APPROACHES TO SEISMIC-HAZARD MITIGATION BY LOCAL GOVERNMENTS—AN EXAMPLE FROM KING COUNTY, WASHINGTON

By Derek B. Booth[1] *and* John P. Bethel[2]

ABSTRACT

In areas of rapid urban development, local governments have the opportunity to effectively reduce seismic risk by regulation. Basic risk-reduction strategies in hazardous areas either limit the intensity of land use or apply more stringent building requirements to the development that occurs. These two strategies can be implemented through a combination of methods, including policy-setting comprehensive plans, policy-implementing functional plans, building codes, and hazard-area delineation and regulation.

King County, Washington, has utilized all these methods in addressing seismic hazards. The county's experience with hazard-area delineation and regulation, through its Sensitive Areas Ordinance, is a particularly relevant example for other jurisdictions to study. Major weaknesses in present efforts to address seismic hazards include the poor data available from which to map hazard areas and the uneven quality of site-specific reports by private consultants. Recommendations to any local government contemplating a similar effort include a clear articulation of policies regarding basic strategy; zoning designations that are explicitly derived from functional plans and that reflect the stated policy; regional hazard mapping that is conservative but credible; and sufficient staff geotechnical expertise to adequately establish and implement an effective hazard-reduction program in cooperation with private geotechnical and design consultants.

INTRODUCTION

Local governments are pivotal in the mitigation of seismic hazards. They establish land-use policies, apply zoning, and review all new development within their jurisdictions. Whether intentionally or not, the policies and ordinances administered by these governments determine the vulnerability of all new urban construction to damage from earthquakes. In established cities, the influence over new construction may affect only a small proportion of the total number of structures. Here, risk reduction may require more aggressive efforts to upgrade existing buildings and ensure postearthquake function of utilities and emergency operations. In rapidly growing regions, however, new development may become a significant, or even the predominant, component of the built environment. We focus our attention on these regions because the opportunities for effective risk reduction are most promising and most attainable.

Once seismic hazards are recognized, reducing them for new developments can involve one of two broad strategies. If the seismic risk is perceived as severe and cannot be reduced, then intensive development can be prohibited through zoning regulations. If the risk is perceived as minor or can be mitigated to that level, then development with appropriate conditions may be allowed. The choice of strategies reflects a social rather than a purely technical judgment about the ultimate severity of that risk. That judgment also is likely to be influenced by the size of the area affected, the certainty of the available hazard data, and the economic impacts of the alternative strategies. In general, even in the most hazard-prone areas of North America, only the latter strategy of development modification has been actively pursued.

Within both of the strategies for hazard reduction, four tools are available to local governments. They apply at different stages and in different ways to land development, but each may be part of an overall effort to reduce seismic hazards.

1. Comprehensive Plans. These documents establish land-use and land-development policy throughout a region. They do not regulate land use themselves; indeed, the area of a comprehensive plan developed by a county may include incorporated cities over which the county has no jurisdiction. These plans are intended to establish the policy by which parcel-specific zoning decisions will subsequently be made.

[1]King County Basin Planning, 770 Dexter Horton Building, Seattle, WA 98104, and Department of Geological Sciences, University of Washington, AJ–20, Seattle, WA 98195.

[2]King County Building and Land Development Division, Eastgate Plaza, Bellevue, WA 98004.

They therefore define which of the two basic strategies, prohibition or modification, will guide future efforts at seismic-hazard mitigation.

2. Functional Plans. These documents apply zoning regulations over large regions of the issuing jurisdiction. They control allowable land uses and intensity of development for specific parcels within these regions. In theory, functional plans simply implement policies articulated in the comprehensive plan. In practice, they may postdate the relevant policy document to the extent that what is actually implemented reflects subsequent community or political evolution.

