7th Canadian Conference on Earthquake Engineering / Montreal / 1995
7ième Conférence canadienne sur le génie paraséismique / Montréal / 1995

Overview of Major Issues Involved in Preparing New Seismic Loading Provisions for the 2000 Edition of the National Building Code of Canada

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ABSTRACT

The Canadian National Committee on Earthquake Engineering (CANCEE), in recognition of major changes to be made in future seismic loading provisions in the National Building Code of Canada (NBCC), has established a task force to coordinate major redevelopment of those provisions for the 2000 edition of the NBCC. This paper is a progress report from this task force, presenting details concerning ongoing developments in seismic hazard analysis and the evaluation of level of protection. The paper also discusses other code development issues briefly.

INTRODUCTION

The Canadian National Committee on Earthquake Engineering (CANCEE) has the responsibility of preparing and recommending the seismic loading provisions of the National Building Code of Canada (NBCC). Since 1980, the code development cycle for the NBCC has been five years, with CANCEE's recommendations for proposed changes for the next edition required to be made about two years in advance. In late 1992, CANCEE was completing the plans for changes to be introduced in the 1995 edition of NBCC, which were relatively minor in nature. However, CANCEE recognized that major changes would be necessary for the subsequent (2000) edition of NBCC and approved a resolution along the following lines:

"that CANCEE place a very high priority on a major redevelopment of the seismic loading provisions of the 2000 edition of NBCC, with particular emphasis on:

a) developing a format suitable for utilizing seismic hazard expressed as uniform hazard spectra, and

b) evaluating the appropriateness of the level of protection (expressed as the minimum lateral seismic force V) by comparison with that used in various U.S. codes (e.g. UBC, SEAOC and NEHRP), including comparisons of seismic hazard determined at points along the Canada-U.S. border

and, that CANCEE maintain close linkages with various U.S. code development projects in order to benefit from their experience".

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To implement this resolution, CANCEE established the NBCC 2000 Task Force comprising the three authors of this paper. This task force was given the responsibility for generating a detailed redevelopment plan and for coordinating code development work which would subsequently be submitted to CANCEE for its approval. The task force began by preparing a preliminary listing of major issues, which was published in the November 1993 issue of the Canadian Association for Earthquake Engineering (CAEE) Newsletter. At that time the following six major issues were identified:

1. Seismic loading format suitable for utilizing spectral ordinates determined from seismic hazard analysis,
2. Evaluation of current level of protection,
3. Role of different design (or performance) levels in the code,
4. Development of direct site spectra to recognize different site soil conditions,
5. Development of design requirements for low to moderate seismic hazard zones, and
6. Explicit or implicit recognition of overstrength in seismic design.

A status report on the above issues, which included a brief summary of work in progress, was presented to CANCEE in February 1994. Following an extensive discussion of that report, CANCEE indicated that the first two of the above issues have the highest priority. With regard to the first issue, CANCEE requested the Geological Survey of Canada to develop seismic hazard maps of spectral ordinates which could be the basis for design value maps in NBCC 2000. With regard to the second issue, CANCEE gave strong endorsement to a research project on the evaluation of the level of protection which had been initiated by A.C. Heidebrecht at McMaster University. The purpose of this paper is to provide a progress report on work underway towards the NBCC 2000 seismic loading provisions, primarily concerning the two priority issues described above. The paper also includes a few brief comments on the other issues.

SEISMIC HAZARD ANALYSIS

The first edition of the NBCC in 1941 contained seismic provisions in an appendix, based on concepts presented in the 1937 United States Uniform Building Code (UBC). The first seismic zoning map of Canada (Hodgson 1956) appeared in the 1953 edition of the NBCC. This first zoning map was produced on the basis of what has come to be called "historical determinism", the first generation of seismic hazard mapping (see Muir Wood 1993) based on earthquake effects recorded in the known historical period that required no knowledge of earthquake causes. The second generation, "historical probabilism", takes the historical record of seismicity and considers it in terms of its duration to achieve some kind of annual probability of the recurrence of earthquake effects. In Canada, this generation produced the 1970 NBCC seismic zoning map (Whitham et al. 1970). The third generation, "seismotectonic probabilism", incorporates geological information and the seismotectonic understanding of earthquake causes. This generation produced the 1985 NBCC seismic zoning maps (Basham et al. 1985).

