

From AIA/ACSA Council on Architectural Research, *Buildings at Risk: Seismic Design Basics for Practicing Architects* (1994)

buildings located in areas with a high seismic risk may require a wider scope of service. Exact scope will depend on applicable requirements, the client's budget, the level of seismic performance the client wants, and the type of structural system that is proposed or in place.

Some teaming considerations. While the structural engineer must play a major role in providing an earthquake-resistant design, the overall design responsibility is shared by the architect and engineer, because architectural decisions affect the seismic design. The architect and engineer must work together from the inception of the project and discuss issues of desired or expected performance before conceptual design begins. The idea of engineer participation in early design concepts is not new, yet often it does not happen, for a variety of economic, cultural, and professional reasons. The owner, architect, and engineer must be able to communicate using a shared language within a common conceptual framework. Both the architect and structural engineer must make sure the client understands that expected seismic performance levels cannot be guaranteed.

The structural engineer will sign the seismic-related drawings, but as always, the architect will retain some liability. The architect should be sure to team with a well-qualified structural engineer, but it is a mistake to assume that the structural engineer will have everything covered. The architect must understand the seismic principles involved, the appropriate standard of care (current state of knowledge in the field), and the applicable codes in order to protect the his or her own professional interests and those of the client.

Generic steps to perform the service. During the programming stage, the client and

CHECKLIST FOR FACILITATING ARCHITECT/ENGINEER INTERACTION

ITEM	MINOR ISSUE	MAJOR ISSUE	SIGNIFICANT ISSUE
<i>Goals</i>			
Life safety			
Damage control			
Continued function			
<i>Site characteristics</i>			
Near fault			
Possible ground failure (landslide, liquefaction)			
Soft soil (amplification, long period)			
<i>Building configuration</i>			
Height			
Size effects			
Architectural concept			
Core location			
Stair locations			
Vertical discontinuity			
soft story			
setback			
offset resistance elements			
Plan discontinuity			
reentrant corner			
eccentric mass			
Adjacency-pounding possibility			
<i>Structural system</i>			
Dynamic resonance			
Diaphragm integrity			
Torsion			
Redundancy			
Deformation compatibility			
Out-of-plane vibration			
Unbalanced resistance			
Resistance location			
Drift/interstory effect			
Strong column/weak beam condition			
Structural system			
ductility			
inelastic demand constant or degrading			
damping			
energy dissipation capacity			
yield/fracture behavior			
special system (e.g., base isolation)			
mixed system			
repairability			
<i>Nonstructural components</i>			
Cladding, glazing			
deformation compatibility			
mounting system			
Random infill			
Ceiling attachment			
Partition attachment			
rigid			
floating			
Replaceable partitions			
Stairs			
rigid			
detached			
Elevators			
MEP equipment			
Special equipment			
Computer/communications equipment			

From AIA/ACSA Council on Architectural Research, *Buildings at Risk: Seismic Design Basics for Practicing Architects* (1994)

CHECKLIST FOR DESIGN SCOPE-OF-WORK GUIDELINES

ITEM	Activity*					
	DESIGN	COORDINATE	CHECK	SHOP DRAWINGS	SIGN/STAMP	FIELD REVIEW
<i>Foundation</i>	SE	A	G	SE	SE	A, SE
<i>Super structure</i>						
Steel frame	SE	A	SE	SE	SE	SE
Concrete frame	SE	A	SE	SE	SE	SE
Precast or post-tensioned floors	V	SE	SE	SE	V, SE	SE
Open web joists	V	SE	SE	SE	V, SE	SE
<i>Cladding</i>						
Precast, stone	V	A, SE	SE	SE	V	A, SE
Metal	V	A	SE	A	V	A
Glass	V	A	A	A	—	A
<i>Stairs</i>	A, SE, V	A	SE	SE	V, SE	A, SE
<i>Elevator</i>	V	A	SE	A, SE	V	A, SE
<i>Ceilings</i>	A	A	SE	A	A	A
<i>Equipment</i>	V	A	SE	A	V, SE	A, SE
<i>MEP systems</i>	MEP	A	SE	MEP	MEP	MEP

*The responsibilities assigned in this table are for a hypothetical project; these responsibilities must be uniquely established for each project.

KEY
 A— architect;
 SE— structural engineer;
 MEP— mechanical, electrical, plumbing consultant;
 V— vendor, subcontractor or manufacturer of manufactured, assembled, or prefabricated components or systems;
 G— geotechnical engineer

From AIA/ACSA Council on Architectural Research, *Buildings at Risk: Seismic Design Basics for Practicing Architects* (1994)

design team must discuss seismic performance, expectations related to different anticipated earthquake levels, and the cost-benefit analysis process. The client's expectations must be clear if any approach beyond strict code adherence is to be considered, and the design objectives must be understood and incorporated into the project's building program documents.

During the programming and predesign phases the architect and engineer discuss technical issues related to site characteristics (seismic risk and soils), building configuration, structural system, and protection of nonstructural components in order to identify seismic-related issues. Based on this discussion, an agreement and scope of work can be developed among the major consultants and suppliers for the seismic aspects of the design process.

During conceptual design, the architect and engineer develop alternative seismic design strategies. It may be necessary to conduct laboratory tests of various building components—for example, a racking test on a curtain wall—where innovative or special designs are under consideration. Preliminary cost and performance analyses of the design options are developed. Where appropriate, the client is presented with cost and performance options and asked to decide among them. (In less complex buildings it may not be necessary to develop more than one design option.)

In design development the selected seismic design is further elaborated. Structural details are fleshed out. Additional cost and performance analyses are conducted. Further seismic modeling analysis or laboratory performance tests may be performed.

In the construction documentation phase the structural engineer prepares detailed drawings and specifications.

During construction administration the structural engineer may observe construction to verify that the intent of the documents is met. The code may require special inspections for certain critical components.

Usual deliverables include seismic analysis reports, photographs, and laboratory test results.

“Seismic Analysis and Design” was originally published in *The Architect’s Handbook of Professional Practice*, 13th edition, ©2000 by the American Institute of Architects, published by John Wiley & Sons, Inc.

The AIA provides a contract document designed especially for alternative architectural services.

B102–2007, Standard Form of Agreement Between Owner and Architect without a Predefined Scope of Architect’s Services.

AIA Document B102–2007 is a standard form of agreement between owner and architect that contains terms and conditions and compensation details. B102–2007 does not include a scope of architect’s services, which must be inserted in Article 1 or attached as an exhibit. Special terms and conditions that modify the agreement may be included in Article 8.

The separation of the scope of services from the owner/architect agreement allows users the freedom to append alternative scopes of services.

AIA Document B102–2007 replaces and serves the same purpose as AIA Document B141–1997 Part 1.

For more information about AIA Contract Documents, visit www.aia.org/contractdocs/about

May 2011 The American Institute of Architects