NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

Headquartered at the State University of New York at Buffalo

Proceedings of the FHWA/NCEER Workshop on the National Representation of Seismic Ground Motion for New and Existing Highway Facilities

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Edited by I.M. Friedland[1], M.S. Power[2] and R.L. Mayes[3]

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1 Assistant Director for Bridges and Highways, National Center for Earthquake Engineering Research
2 Vice President, Geomatrix Consultants, Inc.
3 President, Dynamic Isolation Systems

NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH
State University of New York at Buffalo
Red Jacket Quadrangle, Buffalo, NY 14261

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Overall Objectives of the Workshop

The primary objective of the Workshop is to recommend future directions for a national representation of the seismic ground shaking hazard for the design of new highway facilities and the evaluation and retrofit of existing highway facilities. Emphasis will be placed on appropriate representations of seismic ground motions for use in nationally-applicable guidelines and specifications such as the AASHTO seismic design specifications for bridges. Recommendations will be based on recent developments and new knowledge of seismic ground motions.

A secondary objective is to identify areas where further research and/or development is needed to determine optimum characterization of ground motions for guidelines and specifications.

Specific Objectives and Scope for Topics to be Addressed by the Workshop

I. Topics Related to the Preparation and Utilization of Ground Motion Maps for Highway Facilities Design

National Hazard Portrayal: Consider the utilization of new (1996) USGS national seismic ground shaking maps and supporting information as a basis for the national seismic ground shaking hazard portrayal for highway facilities. Consider whether the maps provide an improved and sufficiently accurate portrayal of the hazard and whether the degree of conservatism in the mapped values is known and appropriate.

Ground Shaking Parameters: Examine how the map information on spectral accelerations and peak ground acceleration should be utilized in specifying ground motions for use in equivalent static and dynamic design procedures. Spectral accelerations for a number of periods of vibrations have been and will be mapped, but perhaps only the maps for two or three periods could be utilized, plus the development of rules (possibly region-dependent) for approximately representing the entire spectrum and lateral force coefficients.

Can strong motion duration be quantified nationwide and can it be utilized in a design procedure? Duration becomes a more important issue for long-period structures because the long-period hazard at some sites (e.g., in the eastern U.S.) may come from large magnitude, distant events, where both the magnitude and the distance contribute to a longer duration. In contrast, the short-period hazard typically comes from local, smaller magnitude events in the eastern U.S. It is desirable to be able to propose both a quantification and a method of utilization of duration in design procedures.

Ground Motion Levels for Design: Examine what should be the appropriate ground motion level(s) for design. What are appropriate probability levels or return periods for design? For example, the proposed 1997 NEHRP Provisions approach is (in part) to use 2% probability of exceedance in 50-years ground motion maps (approximately 2,500 year return period), but 2/3 of these mapped ground motions for design. On the other hand, ATC-33 proposes direct utilization of ground motions for 10% and 2% probability of exceedance in 50-years (approximately 500-year and 2,500-year return periods) in retrofit design of existing buildings. The ATC-18 report

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recommends that a two-level design procedure form the basis of future bridge codes, at least for important bridges; a 2,500-year return period was recommended for the upper level event ground motions for a two-level design procedure and as the single event for a one-level design procedure. Should deterministic considerations be integrated with probabilistically-based ground motion in determining design ground motions? How? (e.g., 1997 NEHRP Provisions, ATC-33). Should there be minimum design levels? On what basis? Should probability levels be region-dependent? (e.g., longer return periods in eastern U.S. because of greater uncertainty in ground motions and greater risk to structures designed for ground motions much lower than "maximum" ground motions).

II. Other Topics of Importance in Specifying Ground Motions for Highway Facilities Design

Site Effects: Examine whether current characterizations of site effects (site factors in current AASHTO Specifications or NEHRP Provisions) are appropriate for use in design procedures for highway facilities. Do recent earthquake data (e.g., Northridge, Kobe) indicate that revisions to currently used site factors should be made? Are there special situations requiring variation in site factors (e.g., high impedance ratios, shallow soil profiles, etc.)?

Vertical ground Motions: Examine whether there should be requirements to design for vertical ground motions and if so, what should the requirements be. Requirements may depend on relative vulnerability of different types of structures to vertical ground motions (e.g., long-span bridges) and the tectonic environment (e.g., enhanced vertical ground motions in the near-source environment).

