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Supporting Documentation for Cost-Impact Assessment Methodology-Examination of B223-91 and R26-94

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NAHB RESEARCH CENTER

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Contents

EXAMINATION OF CODE CHANGES

As part of the effort to test and extend the cost impact estimation methodology, Research Center staff examined two code proposals. This document contains the results of those examinations. B223-91 is the first. This code change was proposed as a modification of the seismic provisions contained in Article 11 of the 1990 NBC. Subsequently modified prior to adoption, the change represented a change in the basis of seismic requirements. The 1990 NBC was based on ASCE 7, B223-91 was based on the provisions of the National Earthquake Hazards Program (NEHRP) Recommended Provisions for the Development of Seismic Regulations for New Buildings. The second code change discussed is R26-94 proposed to the *Council of American Building Officials (CABO) One and Two Family Dwelling Code* and involves expanding Section R-303--Footings and provides for an alternative method of protecting foundations against frost heave. Both of these changes were instructional in allowing anticipation of issues that can arise in developing estimates of the cost impact of code changes.

B223-91 is a complex code change and its analysis requires a systematic approach. A two tier analysis, which first separates requirements by building type, would allow focusing of subsequent analysis. The type of building is determined by more than physical characteristics. Factors such as the potential for seismic hazard and soil type enter into the impact of the change. R26-94 is a more straightforward change. Its impact would be determined by the number of degree days of the potential site.

EXAMINATION OF B223-91

I. INTRODUCTION

This section presents an examination of BOCA code change B223-91, a major change proposed to the seismic requirements of the 1990 NBC. The purpose of the examination is to identify issues that may arise in the future application of the cost impact methodology to similar changes.

All discussions are in terms of conventional low-rise residential construction. That group includes all single-family detached, single-family attached, and multifamily buildings three stories or less in height and of either light-wood frame or masonry construction.

B223-91 proposed to delete and replace most of the seismic requirement contained in Section 1113.0 Earthquake loads of Article 11 of the 1990 NBC. Those sections that were to be deleted were:

- 1113.1 General
  - Figure 1113.1 Map of Seismic Zones and Peak Velocity-related Acceleration (A_v)
  - Table 1113.1 Occupancy Importance Factor, I
  - 1113.1.1 Additions
  - 1113.1.2 Alterations
  - 1113.1.3 Plans and design data
    - 1113.1.3.1 Dead and live loads
    - 1113.1.3.2 Bracing
    - 1113.1.3.3 Sample calculations
  - 1113.1.4 Stress increases
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- 1113.2 Definitions
- 1113.3 Symbols, notations and definitions
- 1113.4 Minimum earthquake forces for structures
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  - 1113.4.3 K Factor
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  - 1113.4.4 C Factor
  - 1113.4.5 T Factor
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1113.4.6 S Factor

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1113.5 Distribution of lateral forces

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1113.5.2 Setbacks

1113.5.3 Structures having irregular shapes or framing systems

1113.5.4 Distribution of horizontal shear

1113.5.5 Horizontal torsional moments

1113.5.6 Diaphragms

1113.6 Overturning

1113.6.1 Overturning moment distribution

1113.8 Alternate determination and distribution of seismic forces

1113.9 Structural systems

1113.9.1 Bearing wall systems

1113.9.2 Building-frame systems

1113.9.3 Moment-resisting frame systems

1113.9.3.1 Connection in steel frames

1113.9.3.2 Ordinary steel frames

1113.9.3.3 Special frames

1113.9.3.4 Semiductile concrete frames

1113.9.4 Dual systems

1113.9.4.1 Dual systems with special frames

1113.9.4.2 Dual systems with semiductile concrete frames

1113.9.5 Braced frames

1113.9.6 Substructures

1113.11 Connections

1113.11.1 Anchorage of concrete or masonry walls

1113.11.2 Load paths

1113.11.3 Exterior panels

1113.11.4 Foundation ties

1113.11.5 Braced frames

1113.12 Nonseismic-resisting structural members

1113.13 Moment-resisting frames

1113.14 Essential facilities

Only two sections from Section 1113.0 of the 1990 NBC would be left in place. They are:

1113.7 Drift and building separation

1113.10 Lateral forces on elements of structures and nonstructural components

Table 1113.10 Horizontal Force Factor, C_p, for Elements of Structures and Nonstructural Components

B223-91 would add the following sections to these requirements:

- 1113.1 General
  - 1113.1.1 Required design data
  - 1113.1.2 Additions to existing buildings
  - 1113.1.3 Change of use
  - 1113.1.4 Seismic ground acceleration maps
    - Figure 1113.1.4a Contour Map of Effective Peak Velocity-Related Acceleration Coefficients, (A_v)
    - Figure 1113.1.4b Contour Map of Peak Acceleration Coefficient, (A_a)
  - 1113.1.5 Seismic hazard exposure groups
    - 1113.1.5.1 Mixed use
    - Table 1113.1.5 Seismic Hazard Exposure Group
  - 1113.1.6 Group III building protected access
  - 1113.1.7 Seismic performance category E
    - Table 1113.1.7 Seismic Performance Categories
  - 1113.1.8 Site limitations for seismic performance category E
- 1113.2 Definitions
- 1113.3 Structural design requirements
  - 1113.3.1 Site coefficients
    - Table 1113.3.1 Site Coefficient
  - 1113.3.2 Soil-structure interaction
  - 1113.3.3 Structural framing systems
    - Table 1113.3.3 Structural Systems
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    - 1113.3.3.2 Combinations of framing systems
      - 1113.3.3.2.1 Combination framing factor (R)
      - 1113.3.3.2.2 Combination framing detailing requirements
    - 1113.3.3.3 Seismic performance categories A, B, C
    - 1113.3.3.4 Seismic performance category D
      - 1113.3.3.4.1 Limited building height
      - 1113.3.3.4.2 Interaction effects
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    - 1113.3.3.5 Seismic performance category E
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    - Table 1113.3.4.1 Plan Structural Irregularities
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    - Table 1113.3.4.2 Vertical Structural Irregularities
  - 1113.3.5 Analysis procedures
    - 1113.3.5.1 Seismic performance category A
    - 1113.3.5.2 Seismic performance categories B and C

1113.5.4 Periods

1113.5.5 Modal Base Shear

1113.5.6 Modal forces, deflections, and drifts

1113.5.7 Modal Story Shears and Moments

1113.5.8 Design Values

1113.5.9 Horizontal shear distribution

1113.5.10 Foundation overturning

1113.5.11 P-Delta effects

A comparison of the sections to be deleted with those that will replace them indicates that this change represents a markedly different approach. The requirements in the 1990 edition that would be deleted by the change are organized into the following major sections:

1113.1 General

1113.2 Definitions

1113.3 Symbols, notations and definitions

1113.4 Minimum earthquake forces for structures

1113.5 Distribution of lateral forces

1113.6 Overturning

1113.8 Alternate determination and distribution of seismic forces

1113.9 Structural systems

1113.11 Connections

1113.12 Nonseismic-resisting structural members

1113.13 Moment-resisting frames

1113.14 Essential facilities

Section 1113.4, 11113.5, 1113.6 and 1113.8 address methods for the determination of the magnitude and distribution of forces to which buildings must be designed and constructed. Section 1113.9 provides design requirements for commonly used structural systems. Section 1113.11 includes provisions for connections, including continuity of load paths. Section 1113.12 addresses design of framing elements that are not considered part of the seismic-force resisting system. Sections 1113.13 and 1113.14 are generally not applicable to residential construction.

The requirements in B223-91 are organized as follows:

1113.1 General

1113.2 Definitions

1113.3 Structural design requirements

1113.4 Equivalent lateral force procedure

1113.5 Modal analysis procedure

This is a more compact organization of seismic requirements. Like Section 1113.0 in the 1990 edition of the NBC, there are sections dedicated to general issues and definitions. Section 1113.3 regulates the use of seismic design and analysis procedures. Sections 1113.4 and 1113.5 provides methods for determining the magnitude and distribution of forces to which buildings must be designed and constructed. These two sections are, to some extent, functional equivalents of Sections 1113.4, 1113.5, 1113.6 and 1113.8 in the 1990 NBC. Section 1113.3 in B223-91, while governing some of the same aspects of design and construction as the 1990 requirements, takes a new approach. As can be seen in the detailed listing of the requirements in B223-91, many of the requirements for the design and construction of a building are driven by its "Seismic performance category" (SPC). The categorization scheme takes into consideration, either directly or indirectly, the nature of the occupancy and the relative seismicity of its location. Obviously, the potential impact of the change will vary according to the relevant characteristics of a building. An analysis of the change must then be structured to recognize this possibility.

II. COMPARISON OF REQUIREMENTS

The following section presents a general comparison of the requirements under the 1990 NBC with those under B223-91. The examination begins with a comparison of the change in exceptions granted under Section 1113.1, the introductory section of the seismic requirements.

A. Comparison of Exceptions

B223-91 proposed to delete the following text devoted to exceptions in Section 1113.1 of the 1990 NBC:

Exceptions

1. Buildings or Structures in Use Group R-3 located in Seismic Zone 0, 1 or 2 are exempt from the requirements of this section.

2. All buildings or structures in Seismic Zone 0 and all buildings or structures in Seismic Zone 1 that have an importance factor (i) in Table 1113.1 of less than 1.5, shall only be required to comply with Sections 1113.11.1 and 1113.11.2.