There are four main reasons why the time is right for new seismic hazard maps of Canada: i) sixteen years of additional seismicity data over that available to prepare the 1985 zoning maps, ii) an improved understanding of seismotectonics in the country, based partly on global inferences, iii) improved estimates for seismic strong ground motion as a function of earthquake magnitude and distance, including an ability to directly estimate response spectral parameters, and iv) improved seismic hazard computation codes that can incorporate both aleatoric and epistemic uncertainty into the hazard estimates. We describe each of these four aspects briefly below. More details can be found in Adams et al.(1995), Atkinson (1995) and Basham (1995).

The development of the 1985 seismic zoning maps was undertaken during the 1979-1982 time frame, and used the seismicity catalogue that was complete up to 1977. Sixteen years of additional seismicity data has improved the understanding of the geographical patterns of earthquake occurrence in many regions of the country, and improved the ability to estimate earthquake occurrence rates as a function of seismic magnitude. Large earthquakes have occurred in previously unexpected regions, the 1985 Nahanni, NWT, and 1988 Saguenay, Quebec, earthquakes being the two best examples. The development of the new Canadian National Seismograph Network in the past five years (North and Beverley 1994) has provided an ability for high fidelity, high dynamic range recording of the entire seismic wave field, providing opportunities for more sophisticated analysis of earthquake properties. New strong motion recordings from the Nahanni and Saguenay earthquakes have significantly added to these opportunities (e.g., Haddon 1992).

Rogers and Horner (1991) and Adams and Basham (1991) provide reviews and comprehensive bibliographies of seismicity and seismotectonics in western and eastern Canada, respectively. Most important among the new discoveries since the early 1980s are: the evidence concerning prehistoric large earthquakes on the Cascadia subduction zone off British Columbia, Washington and Oregon; and the hypothesis concerning the association of the larger earthquakes in eastern North America with the relatively young rift faults that break the integrity of the continental crust. These two findings have a significant influence on seismic hazards in western and eastern Canada, and must be incorporated into new zoning maps as soon as possible.

Atkinson (1991) recommended that Canadian seismic hazard mapping should now be based on uniform-hazard linear response spectra, rather than the traditional parameters of peak ground acceleration and velocity. Spectral ordinates provide a much better representation of earthquake-induced loading than applying historic amplification factors to peak ground parameters, as is done currently. Preliminary spectral response maps have been prepared for trial use in the United States (Building Seismic Safety Council 1991). As indicated by Adams et al. (1995), the current project for hazard mapping will produce response spectral estimates, but it will also produce new versions of peak ground acceleration and velocity maps in order to provide a direct comparison of hazard estimates with those displayed on the 1985 maps.

Significant differences in hazard estimates can result from differences in adopted strong ground motion relations, apart from those due to changes in earthquake source-zone modelling based on new knowledge of seismotectonics. Among seismic hazard practitioners, the ground motion relations are often the *bete noire*. Even in western Canada where geological conditions are similar enough to those in the western United States to enable the adoption of U.S. ground motion relations, into which significant amounts of new data have been incorporated in recent years, there are still problems of having to utilize the relations in magnitude and distance ranges beyond those to which the data apply. For eastern Canada, new important strong motion data from the Nahanni and Saguenay earthquakes have been utilized in refining ground motion relations, but a large amount of uncertainty still exists. Atkinson (1995) shows how the aleatoric and epistemic uncertainty in ground motion relations can be accounted for in hazard estimates.

Computer codes for hazard computation have improved significantly in the past decade. The Geological Survey of Canada is using the FRISK88 code under licence from Risk Engineering Inc. for its hazard mapping project. The code incorporates uncertainty on all of the significant input parameters: seismicity rates, upper bound magnitudes, focal depth, ground motion relations, and source zone models. This provides realistic uncertainties on the computed hazard values and provides opportunities for consideration of "design value" zoning maps for NBCC that may not correspond to any one group of alternate ground motion maps. An example of a design value map is presented by Adams et al. (1995), one in which the larger of two or more estimates resulting from different historical-dominated and geological-dominated source-zone models is chosen for mapping.

