SP 160-1

Review of Current and Proposed Seismic Design Provisions

by Jerome S. B. Iffland and Avanti C. Shroff

Synopsis: This paper summarizes the findings of a research project performed by the American Iron and Steel Institute entitled "Technical Review of Current and Proposed Seismic Design Provisions." In the last several years, both New York City and the Building Officials and Code Administrators International (BOCA) have proposed and drafted seismic provisions for their respective building codes. The purpose of this study was to compare the pertinent provisions of these proposed provisions to each other and to existing building codes (UBC, SEAOC, NEHRP, and ASCE 7). In addition, the American Institute of Steel Construction has adapted seismic provisions in their Load and Resistance Factor Design Specifications. BOCA has proposed a method of adapting these LRFD Seismic provisions into its building code. This study also reviewed these proposed revisions with respect to applicability to East Coast earthquakes, especially in New York City. The impact of both the NYC and BOCA provisions on design and construction costs are also addressed.

Keywords: Building codes; costs; earthquake-resistant structures; lateral pressure; loads (forces)

Jerome S.B. Iffland was a founding principal and Chairman of Iffland Kavanagh Waterbury, P.C., an architectural-engineering firm based in New York City. Mr. Iffland was very active in professional societies, having served as director and officer of several societies and chairman of several prestigious committees. He was the author of over fifty technical publications in structural engineering, structural stability, longspan roof structures, slurry walls and folded plate structures and was a frequent lecturer on these topics in the United States and abroad.

ACI fellow Avanti C. Shroff is senior vice president and head of the structural division of Iffland Kavanagh Waterbury, P.C., New York, New York. He has published numerous papers on inspections and rehabilitation of buildings and bridges. He is a member of ACI Committee 437, Strength Evaluation of Existing Concrete Structures, and Chairman of ACI Committee 364, Rehabilitation.

1. INTRODUCTION

After the March 10, 1933 Long Beach, California earthquake, The City of Los Angeles introduced seismic provisions into its 1933 Building Code. These provisions, consisting of two paragraphs, were probably the first seismic building code provisions in the United States (1). The Los Angeles Building Code seismic provisions were subsequently included in the Uniform Building Code (UBC), which is a model code initiated in 1927 by the International Conference of Building Officials. A Joint Committee of the San Francisco Section of the ASCE and the Structural Engineers Association of Northern California drafted a lateral force provisions for building codes which was published in 1952 (2). While seismic provisions in these building codes grew over the years, the publication of the "Recommended Lateral Force Requirements and Commentary," by the Seismology Committee of the Structural Engineers Association of California (SEAOC) in 1967 was a major turning point and this document contributed substantially to future building code seismic provisions (3). This document, termed the "Blue Book" has subsequently been utilized for changes and revisions to the UBC document. Up into the early 1970's, the L.A. Code, the UBC, and the "Blue Book" were the major source of building code seismic provisions for the entire country.

A "Disaster Preparedness Study," published in 1972 by the U.S. Office of Emergency Preparedness, led to an August, 1972 "National Workshop on Building Practices for Disaster Mitigation" sponsored by The National Science Foundation (NSF) and The National Bureau of Standards (NBS). This workshop led to preparation of "Tentative Provisions for the Development of Seismic Regulations for Buildings" (4) prepared by the Applied Technology

Council (ATC) for NSF and NBS. This document, known as ATC-3-06, presented the state-of-the-art of earthquake engineering up to the mid 1970's. Unlike previous work, it addressed seismic building code provisions throughout the entire nation. This is still a major source document for building code writers.

The next major impetus to seismic provisions in codes was the 1977 enactment of the National Earthquake Hazards Reduction Program (NEHRP). This program is now in a current Five Year Plan for FY 1989-1993. This program is administered by the Federal Emergency Management Agency (FEMA), the U.S. Geological Survey (USGS), the NSF, and the NBS, now redesignated as the National Institute of Standards and Technology (NIST). This program led to the initiation and development of the NEHRP Recommended Provisions prepared by the Building Seismic Safety Council (BSSC) in 1986 and subsequently revised in 1988. The NEHRP also resulted in establishment of the National Center for Earthquake Engineering Research (NCEER) at the State University of New York-Buffalo.