Near-Source Ground Motions: Examine whether the unique characteristics of near-source ground motions should be considered in design and, if so, whether they can be quantified in a simplified manner for the design of ordinary structures without special site-specific studies. For example, are the long-period pulsive characteristics of near-source ground motions adequately captured in mapped spectral values near faults? Should directionality of long-period ground motions near faults be required to be considered in design? How? For time history dynamic analysis, how should the pulsive characteristics of near-source ground motions be specified (amplitude and frequency content characteristics of pulses)?

Spatial Variations of Ground Motions: Examine the conditions for which spatial variations of ground motions (e.g., wave passage effects, incoherence) should be explicitly quantified for design. Are there classes for structures for which these variations can be neglected? For ordinary structures, can spatial variations in ground motions (or their effects on structures) be quantified in a simplified manner without special studies?

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Introduction

Background

A significant amount of research has been conducted within the FHWA/NCEER Highway Project between 1993 and 1997 on how to adequately portray the national seismic hazard in highway design specifications and guidelines. This work included a review of existing national, state, and regional seismic hazard maps, an evaluation of alternative strategies for the future portrayal of the national seismic hazard, and the development of alternative recommendations for presentation to AASHTO and other highway design and specification authorities. During this time, the USGS published new national seismic ground motion maps in 1996 which appear significantly different that those currently in AASHTO specifications.

In order to ensure that the key issues related to the development of national seismic hazard portrayals were adequately addressed, NCEER organized and conducted the FHWA/NCEER Workshop on the National Representation of Seismic Ground Motion for New and Existing Highway Facilities on May 29 and 30, 1997, in San Francisco, California. The workshop provided a forum under which more than 50 earth scientists, geotechnical engineers, and structural engineers were brought together to discuss a number of these key issues and develop consensus recommendations with respect to their implementation in new highway facility design specifications.

Objectives and Scope of Workshop

The objectives of the FHWA/NCEER Workshop on the National Representation of Seismic Ground Motion for New and Existing Highway Facilities were to:

- explore a number of important issues involved in national representations of seismic hazard and ground motions for design of highway facilities;

- recommend future directions for national seismic ground motion representation with respect to these issues, especially for use in nationally applicable guidelines and specifications such as the AASHTO seismic design provisions for bridges; and

- identify areas where further development and/or research are needed to better define ground motion representation for future guidelines and specifications.

The ground motion issues that have emerged in recent years as potentially important to highway facilities design and that were considered at the Workshop were:

> Issue A: Should new (1996) USGS maps provide a basis for the national seismic hazard portrayal of highway facilities? If so, how should they be implemented in terms of design values?

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Issue B: Should energy or duration be used in a design procedure?

Issue C: How should site effects be characterized for design?

Issue D: Should vertical ground motions be specified for design?

Issue E: Should near-source ground motions be specified for design?

Issue F: Should spatial variations of ground motions be specified for design?

These issues were considered sequentially at the Workshop. For each issue, selected Workshop participants prepared papers and made presentations illuminating the issues and proposing a course of action in terms of design criteria and procedures and/or further development. These Proceedings contain papers covering the presentations by each speaker. Following the presentations on each issue, the Workshop participants as a whole discussed the issues and developed conclusions and consensus recommendations. The following summarizes the key elements in the discussion of each issue and the conclusions and consensus recommendations resulting from the Workshop.

ISSUE A: Should the New USGS Maps Provide a Basis for National Seismic Hazard Portrayal for Highway Facilities? If so, How Should They be Implemented in Terms of Design Values?

In 1996, the U.S. Geological Survey (USGS) developed new seismic ground shaking maps for the contiguous United States (maps for Alaska and Hawaii are under development). These maps depict contours of peak ground acceleration (PGA) and spectral accelerations (SA) at 0.2, 0.3, and 1.0 second (for 5% damping) of ground motions on rock for probabilities of exceedance (PE) of 10%, 5%, and 2% in 50 years, corresponding to return periods of approximately 500, 1000, and 2500 years, respectively. These maps for the contiguous United States and separately for California and Nevada are available from and can be viewed or downloaded on the USGS World Wide Web site at

http://geohazards.cr.usgs.gov.