3. Building Codes. Most municipalities in the Western United States have adopted the Uniform Building Code (UBC) as the basis for their building regulations. The seismic provisions of the UBC set standards for new structures. Where no other attention to seismic hazards is given, the UBC is implicitly assumed to satisfy any stated (or unstated) policies regarding the minimum acceptable level of safety to be provided to the public. Yet the seismic-design section of the UBC addresses only one element of seismic risk, lateral acceleration. Any seismic hazards other than those related specifically to lateral forces on the structure need to be addressed through other measures.

4. Zoning Overlays. Where a jurisdiction knows of or suspects the existence of specific areas that have an enhanced risk of seismic damage, it may choose to control development in those areas. This approach requires the designation of specific hazard zones by means of an overlay (that is, an area-specific change to established zoning restrictions) and a procedure to evaluate and condition development proposals that lie in the areas so designated. One such effort, King County's Sensitive Areas Ordinance, is discussed in detail in the following section.

ACKNOWLEDGMENTS

We thank our colleagues in King County's Building and Land Development Division, particularly geologist Steve Bottheim, for development of the ideas in this chapter. David Masters, a senior planner in the county's Parks Planning and Resources Department, offered us valuable clarifications of zoning theory and practice, and improved the discussions in the text through his review. Reviewer Martha Blair-Tyler made extensive recommendations that have allowed us to better focus our discussion. We hope that the result will be of value to other jurisdictions contemplating a similar program.

KING COUNTY—A CASE STUDY

INTRODUCTION

In the Puget Sound region, unincorporated King County (fig. 249) has probably progressed furthest in specifically addressing seismic hazards on undeveloped land (May, 1989). The county has used, to varying degrees, each of the four basic approaches to hazard reduction listed in the previous section. The ultimate goal is defined by two policies of the King County Comprehensive Plan, adopted in 1985:

E–308. In areas with severe seismic hazards, special building design and construction measures should be used to minimize the risk of structural damage, fire, and injury to occupants, and to prevent postseismic collapse.

E–309. Prior to development in severe seismic hazard areas, builders should conduct special studies to evaluate seismic risks and should use appropriate measures to reduce the risks.

These policies mandate, at most, modification but not prohibition of development, reflecting the prevailing local attitude towards seismic risk. This approach contrasts with the treatment afforded certain other types of geologic hazards, such as active landsliding or coal-mine subsidence. In areas of such hazards, policies and subsequently adopted restrictions effectively prohibit most development on the constrained parts of the sites. Subsequent functional plans have reiterated these two seismic-hazard policies and do not implement land-use restrictions on the basis of seismic risk.

King County uses both area-wide and site-specific approaches to reduce seismic hazards. These approaches predate the 1985 Comprehensive Plan, and thus the Comprehensive Plan policy does not guide but simply reiterates

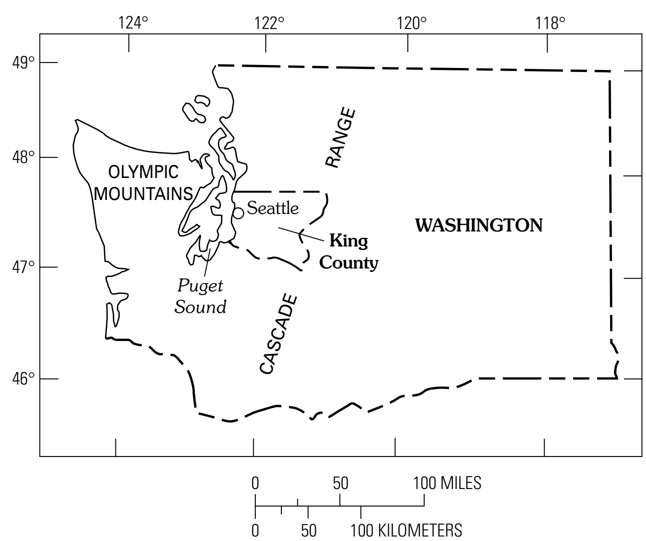

Figure 249. Index map of Washington showing location of King County.

established practice. Area-wide control is provided by the seismic provisions in the UBC. Site-specific risk-reduction measures for hazards not addressed by the UBC have been provided by the county's Sensitive Areas Ordinance, adopted in 1979 and substantially revised in 1990. That ordinance also designates landslide, erosion, and coal-mine-hazard areas and provides for studies and site-specific mitigation to avoid the worst consequences of development in geologically hazardous areas.