NCEER has, and is, taking an active role in promulgating seismic provisions in building codes. The fact that New York City is considering seismic provisions for its Building Code is no accident. NCEER's strategy specifically targeted New York City (5), and as part of this strategy, organized a conference in Sterling Forest in 1987 (6) and participated in organizing one in New York City with The New York Academy of Sciences in 1989 (7) with the express purpose of influencing and promoting seismic provisions in The New York City Building Code. This activity sponsored by the NCEER, and the publicity resulting from an October 25, 1988 earthquake in Quebec, Canada and the December, 1988 Armenian earthquake, substantially aided The New York City effort. Relentless media attention on the Armenian earthquake with parallels drawn to U.S. cities, a well alerted audience at a hearing at the U.S. Embassy to The United Nations, and a study estimating damages in New York City for a moderately large earthquake (8) of 25 Billion U.S. Dollars, triggered The NYC Building Commissioner to establish an expert committee to draft seismic provisions for The NYC Code.

Publication of the ATC-3-06 report and the subsequent NEHRP provisions has stimulated considerable activity in the last few years in revising the seismic provisions in other building codes. This is mainly due to substantial differences in the approach of these two documents compared to the UBC provisions. A list and a brief description of other building codes in approximate historic order of their development that are reviewed in this report follows:

1. UBC (9):

UBC is a Model Building Code and is intended for nationwide use. However, it is used primarily in the West. The UBC document traditionally incorporates SEAOC provisions with some modifications. It changes the local character of SEAOC to a national character by covering the areas of moderate seismicity (zone specific detailing requirements) by providing a map to cover the entire U.S.A. (The supplement has subsequently been adopted as the 1991 UBC).

2. SEAOC (2):

The SEAOC document addresses the various zones, structural systems, lateral load resisting systems and the detailing requirements. Because it is prepared by California structural engineers, it is revised very quickly after each seismic event to address possible or real problems in the California area and to incorporate new thinking and ideas. It does not address national seismic issues. (A 1991 edition of the Blue Book has been published).

3. NEHRP (11):

The NEHRP document addresses the needs of the different earthquake zones in the United States. The NEHRP document defines not only zone specific lateral forces, but it also defines zone-specific methods of analysis and zone specific detailing requirements.

4. NYC (12):

The NYC proposed code document addresses the various zones, structural systems, lateral load resisting systems and the detailing requirements. It is based on the Uniform Building Code with modifications for local conditions.

5. BOCA (13):

BOCA is a Model Building Code used mainly in the Eastern part of the U.S.A. The proposed 1991 BOCA draft now covers a comprehensive seismic provision in Section 1113.0. This proposed draft is based upon the NEHRP 1988 document which addresses the different earthquake zones in the United States. The BOCA draft defines seismic performance categories, each one depending on both the seismic hazard exposure group and a value of A_v. The BOCA draft not only defines zone specific lateral forces, but also defines zone specific methods of analysis and zone specific detailing requirements.

6. ASCE 7 (Formerly ANSI A58-1 - 1982) (14):

ASCE 7 (Formerly ANSI A58.1) is a reference document for building codes and is applicable nationwide. The proposed draft of Section 9 presents the earthquake provisions. The provisions have been adapted from the NEHRP 1988 provisions.

7. AISC - LRFD (15):

The seismic design provisions for Load and Resistance Factor Design Specifications for Structural Steel Buildings, American Institute of Steel

Construction are reviewed and compared to the appropriate sections of the other six codes being reviewed.

2. SCOPE

Both New York City and the Building Officials and Code Administrators International, have proposed and drafted seismic provisions for their respective Building Codes. The purpose of this study is to compare the pertinent provisions of these proposed provisions to each other and to other existing building codes or code reference documents covering seismic designs. In addition, the American Institute of Steel Construction has adapted seismic provisions in their Load and Resistance Factor Design Specifications. BOCA has proposed a method of adapting these LRFD Seismic provisions into its building code. This report reviews these proposed revisions with respect to applicability to the NYC Seismic Provisions. The impact of both the NYC and BOCA provisions on design and construction costs are addressed. This Report also addresses issues and possible future direction.