3. Buildings and structures that represent a low hazard to human life in the event of failure, such as agricultural buildings, certain temporary facilities and Use Group U storage facilities, are exempt from the requirements of this section.

These exceptions would be replaced by the following:

Exceptions

1.Buildings of Use Group R-3 that are located in seismic map areas having an effective peak velocity-related acceleration, (A_v), according to Section 1113.1.4, value less than 0.15 are exempt from the requirements of this section.

2. Agricultural storage buildings which are intended only for incidental human occupancy are exempt from the requirements of this section.

3. Buildings or structures located where the seismic coefficient representing the effective peak velocity-related acceleration, (A_v), is less than 0.05, need only comply with Section 1113.3.6.1.

4. Buildings of Use Groups R-3 with a building height not more than 35 feet, which have seismic load-resisting systems which are entirely of wood frame construction, in accordance with the requirements of Section 1703.2, and are located in seismic map areas having an effective peak velocity-related acceleration, (A_v), value equal to or greater than 0.15, need only comply with Section 1113.3.6.1.

5. Buildings assigned to seismic performance category B, according to Section

1113.1.4 and 1113.1.7, which have seismic load-resisting systems which are entirely of light frame wood construction in accordance with the provisions of Section 1703.2, need only comply with Section 1113.3.6.1.

In interpreting the implications of these exceptions and comparing their impacts, some background information is required. Figure 1113.1 in the 1990 edition of the NBC contains a map of the 50 states on which a set of contour lines differentiating seismic regions by their seismic hazard potential is superimposed. These lines divide the country into "seismic zones" which are assigned a numerical designation 0 through 4. This designation is based on the magnitude of the effective peak velocity-related rate of acceleration (A_v) of that zone. Seismic Zone 0 corresponds to areas where A_v is less than 0.05. In areas designated as Seismic Zone 1, A_v is greater than or equal to 0.05 and less than 0.10. Seismic Zone 2 are those areas where A_v is equal to or greater than 0.10 but less than 0.20. In areas designated as Seismic Zone 3, A_v is equal to or greater than 0.20 but less than 0.40. Finally, in Seismic Zone 4, A_v is equal to or greater than 0.40. The exceptions contained in the 1990 edition of the NBC are stated in terms of Seismic Zone locations.

Converting the references in Exception 1 of the 1990 NBC from a "Seismic Zone" basis to a velocity-related acceleration (A_v) basis, indicates that R-3 Use Group buildings constructed where A_v is less than 0.20 are exempt from the other seismic requirement in the section. Exception 1 in B223-91 exempts R-3 Use Group buildings constructed in areas where A_v is less than 0.15. Combining these two facts, we see that **R-3 Use Group buildings constructed where A_v is less than 0.15 would not affected by the adoption of B223-91.**

However, the 1990 NBC exemption extends beyond this to all R-3 buildings where A_v is greater than or equal to 0.15 but less than 0.20. Exception 4 in B223-91 addresses some of those buildings. According to that exception, R-3 buildings having an entirely wood-frame seismic load-resisting system per Section 1703.2, constructed where A_v equals or exceeds 0.15 and 35 feet or less in height, are required to comply only with Section 1113.3.6.1 (continuity connections requirements).

Section 1703.2 in the 1990 NBC contains the provisions governing wood frame design and construction and is as follows:

> *1703.2 Wood frame construction: Exterior walls, interior partitions, floors and roofs of wood construction shall be designed and constructed in accordance with Sections 1701.0, 1702.0 and Sections 1703.2.1 through 1703.2.11.*

Reference to Section 1701.0 reveals:

> *1701.1 Structural design: All structural wood members and connections shall be of sufficient size or capacity to carry all superimposed loads as required by Article 11..."*

The above, then, means that R-3 Use Group buildings having a wood-frame seismic load-resisting system constructed where A_v equals or exceeds 0.15 and are 35 feet or less in height need only comply with the requirements in 1113.3.6.1.

Combining this fact with Exemption 1 in the 1990 NBC indicates the following impact:

R-3 Use Group buildings having a wood-frame seismic load-resisting system constructed where A_v equals or exceeds 0.15 but is less than 0.20 and are 35 feet or less in height were totally exempt from seismic requirements in the 1990 edition of the NBC but would be required to comply with Section 1113.3.6.1 in B223-91.

R-3 Use Group buildings having a wood-frame seismic load-resisting system constructed where A_v equals or exceeds 0.15 but is less than 0.20 and are greater than 35 feet in height receive no exemption in B223-91. These buildings are exempt under Exception 1 of the 1990 NBC. **The impact of adopting B223-91 on R-3 buildings having a wood-frame seismic load-resisting system constructed where A_v equals or exceeds 0.15 but is less than 0.20 and having a building height of greater than 25 feet would be the difference between**

having to comply with no seismic requirements under the 1990 code and having to comply with relevant remaining sections of B223-91.