Seismic hazard mapping in terms of spectral ordinates raises important issues relative to the determination of base shear. Not only is it necessary to develop new expressions for base shear, but it is necessary to choose the appropriate spectral ordinates which would best represent the spectrum for design purposes. The appropriate ordinates may well differ in various locations in the country. Also, the code base shear formulation must be for a variety of structures, most of which are multi-degree of freedom (MDOF) in character, whereas spectral ordinates are for single-degree of freedom (SDOF) systems. The 1991 NEHRP Provisions (Building Seismic Safety Council 1991) includes an appendix which suggests a base shear formulation based on spectral ordinates. Heidebrecht et al. (1994) suggest a format based on maximum spectral accelerations and velocities for both SDOF and MDOF systems and illustrate the appication of that format to structures designed in Ottawa and Vancouver. Naumoski and Heidebrecht (1995a) discuss the implications of developing design values from the preliminary spectral ordinates given by Adams et al. (1995).

EVALUATION OF LEVEL OF PROTECTION

Numerous changes have taken place in the seismic loading provisions of the NBCC since such provisions were first included in the main text of NBCC in 1953. Uzumeri et al. (1978) have described the developments in NBCC seismic loading provisions up to the 1977 edition; a number of further changes have taken place since 1977. Without detailing all of the changes, the following are particularly significant:

- three versions of zoning maps (1953, 1970 and 1985)
- move from using zonal factors to peak ground acceleration and velocity
- changes in seismic response factor, i.e. how base shear varies with period
- changes in how ductility capacity is taken into account
- changes in determination of structural period
- changes in how seismic loading is distributed along the height of a structure

While each set of code changes was weighed carefully with due consideration for their impact on the design of various types of building structures, there has been no systematic evaluation of the cumulative effect of all of these changes. As one looks ahead, further major changes can be anticipated, including a new set of seismic zoning maps based on recent developments in seismic hazard methodology.

Consequently, as has been recognized by CANCEE, it is important that there be an overall evaluation of the level of protection provided by the NBCC seismic loading provisions prior to the introduction of any further major changes in those provisions. There is also a strong linkage between level of protection and seismic hazard. If an evaluation determines that the current level of protection is appropriate, then the results of a new seismic hazard analysis may well have to be scaled at a few key locations in the country in order to maintain the current level of protection. Some form of scaling will be necessary if it is determined that there is justification for a significant change in the level of protection.

As indicated in the introduction, a research project to evaluate this level of protection has been initiated at McMaster University. The primary objective of that project is to evaluate the level of protection for building structures designed according to NBCC and to compare this level with that provided by the UBC provisions in the U.S. The overall framework of the project includes the determination of Canadian and U.S. locations having equivalent seismic hazard, selecting representative types of building structures, determining vulnerability of those building structures for various damage parameters as a function of level of seismic hazard and an assessment of the seismic risk of such structures in various locations.

Work on equivalence of seismic hazard for Canadian and U.S. locations has originally been based on comparing existing zoning maps which are based on different hazard methodologies. A comparison of NBCC 1990 and UBC 1991 base shears described by Naumoski and Heidebrecht (1995b) includes an equivalence of seismic zone factors (i.e. Z_a and Z_v in NBCC and Z in UBC) based on a detailed evaluation of the bases for the seismic zoning maps in the two countries. Nevertheless, it is recognized that it is necessary to use information from a number of sources, e.g. zoning maps, earthquake activity, seismotectonic similarities and "expert" opinion in order to arrive at equivalencies which are more reliable.

Discussions with engineering practitioners and academic researchers are currently underway to select appropriate types of building structures for detailed comparative studies. Some of these will involve evaluating actual building designs in various locations and others will involve designing prototype "standard" structures in different geographical locations.

Vulnerability functions describe either the structural damage or the resulting cost of replacement or repair as a function of the level of seismic hazard, e.g. peak ground or spectral velocity. Methodologies for determining structural damage parameters (e.g. interstorey drift or damage indices) for reinforced concrete structures are well known and are already being used in this project. Methodologies for some other types of structures (e.g. masonry) are not well developed and require considerable further work before they can be used to determine vulnerability functions. A proposed generic approach for determining vulnerability functions is now being developed; such an approach will enable consistent interpretation of the results of research projects done in various places.

Current work on developing vulnerability functions involves two sets of reinforced concrete frame structures ranging from 4 to 18 storeys in height and designed in accordance with NBCC 1990 loading provisions in velocity-related (Z_v) zones 2, 4 and 6. One set of these buildings involves both ductile and non-ductile versions of the same building frame. Research on these buildings involves the determination of both structural drift and a global damage index (Park and Ang 1985) using inelastic dynamic analysis when the buildings are subjected to ensembles of representative ground motion records. Arrangements have also been made to have one set of these buildings designed in accordance with UBC 1991 for both UBC zones 3 and 4, which apply in California. These buildings will then be subject to the same type of vulnerability analysis for purposes of making comparisons of structures designed in various Canadian and U.S. locations. Research of this type will also be done on other types of building structures.