This comparison is hindered by the problem of comparing moving targets. The NYC Seismic Code has been under constant revision during this study and the committee preparing the draft did not forward it to the commissioner of the Department of Buildings until April 18, 1991. It may, and probably will, go through subsequent changes before it is approved. Similarly the proposed changes to the BOCA National Code have been undergoing continuous revisions. The drafters prepared a final version for public hearing at the April 8-13, 1991 Spring meeting. Final consideration is not until September 15-20, 1991. Additional changes can be anticipated. The UBC seismic provisions were also being changed during the process of writing this report. The supplement to the 1988 Code has been incorporated into the 1991 UBC. The 1991 SEAOC Blue Book corresponds to this version. At this writing, NEHRP, ASCE 7, and the AISC Specifications are all in the process of undergoing revisions. None of these revisions will be available this year (1991), so comparisons are based on the current published proposed versions that are available.

3. RELATIONSHIP AMONG CODES

Earthquake provisions in all code documents are related because the committee that writes one set of provisions is familiar with other existing earthquake codes and quite often holds joint committee memberships.

The 1988 Edition of UBC is basically the same as SEAOC. A few sections differ, e.g. the P-Delta requirements and some SEAOC sections are not incorporated in UBC, e.g., special inspection of wood construction. The UBC 1991 has been published incorporating 1989 supplements and proposed 1990 revisions.

SEAOC is based on the previous edition of SEAOC, ATC 3-06, and the 1985 Edition NEHRP. It includes expanded provisions for both analysis and detailing. Essentially new sections are the configuration requirements, the rules for selecting a lateral force procedure (including definitions of irregular structures), the dynamic lateral force procedure, and the steel detailing chapter.

The 1988 Edition of the NEHRP provisions represents a major product of the Building Seismic Safety Council's Multiyear, Multitask Program on Improved Seismic Safety Provisions.

The NYC Seismic Code Committee draft is essentially based on the UBC 1988, the 1989 Supplements, and the proposed draft of 1990 supplements. (Now published as UBC 1991).
A few of the NYC sections that differ are:

1. The equivalent static and dynamic analysis loading functions to properly account for the nature of NYC seismic hazard.
2. Extended and modified soils classifications and factors.
3. New provision to assess potential for soil liquefaction.
4. Revised occupancy classifications, and associated design requirements are included.
5. An extended list of qualified structural systems is provided.
6. Adapted and adopted provisions for material detailing including:
   a. NFPA provisions for wood construction.
   b. ACI 530-88/ASCE 5-88 and ACI 530.1-88/ASCE 6-88 Requirements for Masonry Structures to replace existing NYC Building Laws Reference Standards RS10-1 and RS10-2. This will apply to all masonry construction.
   c. ACI 318-89 Requirements for Reinforced Concrete.
   d. UBC Chapter 27 requirements for steel structures.

The proposed draft of BOCA 1991 is primarily based on the NEHRP 1988 Edition with some minor revision, e.g.; the reinforced concrete section is new and is based on ACI 318-89; the Steel Section reflects the 1989 AISC ASD and LRFD specifications; and the Masonry and Wood Sections slightly differ from the NEHRP provisions.

The proposed draft of Section 9 of ASCE 7 is based on the 1988 Edition of NEHRP provisions.

3.1 COMPARISON OF LATERAL FORCES

UBC, SEAOC, NEHRP, NYC, BOCA, and ASCE 7 use the terminology "for the effects of wind and earthquake". "Loads" is used for gravity effects (dead, live, snow). AISC-LRFD refers to wind and earthquake directly as loads.

There is an essential difference in determining lateral forces between ASCE 7, BOCA, NEHRP, NYC, SEAOC, and UBC earthquake codes. ASCE 7, BOCA, and NEHRP lateral forces are based on strength (limit state design) while NYC, SEAOC, and UBC internal forces are based on working stress design. This difference is in the level of lateral forces as well as in the load factors applied to the earthquake load. In ASCE 7, BOCA, and NEHRP a load factor for earthquake load equal to 1.0, is given in the section "Combination of Load Effects". SEAOC does not give load factors for general use but it does state in Section I-1, "The minimum design lateral forces prescribed in these recommendations are at a service level (rather than yield or ultimate level)". In Chapter 3 on reinforced concrete, SEAOC modifies the load factors given in ACI 318-83 and prescribes a load factor of 1.4 to be applied to the earthquake forces. Because of the difference in philosophy for lateral force levels, when comparing the base shear of ASCE 7, BOCA, NEHRP with that of the other documents, one must multiply the base shear given in any of these other documents by a factor of 1.4 to 1.5.