R-3 Use Group buildings other than those with wood-frame seismic load-resisting systems (i.e. of masonry construction) constructed in areas where A_v is greater than or equal to 0.15 but less than 0.20 would also be exempted by Exception 1 in the 1990 edition of the NBC. The exceptions in B223-91 grants no exemption to these types of structures. **The impact of the change in exceptions for R-3 Use Group buildings other than those with wood-frame seismic load-resisting systems (i.e. of masonry construction) constructed in areas where A_v is greater than or equal to 0.15 but less than 0.20 would be the additional requirements levied through the seismic requirements in the remaining portions of B223-91.**

R-3 Use Group buildings having a wood-frame seismic load-resisting system constructed where A_v is greater than or equal to 0.20 receive no exemption from the seismic requirements in the 1990 NBC. Exception 4 in B223-91 requires that such buildings comply with Section 1113.3.6.1. **Therefore, the impact of the exceptions on R-3 Use Group buildings having a wood-frame seismic load-resisting system constructed where A_v is greater than or equal to 0.20 is the difference between complying to the seismic requirements in Article 11 of the 1990 NBC versus complying with 1113.3.6.1 in B223-91.**

Since R-3 Use Group buildings other than those with wood-frame seismic load-resisting systems (i.e. of masonry construction) constructed in areas where A_v is greater than or equal to 0.20 receive no exemption in either the 1990 edition of the NBC or in B223-91, the impact of change on these structures would be the difference between those two sets of seismic requirements.

Exception 2 in the 1990 edition of the NBC and Exceptions 3 and 5 in B223-91 effect the impact of seismic requirements on R-2 Use Group buildings.

R-2 buildings have an importance factor (I) of 1, therefore Exception 2 would govern all R-2 buildings constructed where A_v is less than 0.10. Exception 3 of B223-91 would govern R-2 buildings constructed where A_v is less than 0.05. Combining these two requirements would indicate that **the requirements for any R-2 building constructed in an area where A_v < 0.05 change from those presented in Sections 1113.11.1 and 1113.11.2 to those contained in Section 1113.3.6.1 in B223-91.**

Exception 5 also applies to R-2 buildings. In order to understand the implications of this exemption, a preliminary explanation of the concept Seismic Performance Group is required. There are 5 Seismic Performance Categories, A though E. These categories are based on effective peak velocity-related acceleration (as above) and on seismic hazard exposure group classification. The latter is similar to the occupancy importance factor in the 1990 NBC. Residential buildings are classified as Group I. Group I buildings of Seismic Performance Group B would be those residential structures constructed where A_v is less than 0.10 but greater than or equal to 0.05. Exception 5 would then mean that R-2 buildings with seismic load-resisting systems of light frame wood construction would be required to comply with Section 1113.3.6.1. Comparing this with Exception 2 in the 1990 edition of the NBC means that: **requirements for R-2 buildings having a light-frame wood seismic load-resisting system in areas where A_v is greater than or equal to 0.05 and less than 0.10 change from those contained in Sections 1113.11.1 and 1113.11.2 of the 1990 edition of the NBC to those in Section 1113.3.6.1 of B223-91.**

Exception 2 in the 1990 edition of the NBC also applies to masonry framed R-2 buildings constructed where A_v is less than 0.10 but greater than or equal to 0.05. B223-91 grants no exception for this type of building, therefore **requirements for masonry framed R-2 buildings in areas where A_v is greater than or equal to 0.05 and less than 0.10 change from those contained in Sections 1113.11.1 and 1113.11.2 in the 1990 edition of the NBC to the seismic requirements contained in the remaining portion of B223-91.**

Neither the 1990 edition of the NBC nor B223-91 grants exemptions relevant to any other R-

2 buildings, therefore **requirements for any R-2 building constructed where A_v is greater than or equal to 0.10 change from the seismic requirements contained in the remaining portions of Article 11 of the 1990 NBC to those contained in the remaining portion of B223-91.**

B. Approaches To Seismic Requirements

The approach embodied in the seismic requirements contained in Article 11 of the 1990 NBC differs fundamentally for that in B223-91. The following section presents both sets of requirements as they relate to the low-rise residential construction. It should be remembered that for the purposes of this examination, that type of construction refers to single-family and multifamily buildings with either light wood-frame or masonry construction using either bearing wall systems or building-frame systems.

