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Developing a rational seismic safety policy for urban areas with 'fuzzy' seismicity

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ABSTRACT: Problems in establishing and mitigating seismic risk in an urban area when seismicity is not confidently based on instrumental records are discussed. Urban Southwestern Ohio is taken as a specific example. Arguments are presented for the need to rigorously establish the seismic risk. Social, economic, and political factors as well as technical problems which make seismic risk mitigation planning and implementation difficult are identified. Related research and application needs are offered.

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1 INTRODUCTION

The effects of the Loma Prieta Earthquake, as it struck the San Francisco Bay Area in 1989, was nationally televised. This helped to develop an awareness for seismic risk in many urban areas that are located East of the Rocky Mountains. In most regions of Midwestern and Eastern U.S., the characterization of seismic hazard remains "fuzzy", i.e. based on historic accounts of damage which are subjective. Many state and local governments located in such regions were not enforcing seismic design provisions and started questioning the issue of seismic risk for the first time after the Loma Prieta earthquake. Ohio is one of these.

A large number of seismic shocks had been recorded in Ohio going back to 1776. There were accounts of substantial earthquake damage throughout Southwestern Ohio (SWOH) due to the New Madrid seismic events of 1811-1812. The 9 March 1937 seismic event at Anna, Ohio is listed amongst the notable historic earthquakes in the U.S. [FEMA-84, 1985]. However, as it has been the case in most areas East of the Rocky Mountains, state, county, and local governments regulating design and construction did not enforce any seismic provisions in SWOH until recently.

2 OBJECTIVES

The objectives of the paper are to: (a) Review the definitions for seismic risk and the main parameters affecting seismic risk; (b) discuss the exposure of SWOH to seismic risk; (c) discuss recent developments in the understanding of seismic hazard in SWOH and review the seismic design demands described in the model codes as well as documents issued by federal agencies; (d) discuss recent findings regarding the vulnerability of constructed facilities in SWOH; and, (e) formulate recommendations for improving the seismic safety in SWOH in conjunction with the social, political, and economic realities of the area.

3 DEFINITION OF SEISMIC RISK AND ASSOCIATED TERMS

Seismic Risk: Seismic risk of a region has been defined as the probability that social and economic consequences of earthquakes will exceed a specified value in the region during a specified exposure time [EERI, 1984]. It has also been established that three primary parameters influence seismic risk: (a) Seismic hazard;

(b) seismic vulnerability; and, (c) exposure or value at risk [Bertero, 1988].

Seismic Hazard: Seismic hazard is the probability of occurrence of earthquakes that will affect a region with damage potentials exceeding a specified level and during a specified exposure time.

Seismic Vulnerability: Seismic vulnerability of an urban area is defined as the probability of undesirable consequences arising from earthquakes within a specified exposure time. These would be casualties and damage distribution to constructed facilities of an intolerable nature due to direct or indirect effects of ground motions. The direct effects include different modes of ground, soil and foundation-structure failures. Indirect effects include fires, floods and release of hazardous materials.

4 EXPOSURE OF SWOH TO SEISMIC RISK [McSweeney, 1990]

With 1.7 million people, the Cincinnati CMSA ranks 23rd according to 1989 Census. For the purposes of exposure to seismic risk, the Cincinnati CMSA may be smeared with the adjacent Dayton-Springfield Metropolitan Statistical Area with 0.9 million people.The annual income of the 2.6 million residents of these two areas add up to $33 billion, 25% of the state's total. The value represented by the physical infrastructure at risk in SWOH is estimated to exceed $25 Billion. The infrastructure maintained by the City of Cincinnati alone has been estimated to-be over $10 Billion (City of Cincinnati Infrastructure Commission, 1987).

Cincinnati and Dayton are home to industries such as Procter and Gamble, AT&T-NCR, Milacron, Merrell-Dow, GE Aircraft Engine Group, several divisions of GM and American Honda amongst others. DOE Fernald Nuclear Facility, US EPA, Wright Patterson Air Force Base, Wright State University and the University of Cincinnati are some of the significant federal and state agencies located in the region.

SWOH serves as a transportation corridor. Two major NS freeway systems (I71 and I75) cross the Ohio river at the Cincinnati CMSA, connecting many Southern states to the Midwest and North. In addition, one major EW freeway (I70) passes through Dayton. The Ohio river further serves as a major artery through the Cincinnati CMSA. Finally, several gas and product pipelines and major electrical transmission lines of the Midwest power pool traverse the Cincinnati CMSA. It follows that SWOH represents a critical exposure in terms of population, physical infrastructure, manufacturing industry and other facilities that are quite critical for the economy and the national security. If a "moderate" earthquake damages 25 % of the physical infrastructure, disrupts the manufacturing activity and renders the major transportation facilities and the lifelines inoperable for several months, the regional near-term financial consequences may easily exceed $50 Billion. Longer-term regional and national consequences may far exceed this estimate.