Figures 1 through 6 show the base shear coefficient, V/W, as a function of period for three typical framing systems. These figures from Luft (16) are modified to include NYC provisions. A comparison of lateral force requirements in ASCE 7, BOCA, NEHRP, NYC, SEAOC, UBC, and AISC-LRFD Design Specification is given in Table 1. This table, adapted from Luft (16), provides in Line 1, the formula for base shear and summarizes the items that go into it. Below are given some comments related to the lateral force requirements (16).

3.1.1 Period-Dependent Coefficient

The period-dependent numerical coefficient C or C_s, is a function of $T^{-2/3}$ (Line 2, Table 1), where T is the first natural period of vibration. The numerical coefficient in ASCE 7, in BOCA, in NEHRP in NYC, in SEAOC, and in UBC comes from the ATC 3-06 documents. The AISC-LRFD refers to the applicable building code.

All numerical coefficients are derived from smoothed earthquake response spectra. These response spectra have been found to depend on the peak ground displacement, peak ground velocity and peak ground acceleration. All documents place an upper limit on the numerical coefficient C or C_s (Line 3, Table 1). ASCE 7, BOCA, and NEHRP provide two upper limits for C_s

depending on the soil factor and the zone. NYC, SEAOC, and UBC specify an upper limit on C equal to 2.75 and this may be used without regard to soil type or structure period.

All Code Documents and AISC-LRFD place lower limits in C or C_s. T_a was obtained from the statistical analysis of period measurements of existing buildings. This limit on the maximum period T to be used for computing the base shear complicates the analysis because two levels of base shear must be used to comply with strength and drift provisions. The base shear used for establishing the required strength of structural members must be based on a period that does not exceed C_aT_a, while for story drift determinations, a base shear computed with the calculated fundamental period T of the building may be used.

3.1.2 Zone Factor

A single zone factor Z is used in NYC, SEAOC, and UBC while ASCE 7, BOCA, and NEHRP use two coefficients, A_a and A_v, called the effective peak acceleration and the effective peak velocity rated acceleration (Line 5, Table 1). A_a and A_v, enter into the determination of the numerical coefficient C_s (Line 2 and 3, Table 1). At most localities, the numerical values of A_a and A_v are the same.

The zones defined in SEAOC apply only to California. The Seismic Zone Map for California in SEAOC includes a Zone 2. UBC has no Zone 2 in California.

The zoning map included in NYC and UBC are based on the map published in the ATC 3-06 document, which in turn, is based on maps published by Algermissen and Perkins in the 1976 US Geological Survey open file Report 76-416 (17). The peak acceleration shown on any point of the Algermissen and Perkins map has a probability of 90% of not being exceeded in a period of 50 years. The zoning maps included in ASCE 7 and BOCA are based on the NEHRP provisions. The zoning factor proposed in NYC has been adopted from UBC 1988. In the NEHRP provisions, a new set of zoning maps are included in the Appendix to Chapter 1. AISC-LRFD refers to the Applicable Building Code.

3.1.3 Importance Factor

The importance of a building for post earthquake recovery is handled in NYC, SEAOC and UBC by an importance factor I and in ASCE 7, BOCA, and NEHRP by the seismic hazard exposure group. The importance factor I is a multiplier within the base shear formula for NYC, SEAOC, and UBC. This means that the importance factor increases the level of base shear applied to essential facilities. In ASCE 7, BOCA, and NEHRP, the seismic hazard exposure group together with the seismicity index, or the value of A_v, defines the seismic performance category of a building. In ASCE 7, BOCA, and NEHRP the allowable story drift is dependent on the seismic hazard exposure group (a more restrictive drift limit is imposed for higher hazard) while the seismic performance category restricts the analysis procedures, the permissible framing systems and the required detailing. In other words, UBC, SEAOC, and NYC attempt to increase the safety of the essential facility by the level of lateral forces applied to the building while ASCE 7, BOCA, and NEHRP attempt to increase the safety of an essential facility by placing stricter requirements on drift, requiring more detailed analysis, placing restrictions on the type and height of framing to be used, and imposing more restrictive detailing requirements. The Importance Factor for NYC is essentially the same as the UBC requirements. AISC-LRFD refers to the Applicable Building Code.