1. Section 1113.0 - 1990 NBC

The 1990 NBC takes a general approach to seismic requirements. Section 1113.1, as stated earlier, was the general introductory section of the seismic requirements. It contained the exceptions examined above and addressed plans and design data, stress increases and combined vertical and horizontal forces. These will be examined later in this report. Sections 1113.2 and 1113.3 addressed definitions and symbols. The information contained in those sections came into play only through the other sections of Article. Given all of this, the following sections contained the seismic requirements relevant for the types of residential buildings under consideration.

1113.4 Minimum earthquake forces for structures

1113.5 Distribution of lateral forces:

- 1113.5.1 Structures having regular shapes or framing systems
- 1113.5.2 Setbacks
- 1113.5.3 Structures having irregular shapes or framing systems

1113.5.4 Distribution of horizontal shear

1113.5.5 Horizontal torsional moments

1113.5.6 Diaphragms

1113.6 Overturning

1113.6.1 Overturning moment distribution

1113.7 Drift and building separation

1113.8 Alternate determination and distribution of seismic forces

1113.9 Structural systems

1113.9.1 Bearing wall systems

1113.9.2 Building-frame systems

1113.10 Lateral forces on elements of structures and nonstructural components

Table 1113.10 Horizontal Force Factor, C_p, for Elements of Structures and Nonstructural Components

1113.11 Connections

1113.11.1 Anchorage of concrete or masonry walls

1113.11.2 Load paths

1113.11.3 Exterior panels

1113.11.4 Foundation ties

1113.12 Nonseismic-resisting structural members

Section 1113.4 stipulates that: " Except as provided for in Sections 1113.8 and 1113.10, every structure shall be designed and constructed to resist minimum total lateral seismic forces assumed to act nonconcurrently in the direction of each of the main axes of the structure in accordance with the following formula: "

$$V = 2.5A_vJKCSW$$

The remaining entries in Section 1113.4 pertain to derivation of the above and related formulas and will be discussed in more detail later in this report. Section 1113.5 requires that imposed lateral forces be governed by Sections 1113.5.1 through 1113.5.6. Section 1113.6 requires all buildings to be designed to resist the overturning effects caused by the earthquake forces specified. Section 1113.9 governs the design of structural systems. Only Sections 113.9.1 and 1113.9.2 are relevant for the type of residential construction referenced above.

Section 1113.10 governs design of "Parts or portions of buildings or structures, nonstructural components and anchorage of such components to the main structural system...", while Section 1113.11 regulates connections. Finally, Section 1113.12, which governs nonseismic-resisting structural members, is relevant in areas where A_v is greater than or equal to 0.20.

2. B223-91

Under the requirements of B223-91, a building is required to comply with specific sets of design and construction provisions based on its SPC. A breakdown of these requirements for each Seismic Performance Category A - D follows.

Requirements for SPC A R-2 use group buildings

Buildings in Seismic Performance Category A must comply with the following requirements:

Table 1113.3.3 - Structural Systems:

Section 1113.3.5.1 - Seismic Performance Category A: (Analysis Procedures)

Section 1113.3.6.1 - Seismic Performance Category A: (Design, detailing requirements and structural component loads)

- Section 1113.3.6.1.1 - Ties and continuity
- Section 1113.3.6.1.2 - Concrete and masonry wall anchorage

Section 1113.3.3 requires that all buildings of Seismic Performance Category A comply with the building height and structural system limitations in Table 1113.3 for the selected base structural system. The most common building systems found in residential construction are bearing wall systems and building frame systems. This table presents no building height limitations for those systems in SPC A. Since Section 1113.3.5.1 requires no analysis of seismic forces for the building as a whole, entries related to response modification and deflection amplification factors are not relevant.

Section 1113.3.5.1 - Seismic Performance Category A: No analysis of the seismic forces for the building as a whole is required for either regular or irregular buildings in SPC A. "The requirements of 1113.3.6.1 apply".

Requirements for SPC B R-2 use group buildings

Buildings in Seismic Performance Category B must comply with the following requirements:

Table 1113.3.3 - Structural Systems

Table 1113.3.4.2 - Vertical Structural Irregularities

Section 1113.3.5.2 - Seismic performance Category B and C: (Analysis Procedure)

Section 1113.3.6.1- Seismic Performance Category A: (Design, detailing requirements and structural component loads)

- Section 1113.3.6.1.1 - Ties and continuity
- Section 1113.3.6.1.2 - Concrete and masonry wall anchorage

Plus:

Section 1113.3.6.2 - Seismic Performance Category B: (Design, detailing requirements and structural component loads)

- Section 1113.3.6.2.1 Materials:
- Section 1113.3.6.2.2 Openings:
- Section 1113.3.6.2.3 Orthogonal effects:
- Section 1113.3.6.2.4 Discontinuities in vertical system:
- Section 1113.3.6.2.5 Nonredundant systems:
- Section 1113.3.6.2.6 Collector elements:
- Section 1113.3.6.2.7 Diaphragms:
- Section 1113.3.6.2.8 Bearing Walls:
- Section 1113.3.6.2.9 Inverted pendulum-type structures:

and

Section 1113.4 Equivalent Lateral Force Procedure:

Buildings in Seismic Performance Category B must comply with the design, detailing requirements and structural component loads effects for buildings in Seismic Performance Category A plus the structural design requirements of Section 1113.3.3, the building configuration requirements of Section 1113.3.4, the analysis procedure of Section 1113.5 and the additional design, detailing requirements and structural component load effects of Section 1113.3.6 for Category B. The sections and tables listed above reflect this combination of requirements.