5 SEISMIC HAZARD IN SWOH

5.1 *Problems in Establishing the Seismic Hazard Accurately*

To accurately establish seismic hazard of a region in probabilistic terms, instrumental ground-motion records are needed in sufficient quantity for a statistical data-base. In addition, identification of all the possible geological source mechanisms would be required [ATC-3, 1978]. On the other hand, no strong-motion records have been retrieved in SWOH since the past destructive earthquakes occurred before the modern instruments were developed. No ground-motion records could be retrieved from the minor shocks which affected SWOH in recent times as the modern seismic instrumentation networks in the Midwest have not extended to this area. Geophysical studies aimed at establishing possible earthquake source mechanisms recently identified a precambrian rift extending from Kentucky through SWOH past Dayton, Ohio [Potter, Richard, Wolfe, and Sitler, 1991]. Additional geophysical and paleo-seismic studies and developing a regional seismic instrumentation network are two urgent needs in order to start establishing the seismic hazard in SWOH in scientific terms.

5.2 *Seismic Hazard Expressed by National Model Building Codes*

Until the 1970's the seismic hazard maps incorporated in building codes were constructed from historic accounts, based on an estimate of the maximum ground shaking experienced by a region without considering the frequency of occurrence of earthquakes. A 1969 map developed by Algermissen [Algermissen, 1969] was adopted by the 1973 through 1985 Editions of the Uniform Building Code [UBC]. This map placed SWOH in the moderate seismic zone (Zone 2 of 4 zones). Similarly, a moderate level of hazard have been assigned to SWOH by the Building Officials and Code Administrators International [BOCA] Code until its 1987 edition.

Algermissen and Perkins developed a new seismic hazard map for U.S. in 1976, to incorporate any established source mechanisms, magnitude and frequency of occurrences and proper attenuation relationships based on instrumental data. This map envisioned a 50-year service life for constructed facilities since it was based on a 10% probability of exceedence within 50 years, i.e. a 475-year return period. The map depicted a lower seismic hazard for SWOH than the 1969 map, this is attributed to a lack of knowledge of the precise earthquake source mechanisms and a lack of instrumental recordings for this area as well as the low frequency of occurrence of damaging ground motions in the past.

The 1976 map by Algermissen and Perkins was adopted after minor modifications by several model code documents such as the ATC-3 [1978], ANSI [1982], NEHRP [1985], BOCA [1987], and UBC [1988]. The State of Ohio adopted the 1987 Edition of the BOCA code in 1989 as the Ohio Basic Building Code [OBBC] and most of the local governments in SWOH have adopted OBBC. Therefore, presently a "low" seismic hazard corresponding to Zone 1 of 4 zones is indicated by the code adopted by the state of Ohio and the local governments in SWOH.

To better illustrate variations in the seismic hazard of SWOH depicted by past and present model building codes, seismic design coefficients for a typical low-rise (0.5 Sec. period, ~1-6 stories) and a medium-rise (1.77 Sec. period, ~20-40 stories) building were calculated based on various editions of BOCA and UBC codes [Somaprasad and Aktan, 1992]. According to pre-1987 BOCA and pre-1985 UBC seismic design provisions, the low-rise and mid-rise buildings would have to be designed for about 26.5% and 16% base shear, respectively. According to the present codes which have adopted the 1976 map by Algermissen and Perkins, the low-rise and mid-rise buildings would have to be designed for about 15% and 7% base shear respectively. It follows that the seismic hazard defined by model codes for SWOH was reduced by about 50% after a probabilistic model based on a 50 year design life was adopted by the codes.

5.3 *Recent Changes in Seismic Hazard Depicted for SWOH*

In 1988, FEMA issued an update to the 1985 Edition of the NEHRP Recommended (Seismic) Provisions [FEMA 95, 1985]. The fundamental change was that additional hazard maps were presented to define seismic hazard for two different levels of earthquake [FEMA 162, 1988]. The new maps characterize the hazard corresponding to a maximum credible earthquake (2375-year return period) in addition to an expected design earthquake (475-year return period).

The maximum credible earthquake corresponds to a constructed facility service life of 250 years, i.e. a 10% probability of exceedence in 250 years. For Ohio, the maximum credible earthquake has 2-3 times higher damage potential than the design earthquake depending on the characteristics of the structure being designed. As an example, the design demands for the low and mid-rise buildings described earlier were recalculated based on the 1988 NEHRP provisions. When a 50-year service life (475-year return period) earthquake was considered, the low-and-mid-rise buildings would have to be designed for 14% and 6% base shear, respectively. When a 250-year service life is considered, the design base shears for the low-and-mid-rise buildings increase to become 34% and 11%, respectively.