The Sensitive Areas Ordinance has proven more complex in its administration and far-reaching in its implications than simple building codes. We therefore describe its elements and its application in some detail, because such an approach to seismic-hazard reduction is probably most feasible for a wide range of local governments.

Several components are necessary for any regulatory effort designed to mitigate any seismic or geologic hazard. These include (1) definition of the hazard; (2) characterization of a set of hazardous site conditions; (3) delineation of the hazard zones on a map; (4) screening of proposed development; and (5) review and conditioning of developments in mapped hazard areas. Each component is described herein, both in a general context and in light of King County's specific experience.

HAZARD DEFINITION

Seismic hazards take a variety of forms. They are generally divided into the direct and indirect effects of earthquakes. Direct effects include immediate ground shaking and displacement, ground rupture, differential settlement, and liquefaction. Indirect effects, often as damaging or more so, include landslides, tsunamis and seiches (ocean and lake waves), floods from damaged dams or levees, and fire.

Planning efforts are typically motivated by past earthquakes; therefore, experience usually guides the choice of relevant concerns in a particular region. In the Puget Sound area, the 1949 and 1965 earthquakes (Thorsen, 1986) indicate that direct effects, particularly shaking-induced ground failure and shaking of buildings, are the primary concerns in this region. The indirect effects of landslides, seiches, and liquefaction were reported in several localities as well but were generally less severe.

CHARACTERIZATION OF HAZARDOUS SITE CONDITIONS

Characterizing hazardous site conditions for seismic hazards primarily involves attempting to recognize those areas where earthquake damage will be anomalously high. Any map of damage after a single earthquake shows some areas where damage is as high as in other areas much closer to the epicenter, and other areas where the effects appear anomalously mild relative to the surrounding region (for example, see Plafker and Galloway, 1989).

Conditions that will control the spatial variability of earthquake-related damage include: (1) proximity to active faults; (2) proximity to, and characteristics of, nearby water bodies; (3) thickness, character, and stratification of surficial deposits; (4) depth to ground water; and (5) site topography.

Any of these factors could in theory be made a part of the basis for seismic zonation of an area (that is, the discrimination of areas of differing seismic hazard or risk). In practice, some of these determinants are more applicable or usable than others.

In King County, only soil conditions and slope angle are presently used to identify hazardous areas; other potential criteria are not applied. Historical earthquakes here have been relatively deep seated, and no surface trace of active faults in this part of the Puget Lowland has been unequivocally identified, so proximity to known faults is not relevant (despite a few local examples of building setbacks from inactive Tertiary-age faults). Tsunamis and seiches have not caused significant damage in historical earthquakes.

Soil and substrate characteristics have long been accepted as primary determinants of earthquake damage. Areas underlain by thick deposits of low-strength, low-density soils have commonly been associated with severe earthquake damage (for example, see Bolt, 1988). Such damage may result from liquefaction or amplification of low-frequency seismic waves. In King County, most of the soil has been consolidated to a high density by multiple glacial episodes. The most extensive low-density deposits are therefore in areas where postglacial sedimentation has filled valleys or depressions in the glaciated ground surface. The Sensitive Areas Ordinance therefore identifies "recent alluvium and organic soils" as indicators of high seismic hazard.