Section 1113.3.3 requires that all buildings of Seismic Performance Category B comply with the building height and structural system limitations in Table 1113.3 for the selected base structural system. The most common building systems found in residential construction are bearing wall systems and building frame systems. This table presents no building height limitations for those systems for SPC B. Section 1113.3.4 states that buildings will be classified as regular or irregular based on plan and vertical configuration. Type 5 vertical irregularity (weak story) in Table 1113.3.4.2 of that section is the only building irregularity that is relevant to Seismic Performance Category B. The item refers the user to the requirements in Section 1113.3.6.2.4.

Finally, according to Section 1113.3.5.2, both regular and irregular buildings must be analyzed according to Section 1113.4.

Requirements for SPC C R-2 use group buildings

Buildings in Seismic Performance Category C must comply with the following sections and tables:

Table 1113.3.3 - Structural Systems

Table 1113.3.4.1 - Plan Structural Irregularities

Table 1113.3.4.2 - Vertical Structural Irregularities

Section 1113.3.5.2 - Seismic performance category B and C: (Analysis Procedure)

Section 1113.3.6.1- Seismic Performance Category A: (Design, detailing requirements and structural component loads)

Section 1113.3.6.1.1 - Ties and continuity

Section 1113.3.6.1.2 - Concrete and masonry wall anchorage

Plus:

Section 1113.3.6.2 - Seismic Performance Category B: (Design, detailing requirements and structural component loads)

Section 1113.3.6.2.1 Materials:

Section 1113.3.6.2.2 Openings:

Section 1113.3.6.2.3 Orthogonal effects:

Section 1113.3.6.2.4 Discontinuities in vertical system:

Section 1113.3.6.2.5 Nonredundant systems:

Section 1113.3.6.2.6 Collector elements:

Section 1113.3.6.2.7 Diaphragms:

Section 1113.3.6.2.8 Bearing Walls:

Section 1113.3.6.2.9 Inverted pendulum-type structures:

Plus:

Section 1113.3.6.3 - Seismic performance category C: ((Design, detailing requirements and structural component loads)

Section 1113.3.6.3.1 Plan irregularity:

Plus:

Section 1113.4 Equivalent Lateral Force Procedure:

And the additional section for buildings with plan irregularities as referenced in Tables 1113.3.4.1 and 1113.3.4.2 -- Section 1113.4.3.1 - Torsion

Buildings in Seismic Performance Category C must comply with the design, detailing requirements and structural component load effects for buildings in Seismic Performance Category B plus the structural design requirements of Section 1113.3.3, the building configuration requirements of Section 1113.3.4, the analysis procedure of Section 1113.3.5 and the additional design, detailing requirements and structural component load effects of Section 1113.3.6 for Category C. The sections and tables listed above reflect this combination of requirements.

Section 1113.3.3 requires that all buildings of Seismic Performance Category C comply with the building height and structural system limitations in Table 1113.3 for the selected base structural system. No limitation is placed on building height for bearing wall or building frame systems; however, "unreinforced" shear walls are required to have "nominal reinforcement per ACI 530/ASCE 5.

Items 1 and 5 in Table 1113.3.4.1 and Item 5 in Table 1113.3.4.2 provide references for instances of irregularity in buildings constructed in Seismic Zone C. They refer the user to: Section 1113.4.3.1; Section 1113.3.6.3.1; and Section 1113.3.6.2.4 respectively. Significantly, both regular and irregular buildings in Seismic Performance Category C are required by Section 1113.3.5.2 to be analyzed according to the provisions of Section 1113.4.