The Workshop considered whether the new USGS maps should replace or update the maps currently incorporated in AASHTO specifications, which were developed by the USGS in 1990. The key issue regarding whether the new USGS maps should provide a basis for the national seismic hazard portrayal for highway facilities is the degree to which they provide a scientifically improved representation of seismic ground motion in the United States. Based on an analysis of the process of developing the maps, the inputs to the mapping, and the resulting map values, the Workshop concluded that these new maps represent a major step forward in the characterization of national seismic ground motion. The maps are in substantially better agreement with current scientific understanding of seismic sources and ground motion attenuation throughout the United States than are the current AASHTO maps. The Workshop therefore concluded that the new

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USGS maps should provide the basis for a new national seismic hazard portrayal for highway facilities.

The Workshop also examined the issue of an appropriate probability level or return period for design ground motions based on the new USGS maps. Analyses were presented showing the effect of probability level or return period on ground motions and comparisons of ground motions from the new USGS maps and the current AASHTO maps. The Workshop recommended that for design of highway facilities to prevent collapse, consideration should be given to adopting probability levels for design ground motions that are lower than the 10% probability of exceedance in 50 years that is currently in AASHTO (i.e., ground motion return periods longer than 500 years should be considered). This recommended direction is consistent with proposed revisions to the 1997 NEHRP Provisions for buildings, in which the new USGS maps for a probability of exceedance of 2% in 50 years (an approximate 2500 year return period) have been adopted as a collapse-prevention design basis. (The NEHRP proposal for buildings was described at the Workshop and is summarized in these Proceedings.)

ISSUE B: Should Energy or Duration be used in a Design Procedure?

At the present time, the energy or duration of ground motions is not explicitly recognized in the design process for bridges or buildings, yet many engineers are of the opinion that the performance of a structure may be importantly affected by these parameters, in addition to the response spectral characteristics of the ground motion. Based on the presentations and discussions at the Workshop, the participants concluded that some measure of the energy of ground motions is important to the response of a bridge, but, at present, we do not have an accepted design procedure to account for energy. Research in this area should be continued to develop energy-based design methods that can supplement current elastic response-spectrum-based design methods. The Workshop also concluded that energy, rather than duration, is the fundamental parameter affecting structural behavior.

ISSUE C: How Should Site Effects be Characterized for the Design of Highway Facilities?

At a Site Effects Workshop held in 1992 at the University of Southern California (USC), which was supported by NCEER, SEAOC, BSSC, NSF, and the USGS, a revised quantification of site effects on response spectra and revised definitions of site categories were proposed. Subsequently, these revised site factors and site categories were adopted into the 1994 NEHRP Provisions and the 1997 Uniform Building Code (UBC). Since the development of these revised site factors, two significant earthquakes occurred, Northridge in 1994 and Kobe in 1995, which provided substantial additional data for evaluating site effects on ground motions, and research using these data has been conducted.

The site factors and site categories in the current AASHTO specifications are those that were superseded by the USC Workshop recommendations for the NEHRP Provisions and the UBC. The questions for consideration at this Workshop were whether the USC Workshop recommendations should be utilized in characterizing ground motions for highway facilities

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design and whether they should be modified to reflect new data and new knowledge since the 1992 Workshop. The most significant differences in the USC Workshop recommendations and the previous site factors (those currently in AASHTO) are: (1) the revised site factors include separate sets of factors for the short-period and long-period parts of the response spectrum, whereas the previous site factors were only for the long-period part; (2) the revised site factors are dependent on, rather than independent of, intensity of ground shaking, reflecting soil nonlinear response; and (3) the revised site factors are larger (i.e., show a greater soil response amplification) than the previous factors at low levels of shaking, which is important for the lower-seismicity regions in the United States.

The Workshop found that the post-Northridge and post-Kobe earthquake research conducted to date generally was supportive of the site factors derived during the 1992 USC Workshop, although revisions to these factors might be considered as further research on site effects is completed. The Workshop therefore recommended that the factors developed at the USC Workshop and adopted by the NEHRP Provisions and the UBC be proposed as part of a new national representation of seismic ground motion for highway facilities design.

Additionally, current AASHTO specifications incorporate a conservatively slow decay of long-period response spectra with increasing period (response spectral accelerations proportional to $1/T^{2/3}$, where T = period, rather than $1/T$ as is typically seen in ground motions). The Workshop recommended that the new higher site factors not be coupled with the conservative long-period response spectral decay currently in AASHTO. Rather, long-period ground motions should be permitted to decay in a more natural fashion, i.e., approximately proportional to $1/T$ rather than $1/T^{2/3}$.