It follows that the seismic hazard maps in the current codes that are based on a 50-year service life are significantly underestimating the seismic hazard to constructed facilities in Ohio that need to be designed for an extended service life. It is noted that many important, essential or critical constructed facilities should be designed for an extended service life. It is further important that the discrepancy between design forces for 50 vs 250-year service life is considerably less in Western U.S. than the Midwestern and Eastern regions [ATC-28].

Further evidence that a higher level of seismic hazard should be considered in SWOH when an increased service life is considered has been provided by an Electric Power Research Institute (EPRI) study. This institute conducted an extensive study to assess the seismic hazard in the Central U.S. for designing and evaluating nuclear power plants [1986]. Seismic source zones were identified based on tectonic features and seismotectonic regions. A precambrian rift extending from Cincinnati through Anna, Ohio was identified as a primary seismic zone in SWOH. The study indicated that the earthquake hazard in SWOH may be considerably greater than that is indicated by model codes when return periods of 1000 years or longer (corresponding to a design service life of 100 years or longer) are considered.

6 SEISMIC VULNERABILITY IN SWOH

6 .1 *Vulnerability of SWOH to Ground and Soil Failures*

Cincinnati's geology and glacier-influenced topography makes many sites vulnerable to landslides. The presence of deep-fills and sporadic recurrence of lake-bed clay layers indicate soil vulnerability and site-amplification problems. There has not been an effort to micro-zone the area for ground, soil and site vulnerabilities to the knowledge of the writer. A team of geologists, seismologists, geotechnical, transportation and structural engineers as well as urban planners would be needed to map these vulnerabilities utilizing tools such as the geographic information systems. The resulting micro-zonation maps would be critical for emergency response planners and for structural and geotechnical engineers who would be evaluating the vulnerability of constructed facilities.

6.2 *Vulnerability of Transportation Facilities in SWOH*

According to the Ohio Department of Transportation, none of the highway bridges in this region have been designed and constructed considering seismic effects. Considering that certain bridges would qualify as lifelines, and many others will be critical to emergency response and/or long-term recovery, the implications of the 1988 NEHRP hazard maps for a 2500 year credible seismic event should be carefully and urgently evaluated by transportation officials. The damage potential of a maximum credible earthquake that may affect SWOH as per the 1988 NEHRP hazard maps is not less than the damage potential of the Loma Prieta earthquake which led to the bridge and viaduct failures in San Francisco Bay Area.

Bridge officials would take advantage of the fact that certain bridge types have an inherent resistance to seismic effects. For example, many concrete slab bridges and continuous steel-stringer bridges with integral abutments have been determined through ongoing research by the writer to possess favorable seismic performance characteristics. Some other types of bridges, however, such as steel-stringer bridges that have not been designed with integral abutments, particularly those supported on roller-rocker bearings without any lateral restraint, appear to be extremely vulnerable.

6.3 *Seismic Vulnerability of Buildings in SWOH*

The critical nature of building seismic vulnerability in SWOH arises from the fact that the seismic provisions of building codes were not enforced by local building officials until 1989. After 1989, Cincinnati Department of Buildings and Inspections started enforcing the seismic provisions of the 1987 BOCA code. However most designers continue to omit earthquake provisions by contending that design wind loads are higher than the seismic forces based on the 1987 BOCA code seismic Zone 1 demands.

Many designers apparently do not realize that the nature of seismic loading and philosophy of seismic design differ significantly from wind. Seismic loads prescribed in the building codes are based on the assumption that buildings will resist earthquakes by inelastic energy dissipation. Buildings are expected to remain serviceable, however, under the design wind loads. Therefore, even if the design wind load may exceed the design seismic load for a building located in a low seismic zone, there is no assurance that design against wind would adequately protect against undesirable seismic performance. Only if the non-structural, structural and foundation systems of a building are conceptually designed with an effort to provide desirable seismic attributes to the facility, and detailing is carried out with sufficient attention to seismic performance, that design against wind would ensure that a construction will have capacity against seismic effects as well.

Evaluating the seismic vulnerability of many existing buildings designed and constructed without considering any seismic effects presents special difficulties. FEMA recently issued a handbook for Seismic Evaluation of Existing Buildings [FEMA-178, 1989]. In the Summary of the Handbook, FEMA claims that the provided methodology can be applied nationwide to all existing buildings that are suspected of posing a potentially serious risk of loss of life and injury in the case of a damaging earthquake.