Requirements for SPC D R-2 use group buildings

Buildings in Seismic Performance Category D must comply with the following provisions of this section:

Table 1113.3.3 - Structural Systems

Section 1113.3.3.4 Limited building height:

Section 1113.3.3.4.2 Interaction effects:

Section 1113.3.3.4.3 Deformational compatibility:

Table 1113.3.4.1 - Plan Structural Irregularities

Table 1113.3.4.2 - Vertical Structural Irregularities

Section 1113.3.5.3 - Seismic performance category D and E: (Analysis Procedure)

Table 1113.3.5.3 - Analysis Procedures for Seismic Performance Categories D and E

Section 1113.3.6.1- Seismic Performance Category A: (Design, detailing requirements and structural component loads)

Section 1113.3.6.1.1 - Ties and continuity

Section 1113.3.6.1.2 - Concrete and masonry wall anchorage

Section 1113.3.6.2 - Seismic Performance Category B: (Design, detailing requirements and structural component loads)

Section 1113.3.6.2.1 Materials:

Section 1113.3.6.2.2 Openings:

Section 1113.3.6.2.3 Orthogonal effects:

Section 1113.3.6.2.4 Discontinuities in vertical system:

Section 1113.3.6.2.5 Nonredundant systems:

Section 1113.3.6.2.6 Collector elements:

Section 1113.3.6.2.7 Diaphragms:

Section 1113.3.6.2.8 Bearing Walls:

Section 1113.3.6.2.9 Inverted pendulum-type structures:

Section 1113.3.6.3 - Seismic performance category C: (Design, detailing requirements and structural component loads)

Section 1113.3.6.3.1 Plan irregularity:

Plus:

Section 1113.3.6.4 - Seismic performance category D and E: (Design, detailing requirements and structural component loads)

Section 1113.3.6.4.1 Orthogonal load effects:

Section 1113.3.6.4.2 Plan or vertical irregularities:

Section 1113.3.6.4.3 Vertical seismic loads:

And:

Section 1113.4 Equivalent Lateral Force Procedure:

Section 1113.5 Modal analysis procedure:

Buildings in Seismic Performance Category D must comply with the design, detailing requirements and structural component load effects for buildings in Seismic Performance Category C plus the structural design requirements of Section 1113.3.3, the building configuration requirements of Section 1113.3.4, the analysis procedure of Section 1113.3.5 and the additional design, detailing requirements and structural component load effects of Section 1113.3.6 for Category D. The sections and tables listed above reflect this combination of requirements.

Section 1113.3.3 requires that all buildings of Seismic Performance Category D comply with the building height and structural system limitations in Table 1113.3 for the selected base structural system. A limitation of 160 feet is imposed as a height limitation for buildings with either bearing wall or building frame system in Seismic Performance Category C, with the exception of unreinforced masonry shear walls in either systems. These walls are not permitted in Seismic Performance Category D buildings. In addition, Section 1113.3.3.4.2 (Interaction effects) and Section 1113.3.3.4.3 (Deformational compatibility) are applicable to SPC D buildings.

All five items in Table 1113.3.4.1 and all five items in Table 1113.3.4.2 related to structural irregularities address buildings in SPC D. They refer the user to Sections 1113.3.6.4.2, 1113.4.3.1, 1113.3.6.3.1, 1113.3.5.3 and 1113.3.6.2.4.

Table 1113.3.5.3 contains the following requirements for analysis relevant to low-rise residential construction -

> Regular buildings must be analyzed in accordance with Section 1113.4. Irregular buildings with a height of less than or equal five stories or 65 feet must be analyzed in accordance with Section 1113.4.

Although other entries in the table refer to other forms of analysis, they are irrelevant for low-rise residential purposes.

Requirements for Seismic Performance Category E are contained in B223-91 but do not apply to any structure in Seismic Hazard Exposure Group I (residential).

It also should be noted that an examination of the seismic map in B223-91 indicates that, with the exception of the region around New Madrid County, Missouri, only Seismic Performance Categories A, B and C are likely of general concern for residential construction in BOCA territory.

C. Combining the Exceptions with Requirements

The foregoing discussion addressed the requirements under the 1990 NBC and B223-91 separately, without considering the impact of the exemptions developed earlier in this section. The exceptions, however, determine how these requirements would be applied to the subject residential construction. The following table combines the impact of the exceptions, providing a comparison of the two sets of requirements as they related to conventional low-rise residential construction.