ISSUE D: Should Vertical Ground Motions be Specified for the Design of Highway Facilities?

At present, the AASHTO Specifications do not contain explicit requirements to design for vertical accelerations. Ground motion data from many earthquakes in the past 20 years have shown that, in the near-source region, very high short-period vertical spectral accelerations can occur. For near-source moderate- to large-magnitude earthquakes, the rule-of-thumb ratio of two-thirds between vertical and horizontal spectra is a poor descriptor of vertical ground motions. At short periods, the vertical-to-horizontal spectral ratios can substantially exceed unity, whereas at long periods, a ratio of two-thirds may be conservative. The Workshop demonstrated that our current understanding and ability to characterize near-source vertical ground motions is good, especially in the Western United States where the near-source region is relatively well defined (i.e., near mapped active faults).

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The Workshop also demonstrated that high vertical accelerations as may be experienced in the near-source region can significantly impact bridge response and design requirements in some cases. On the basis of these findings, it was concluded that vertical ground motions should be considered in bridge design in higher seismic zones for certain types of bridge construction. It was recommended that specific design criteria and procedures be developed for identified bridge types.

ISSUE E: Should Near-source Ground Motions be Specified for the Design of Highway Facilities?

The Workshop examined both the characteristics of near-source horizontal ground motions and the effects of near-source ground motions on bridge response. As the distance to an earthquake source decreases, the intensity of ground motions increases, and this increase in ground motion intensity is incorporated in new USGS maps. However, in addition to their higher intensity, near-source ground motions have certain unique characteristics that are not found at greater distances. The most significant characteristic appears to be a large pulse of long-period ground motions when an earthquake rupture propagates toward a site. Furthermore, this pulse is larger in the direction perpendicular to the strike of the fault than in the direction parallel to the strike. This characteristic of near-source ground motions has been observed in many earthquakes, including most recently in the Northridge and Kobe earthquakes. Preliminary analyses of bridge response presented at the Workshop indicate that near-source ground motions may impose unusually large displacement demands on bridge structures. The Workshop concluded that traditional ground motion characterizations (i.e., response spectra) may not be adequate in describing near-source ground motions, because the pulsive character of these motions may be more damaging than indicated by the response spectra of the motions. The Workshop recommended that additional research be carried out to evaluate more fully the effects of near-source ground motions on bridge response and to incorporate these effects in code design procedures. Until adequate procedures are developed, consideration should be given to evaluating bridge response using site-specific analyses with representative near-source acceleration time histories.

ISSUE F: Should Spatial Variations of Ground Motions be Specified for Design?

Spatial variations of ground motions along a horizontally-extended structure such as a bridge include (1) spatial incoherency in ground motions due to scattering of the propagating seismic waves by the geologic media as well as spatial variations in wave superposition from seismic waves arriving from an extended earthquake source; (2) wave passage effects, in which non-vertically incident seismic waves arrive at different locations along the structure at different times (time-lag effects); (3) attenuation effects, in which ground motion amplitudes decrease with increasing distance from the earthquake source; and (4) differential site response due to variations in the geologic conditions along the structure (which can include two- and three-dimensional site response effects in basin environments, as well as simple one-dimensional site response effects). For important long-span bridges, procedures are available and have been employed in many cases which take these effects into account in relatively sophisticated site-

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specific analyses. The issue addressed at the Workshop was whether there are classes of structures (e.g., related to bridge span length and other characteristics) for which spatial variations of ground motions may safely be neglected in design or the effects of these variations incorporated using simplified code-type design procedures.

Results of analyses were presented through which the effects of spatial variations of ground motion were systematically examined. Generally, these analyses indicated that in the absence of strong differential site response effects, the response of "ordinary" highway bridges was not greatly affected by spatial variations of ground motion. However, the Workshop concluded that we cannot yet adequately define those categories of bridges for which spatial variations of ground motions can be neglected, even for the case of relatively uniform soil conditions along the bridge. Further research is needed to define the importance of spatial variations of ground motions as a function of bridge characteristics and to develop simplified procedures for incorporating the effects of these variations in design.

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