3.1.4 Structural Framing Factor

The base shear formulas consider the type of structural framing system by a response modification coefficient R in all documents. All documents, have response modification coefficients that derive from ATC 3-06. As previously stated, the base shear in ASCE 7, BOCA and NEHRP is a limit states load, while the base shear in NYC, SEAOC, and UBC is a service level load. The difference between service state and limit state loads shows up in the magnitude of the response modification coefficients given respectively in the code documents.

The NYC code has modified and added several values of response modification coefficients over the UBC code documents. Some of these changes are outlined in Table 2.

AISC-LRFD refers to the Applicable Building Code.

3.1.5 Soil Factor

The definition of Soil Factors in all documents are derived from the soil factor given in ATC 3-06. Following the Mexico City earthquake a soil factor equal to 2.0 was added to the 1988 Editions of NEHRP, UBC, and SEAOC. The factor 1.0 applies to rocks or stiff soil condition, and for stable deposits of sands, gravels or stiff clays of a depth of less than 200 ft. The factor 1.2 applies to deep cohesionless or a stiff clay soil condition exceeding 200 ft. of depth where the soil types overlying rock are stable deposits of sands, gravels or stiff clays. The factor 1.5 applies to soft to medium stiff clay and sands. The factor 2.0 is for a soil profile containing more than 40 ft. of soft clay (UBC 1988) or more than 70 ft. of soft clays or silts (NEHRP).

The definitions for soil factors S_o to S_4 for the NYC code (see Table 3) are different from all documents. They are related to 11 classes of materials (1-65 through 11-65) as defined by the Unified Soil classification system which is already part of the current NYC Building Code for specifying allowable bearing pressures.

The soil profile definitions in ASCE 7 and BOCA are the same as given in NEHRP.

The in AISC-LFRD refers to the Applicable Building Code.

3.1.6 Weight

The weight to be used in the base shear formula given in Table 1 is in all documents: the total dead load, partition loads, 25% of the live load in storage and warehouse occupancies and in some cases snow load. The UBC and SEAOC documents specify that the snow load be considered only when it is greater than 30 lbs/sq. ft. SEAOC, UBC, and NYC require that the partition load be not less than 10 lbs/sq ft and that all permanent equipment be included in the weight. NYC, SEAOC, and UBC allow the snow load to be reduced up to 75% when permitted by the building officials while ASCE 7, BOCA, and NEHRP states that the effective snow load shall be 70% of the full snow load. ASCE 7, BOCA, and NEHRP also state that where the snow load is less than 30 lbs/sq. ft, the snow load is not required to be included in the seismic loading. NYC code includes 25% live load in parking structures in weight computations.

In base shear formula, AISC-LRFD considers the weight, W. The weight can be calculated based on the various load and load combinations. In AISC-LRFD, separate load and load combinations are given for earthquake loads and are based on the ASCE 7-88 which is the same as ANSI A58.1, 1982.

3.2 COMPARISON OF ANALYSIS PROVISIONS

There are some differences among the code documents. The comparison of analysis provisions for various requirements is summarized in Table 4 (16). In Table 4, AISC-LRFD does not appear, because the AISC-LRFD provision is a design specification and it does not address any analysis provisions except the base shear formula.

3.2.1 Direction of Base Shear

Earthquake codes have traditionally defined the base shear as the total of the horizontal forces assumed to come from any horizontal direction. The lateral seismic forces are assumed to act non-concurrently in the direction of the main axes of the structure. This concept is used in NYC, UBC, and SEAOC codes. Also, these codes contain certain exceptions. Provisions must