Recent research has indicated that significant uncertainty may prevail in applying the FEMA methodology to certain types of construction [Bertero, 1988; Gavlin, et al, 1990; Aktan and Ho, 1990; Somaprasad and Aktan, 1992]. The fundamental problem is in the significant regional differences in building design and construction practice in U.S. Construction of certain prefabricated and/or post-tensioned systems, lift-slab, composite construction or other systems that are designed with soil-foundation-structural attributes that result in undesirable seismic performance are generally not permitted in higher seismic zones. However, these systems are generally the norm in areas with low to moderate seismicity.

Without the experience of a real earthquake, or extensive research involving destructive testing of prototype constructed facilities, it would not be possible to confidently identify all the critical weaknesses of building structural systems characteristic to SWOH. It is important that in the case of most construction with unproven seismic attributes, generally it has been the performance of certain local details that influence the performance of the complete facility during an earthquake. Therefore, unless the seismic performance of many different details which are specific to the construction traditions of a region are carefully investigated, it would not be possible to confidently evaluate whether a constructed facility will perform catastrophically or in an acceptable manner during a damaging earthquake.

7 CONCLUSIONS

According to the seismic hazard maps issued recently by FEMA, as well as studies by EPRI, the seismic hazard in SWOH is considerably higher than what has been depicted by the model building codes adopted by the federal, state, and local regulatory agencies and based typically on a 10% probability of exceedence in 50 years. The new hazard maps issued by FEMA indicate that the damage potential of a maximum credible earthquake with a 2500-year mean return period or 10% probability of exceedence in 250 years is 2-3 times higher than the seismic loads that are being considered in designing ordinary construction with a typical 50-year service-life.

Considering that more than 180 years have elapsed since the New Madrid earthquakes, and that 55 years have elapsed since the Anna earthquakes, a 10% chance of exceedence in a 250-year exposure time should not be taken lightly. It is also important to consider that over 80% of Cincinnati's physical infrastructure exceed 50 years in age, and over 30% exceed 100 years. In conclusion, the risk resulting from the recently increased level of seismic hazard for a 250-year exposure time should not be considered acceptable as per contemporary standards of public safety in the U.S.

The lack of public safety is compounded by the fact that seismic effects have been completely ignored in the design of practically all of the existing bridges and most of the existing buildings in SWOH. Recent research indicates that the performance of many bridges and buildings in Cincinnati may be catastrophic in terms of life-safety in the event of the maximum credible earthquake. It has been estimated that the near-term financial consequences of a maximum credible earthquake may exceed $50 Billion, excluding the impact of casualties.

Information should be generated by experts regarding exposure, seismic hazard, and vulnerability. This should be used as a basis for earthquake risk mitigation planning and implementation which should be initiated through the efforts of dedicated politicians, strategists, and public officials. Earthquake risk mitigation planning would encompass long-term mitigation planning in conjunction with emergency response and long-term recovery planning. The basic components of mitigation planning would include building code development, land use planning and zoning, soil stabilization, soil strengthening, and seismic upgrading of constructed facilities which have been identified as deficient. The latter requires classification of constructed facilities into different exposure groups depending on their importance and definition of criteria for the acceptable performance of each group. Meanwhile, indirect measures such as earthquake insurance, improvements in construction quality, special licensing of design professionals based on their continuing education, and public education would be undertaken.

Even after establishing seismic risk in terms that would convince the politicians and public officials, developing a consensus regarding the extend of mitigation that would be commensurate with the level of risk and in accordance with the social, political, and economic realities of the region remains as a significant challenge. Difficult questions such as the number of permissible casualties, the tolerable extend of near-term and long-term disruptions to the economy of the stricken region, and its impact to the national economy, significance of possible losses to historic and monumental facilities, etc., would have to be answered based on hard, objective data.

After establishing the national, state, and local positions to the above questions, and the commitments for mitigation, additional problems remain with regard to our technical abilities to effectively design and implement seismic upgrading for different types of construction. The uncertainties that prevail in establishing the seismic hazard, as well as the limitations posed by the local state-of-the-engineering education and practice, would dictate the cost for effective seismic upgrading of soil and constructed facilities and the uncertainty that will remain after any implementation. It follows that considerable region-specific research, education and engineering applications will be necessary before accomplishing a contemporary level of safety against seismic risk in SWOH.

In particular, research is needed to accurately establish seismic vulnerability of different types of buildings and bridges. The performance criteria for evaluating different facilities would have to be established in conjunction with the emergency response plans and after identifying the bridges that qualify as lifelines. It is recommended that seismic effects are considered and the 1988 NEHRP hazard maps for 250-year service life be adopted for the design of new critical facilities.

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