OTHER CODE DEVELOPMENT ISSUES

Damage patterns and recorded motions on soil and rock sites in past earthquakes have demonstrated conclusively the significant effects of site conditions on seismic ground motions. In the 1989 Loma Prieta earthquake, major damage occurred on soft soils in the San Francisco-Oakland Region where spectral accelerations were amplified 2 to 4 times over adjacent rock sites (Housner 1990). The large amount of data from the 1989 Loma Prieta earthquake made possible a major re-evaluation of the effects of site conditions on the amplification of ground motions. Borcherdt (1993) proposed amplification factors for the short and mid-period ranges for site categories defined by the average shear wave velocity in the top 30 m of the site; a description of the suggested soil categories and proposed amplification factors is given by Finn (1995). Five soil categories are proposed ranging from hard rock to soft soils. Amplification factors from hard rock to soft soils range from 2 to 4, depending both upon the period range and the intensity of rock motions. This work and the more recent data from the 1994 Northridge earthquake are being used to assess the effectiveness of the NBCC foundation factors for design.

NBCC is a code whose objectives are primarily concerned with life safety, although some provisions are concerned with functionality, e.g. for important structures in which post-disaster operation is required. However, there appears to be an increasing demand for seismic design to broaden the performance criteria for a variety of building types and occupancies. In particular, there is an increasing emphasis on the importance of functionality and reparability of normal structures following a major earthquake; both owners and the public at large are demanding to know the performance expectations of buildings designed in accordance with code provisions. The view has been expressed that the development of performance expectations for a variety of situations should be considered for NBCC 2000.

Most of the NBCC seismic loading provisions have been adapted from codes which are primarily used to guide design in regions of high seismicity, e.g. SEAOC. However, while there are several populated areas of Canada which can be considered highly seismic, most of the country is in fact subject to low to moderate seismicity. Often, the frequency content of seismic ground motions in those regions is substantially different than that of strong ground motions in regions of high seismicity. Also, there are significant differences in the ratios of maximum earthquake motion to design earthquake motion. For example, that ratio (expressed as peak ground acceleration) may range from 1.8 to 2.7 in Eastern North America (low to moderate seismicity) while it only ranges from 1.1 to 1.5 in Western North America (high seismicity) (Sharpe 1992). It is necessary to ensure that the design requirements for the low to moderate seismicity regions of Canada are based on those environments and not just scaled from the requirements for high seismicity regions.

Overstrength is defined as the extra strength achieved in an actual design in comparison with that which is required by the code. There are a variety of reasons for overstrength, including inherent redundancy and non-force code design requirements. Overstrength does not include unanticipated capacity due to the presence of non-structural elements; it is a property of the structure as designed. In general, overstrength is a fairly complex phenomenon, dependent both on the type of structure (i.e. structures with high internal redundancy typically have considerable overstrength) and on the structural period. To assess and to take into account the 'overstrength of a structure', the strength that the chosen structural system <u>must</u> have and the strength of the structure <u>as built</u> are both required. In addition, effect of the relationship of the deformability demands and the deformation capacity provided, is required for the determination of the available or necessary 'overstrength factor'. Since the overstrength ratio (defined as actual to design strength) can range up to 3, it is a major factor which affects the performance of structures designed to resist earthquakes. Consequently, it is important that the role of overstrength be considered in the NBCC seismic loading provisions.

DISCUSSION AND CONCLUSIONS

The issues discussed in this paper have the potential for resulting in major changes in the NBCC 2000 seismic provisions, including changes in level of loading due to geographical seismic hazard changes and changes in relative design forces for different kinds of building structures. As proposals for such changes develop, it is essential that there be feedback from those who use the code, particularly engineering practitioners. CANCEE has a particular responsibility in this regard because of its specific role in the code development process. The NBCC 2000 Task Force is planning to make a detailed report on these issues to CANCEE in June 1995 and will be making specific recommendations in particular concerning seismic hazard zoning and its use in determining design values for the code. In addition, CAEE has an important role in disseminating information about such developments to the broad community of earthquake engineering practitioners and researchers. Short progress reports have appeared regularly in CAEE newsletters and this vehicle should also be used to make detailed information available to those who are interested.

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