Steep slopes have a potential for landslides during and immediately following an earthquake. Therefore, the seismic provision of the Sensitive Areas Ordinance originally included all slopes steeper than 15 percent as seismically hazardous. Unfortunately, this attempt to include areas of both low-density soil and potential slope instability as a single, undifferentiated hazard area on a single map reduced the usefulness of the hazard mapping. For this reason, the 1990 revision to the ordinance deleted sloping areas and instead treats seismically triggered landsliding as a part of the landslide-hazard review process.

MAPPING OF HAZARD ZONES

Ideally, the representation of seismic-hazard zones would be based on complete topographic, hydrologic, geologic, and seismologic information. The risk from the direct effects of ground shaking might be quantified by the maximum horizontal ground acceleration for an earthquake of given energy release. These data could be mapped and contoured based largely on soil and substrate properties.

Other, indirect effects then could be overlaid on this map where relevant in order to define overall levels of risk.

In practice, the data and the resources are rarely available to make such detailed estimates. New mapping is beyond the means of most local jurisdictions, and existing soils and geologic maps are not specifically prepared to identify seismically hazardous soils. Although a complete data source would show and identify the known types of seismic hazards, including artificial fills, recent alluvial soils, low-density organic soils, thick unconsolidated deposits, and landslide susceptibility, more commonly the information available consists only of surface soil types (for example, county soil surveys) and topography. The result is a much more generalized hazard map, discriminating only relatively "good" land from land that is more likely "bad." King County has this kind of generalized hazard map (fig. 250), where the presence of unfavorable soils (alluvial or organic) solely defines the hazard zones. About 10 percent of the land area within the actively developing parts of the county is so categorized.

Despite these deficiencies, the actual determinants of seismic response in most regions correlate fairly well with soils and slope information. Deep, unconsolidated deposits are most common beneath surfaces of alluvial sediment, which typically include areas of loose organic soil as well. Saturation of these sediments is also common. Steeper slopes correlate fairly well with landslide hazards. Yet, use of soils maps may also identify areas where no increased seismic hazard exists, such as shallow pockets of peat on an undulating till surface or moderate-gradient hillslopes underlain by competent bedrock. Conversely, other seismic hazards may pass unnoticed, such as low-lying shorelines and areas of recent artificial fill.

SCREENING OF DEVELOPMENT PROPOSALS

Once a map is prepared, affected development proposals must be screened. In King County, that authority was created by the Sensitive Areas Ordinance, which requires that virtually all proposals requiring a permit be checked against a map showing so-called hazardous and nonhazardous areas. The process is quite straightforward; the location of the project is checked on a 1:62,500-scale map of hazard areas by the intake permit technician (for building permits) or lead planner (for subdivisions or other large projects). If the project falls within a hazard area, it is referred to a staff geotechnical specialist for further review.

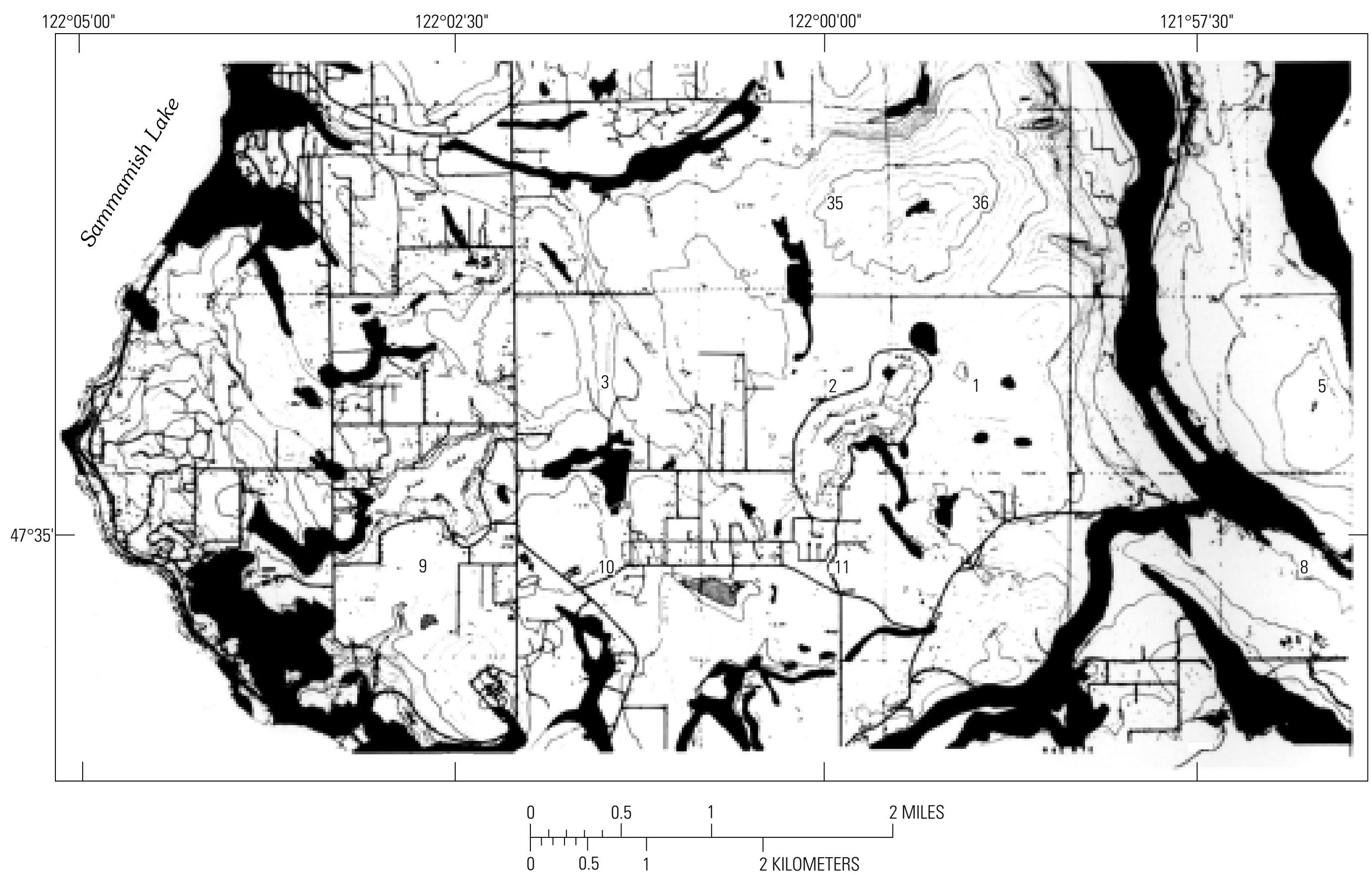

Figure 250. Part of a seismic-hazard map of King County, Washington. Class III areas (dark shade) are defined and regulated under the county's Sensitive Areas Ordinance (King County, 1990). Actual maps are at a scale of 1:62,500.

REVIEW AND CONDITIONING OF PROPOSALS

Once a project has been identified to be in a seismic-hazard zone, the geotechnical specialist must typically choose among the following alternatives to determine if any additional review of the project is needed:

1. Because of the nature of the project, no concern is warranted (for example, kitchen remodeling without any structural change to the building).
2. Despite the project's apparent location within a mapped hazard zone, no concern is warranted (for example, the site is not actually in the hazard zone because of known mapping error or map-reading error).
3. The project lies in a seismic-hazard zone, but the seismicity concerns will be adequately addressed in solving other, more severe, site constraints (such as excessive depth to bearing soil, or active landslide threat). This alternative is most commonly chosen for projects in the seismic-hazard zones in King County.
4. The seismic hazard is in fact a significant concern for the project and requires specific mitigation.

A local government will typically proceed in a similar fashion for either of the last two options, where conditions or requirements beyond the standard zoning and building codes are deemed necessary. The applicant will be directed to hire a professional consultant, normally a geologist or an engineer, to perform a detailed site evaluation and to design an appropriate solution that will be submitted for review (usually) to the local jurisdiction. Detailed site evaluations are routinely required because the existing information regarding site conditions is seldom enough to develop appropriate mitigation. Site evaluations typically characterize the ground-water conditions and address the depth, density, and texture of the subgrade soils. For seismic hazards in King County, proposed mitigations have included subgrade replacement, alternative foundation systems, or improved site drainage. At many sites, these efforts also represent engineering solutions to other nonseismic problems that reduce the seismic hazard to a level equivalent to nonhazardous areas.

EVALUATION OF KING COUNTY'S MITIGATION EFFORTS

King County's primary effort to reduce seismic hazards has several key components. A zoning overlay has been established that defines a method for requiring geotechnical evaluation, thus achieving additional engineering mitigation. No change (that is, no reduction) in the intensity of land use is intended or achieved. Relevant seismic hazards have been identified, namely landsliding and ground failure. A map of these hazard zones has been prepared to screen development proposals. Special engineering studies, prepared by the applicant's consultants, assess any seismic risk and necessary mitigation. Finally, geotechnical review by the county's staff maintains consistency and minimum competency of the mitigation procedures finally adopted.

In this process, two elements are particularly weak. The first is the mapping of hazard areas. Critical because of the sheer volume of development activity (more than 10,000 permits processed in King County in 1989), the seismic-hazard map is imperfectly correlated with zones of actual seismic hazard. King County's current seismic-hazard map displays the extent of several Soil Conservation Services soil types that have been identified as being seismically sensitive (Rasmussen and others, 1974). In practice, it has become apparent that many areas designated as hazardous on this map are not particularly hazardous. Other potentially relevant determinants of seismic hazards have not been fully considered. For example, liquefaction potential is identified only by surface soil types; subregional variability in earthquake intensity because of focusing effects or particularly thick, unconsolidated deposits is nowhere identified. Other potential hazards, particularly seiches or dam breaks, are simply not included in the mapping of any geologic hazard.

The second weak element is the reliance on special engineering studies for specific mitigation strategies. The structural and geotechnical engineering community has a broad range of experience and knowledge in addressing seismic hazards. In the Pacific Northwest, there is little consensus in the geotechnical community on a standard of practice for evaluating site-specific seismic hazards. This lack of consensus is especially apparent in reviewing geotechnical reports for small to moderate-sized projects (residences or small commercial structures). The areas where geotechnical practice is most variable include selection of a design earthquake (namely, the size of the largest earthquake of concern), the scope of adequate subsurface exploration, and appropriate mitigation measures for identified hazards. King County is fortunate in having staff for review, but reliance on these outside studies for design is unavoidable. Currently, the county staff consists of three engineering geologists for all aspects of geotechnical review of development proposals. However, more than 25 years has passed since the last major earthquake in the region. Thus, the experience of local consultants is commonly limited, resulting in reports that vary widely in scope, analytical methodology, and design recommendations.

RECOMMENDATIONS

King County has more than 10 years of experience in implementing a program of seismic-hazard reduction through regulation of land use and building construction. The following recommendations are largely based on this experience and are offered for consideration by other local jurisdictions contemplating a similar program. Their value, however, will be known only after the next large earthquake in the Puget Lowland, followed by a review of developments that were built under this program.

1. Establish Clear Policy. The jurisdiction's comprehensive land-use plan needs to define clearly the policy towards land development in seismically active areas. Without this foundation, subsequent efforts at hazard mitigation will either lack consistency or establish only informal policy. Under the authority of a comprehensive plan, the existence and significance of the seismic threat should be stated clearly, and the types of seismic hazards specific to the jurisdiction should be identified explicitly. Finally, a general framework for hazard mitigation should be established for ultimate implementation through functional plans, building codes, and zoning overlays.
2. Use Policy and Zoning to Minimize Risk. Functional plans, which implement the land-use policies of the comprehensive plan, should reflect both the policy towards and the nature of the seismic hazards. If the hazard can be mitigated during development, then the seismic-hazard delineation should be a factor weighing against intensive land uses but not precluding all uses. This kind of decision would apply to areas subject to liquefaction or settlement of uncontrolled fill, for example. Even hazards that can be mitigated should factor into decisions on locating intensive land uses because of the additional cost of public service to such areas and the potential that mitigation may not be effective. If the hazard (for example, that of potential inundation by tsunamis) cannot be effectively mitigated during development, the hazard should preclude intensive structural land uses (for example, see Nichols and Buchanan-Banks, 1974). Such areas should be set aside for agriculture, recreation, natural-resource production, or other uses that minimize life and property risks.
3. Map Accurately and Conservatively. Although maps associated with zoning overlays are vital to efficient implementation, community-wide seismic-hazard maps are less detailed and less accurate than site-specific studies. For this reason, hazard mapping should be represented and understood as a guideline to the general distribution of seismically sensitive areas rather than as a definitive delineation of such areas. Because the hazard mapping will be approximate, it should err on the side of including too much area in the hazard zone. Errors of this type can be identified during site-specific evaluations. The mapping, however, should not be so conservative that it loses credibility as a useful hazard predictor. It should also seek to incorporate data beyond soil surveys, and it should be updated as new information becomes available.
4. Encourage Uniform Standards for Study Scope and Quality. Jurisdictions should encourage a more uniform approach to seismic-hazard evaluation by working with engineering design professionals and technical experts to establish some baseline hazard-evaluation criteria. In particular, these criteria may include designation of an appropriate design earthquake and establishment of a minimum scope of study for sites in designated seismic-hazard areas. Recent revisions to King County's Sensitive Areas Ordinance provide that authority and also allow more stringent criteria for certain critical structures such as schools, hospitals, and emergency centers.
5. Provide In-House Expertise. Effective implementation of a seismic-hazard-mitigation program requires geotechnical expertise within the jurisdiction as well by the applicant's consultant. Larger governmental bodies, such as the City of Seattle and King County, can justify maintaining a full-time geotechnical staff. This staff is available to assist in all phases of permit processing in seismic-hazard areas, from initial screening to review of construction inspection reports. Smaller municipalities will contract geotechnical review to private consultants, whose overall role in permit processing typically will be more limited. The one step in the permit-review process where geotechnical expertise is most clearly required is the evaluation of geotechnical studies submitted by the applicant. This is the stage at which adherence to a consistent minimum standard of practice must be assured. Yet, without established, well-founded criteria for such a standard, the final results may be far short of needs.

REFERENCES CITED

Bolt, B.A., 1988, Earthquakes: New York, W.H. Freeman and Co., 282 p.

King County, 1990, Sensitive areas map folio: Seattle, King County Department of Parks, Planning and Resources, scale 1:62,500.

May, P.J., 1989, Anticipating earthquakes—Risk reduction policies and practices in the Puget Sound and Portland areas: Seattle, University of Washington Institute for Public Policy and Management, 31 p.

Nichols, D.R., and Buchanan-Banks, J.M., 1974, Seismic hazards and land-use planning: U.S. Geological Survey Circular 690, 33 p.

Plafker, George, and Galloway, J.P., eds., 1989, Lessons learned from the Loma Prieta, California, earthquake of October 17, 1989: U.S. Geological Survey Circular 1045, 48 p.

Rasmussen, N.H., Millard, R.C., and Smith, S.W., 1974, Earthquake hazard evaluation of the Puget Sound region, Washington State: Seattle, University of Washington Geophysics Program, 99 p.

Thorsen, G.W., 1986, The Puget Lowland earthquakes of 1949 and 1965: Olympia, Washington Division of Geology and Earth Resources, Information Circular 81, 113 p.