COMPARISON OF SEISMIC REQUIREMENTS		
	1990 NBC	B223-91
R-3 Buildings		
$A_v < 0.15$	Exempt	Exempt
$0.15 \le A_v < 0.20$		
≤ 35 feet & wood frame seismic load-resisting system	Exempt	Comply with Section 1113.3.6.1
> 35 ft. & light wood frame seismic load-resisting system	Exempt	Comply with requirements for SPC C buildings
Masonry constructed	Exempt	Comply with requirements for SPC C buildings
$0.20 \le A_v$		
≤ 35 feet & light wood frame seismic load-resisting system	Comply with requirements in Section 1113.0	Comply with Section 1113.3.6.1
> 35 ft. & light wood frame seismic load-resisting system	Comply with requirements in Section 1113.0	Comply with requirements for SPC D buildings
Masonry constructed	Comply with requirements in Section 1113.0	Comply with requirements for SPC D buildings
R-2 Buildings		
$A_v < 0.05$	Comply with Section 1113.11.1 & 1113.11.2	Comply with Section 1113.3.6.1
$0.05 \le A_v < 0.10$		
light wood frame seismic load-resisting system	Comply with Section 1113.11.1 & 1113.11.2	Comply with Section 1113.3.6.1
masonry construction	Comply with Section 1113.11.1 & 1113.11.2	Comply with requirements for SPC B buildings
$0.10 \le A_v < 0.15$	Comply with requirements in Section 1113.0	Comply with requirements for SPC C buildings
$0.15 \le A_v < 0.20$	Comply with requirements in Section 1113.0	Comply with requirements for SPC C buildings
$0.20 \le A$	Comply with requirements in Section 1113.0	Comply with requirements for SPC D buildings

As can be seen in the table, the impact of the change is likely to be quite variable. The resources and effort required to perform an analysis of this proposed code change to estimate the cost impact on all of the housing/seismicity combinations listed above would be quite substantial. It may not be necessary to analyze all possible combinations. An analysis of the most prevalent type or two may suffice.

This change serves to illustrate an important point. It may not be necessary to complete a full description of the code change prior to selection of representative types. With a change such as this, it is possible to identify distinct types of housing that are likely to be affected differently prior to the completion of the description development process, and thus save potentially wasted effort. For example, R-2 buildings constructed with light wood frame seismic load-resisting systems in areas where A_v is less than 0.10 but greater than or equal to 0.05 and in areas where A_v is less than 0.15 but greater than or equal to 0.10 would likely serve to typify a great deal of low-rise multifamily construction in the Northeast. The selection of these kinds of buildings to be used in the development of designs would allow the further development of the code change description devoted only to the portions of the code relevant to those buildings.

III. ILLUSTRATIVE EXAMINATION OF REQUIREMENTS FOR TWO R-2 USE GROUP BUILDINGS

This section compares the seismic requirements under the 1990 NBC and B223-91 as they would apply to a low-rise R-2 building with entirely wood-framed seismic load-resisting systems. First, both sets of requirements for such a building constructed where A_v is less than 0.10 but greater than or equal to 0.05 are presented. Then the requirements for the same building constructed where A_v is less than 0.15 but greater than or equal to 0.10 are compared.

A. Areas Where A_v Is Less Than 0.10 But Greater Than Or Equal To 0.05

For an R-2 building with an entirely wood-framed seismic load-resisting system to be constructed where in an area A_v is less than 0.10 but greater than or equal to 0.05, the 1990

NBC requires compliance with Sections 1113.11.1 and 1113.11.2. Those two sections are as follows:

1113.11.1 Anchorage of concrete or masonry walls: Concrete or masonry walls shall be anchored to all floors and roofs that provide lateral support for the wall. Such anchorage shall provide a positive direct connection capable of resisting the horizontal forces specified in Section 1113.10.

1113.11.2 Load paths: All parts of the building or structure that transmit seismic force shall be connected through a continuous path to the resisting element. At a minimum, the connection and the elements along the path to the resisting element shall be capable of resisting a force equal to $0.375A_vI$ *or 0.05, whichever is greater, times the weight of the portion being connected.*

The referenced Section 1113.10 reads:

1113.10 Lateral forces on elements of structures and nonstructural components: Parts or components of buildings or structures, nonstructural components and anchorage of such components to the main structural system shall be designed for lateral forces in accordance with the following formula:

$$F_p = 2.5A_vIC_pW_p$$

The values of C_p *are set forth in Table 1113.10. The value of I shall be as set forth in Table 1113.1. The value of I for anchorage of machinery and equipment required for life safety systems shall be 1.5 for all buildings. The distribution of these forces shall be in accordance with the gravity loads pertaining thereto.*

For the same building to adhere to the requirements of B223-91, Section 1113.3.6.1 would pertain.

1113.3.6.1 Seismic performance category A: The design and detailing of buildings assigned to Seismic Performance Category A shall comply with the requirements of this section.

1113.3.6.1.1 Ties and continuity: All parts of the building that transmit seismic force shall be interconnected. Any smaller portion of the building shall be tied to the remainder of the building with elements having a strength of 1/3 of the effective peak velocity-relate acceleration, (A_v), time the weight of the smaller portion or 5 percent of the portion's weight, whichever is greater.

A positive connection for resisting a horizontal force acting parallel to the member shall be provided for each beam, girder, or truss to its support. The connection shall have a minimum strength of 5 percent of the dead and live load reaction. The horizontal and vertical structural systems which resist lateral loads of the building as a whole are not required to be designed for seismic loads.

1113.3.6.1.2 Concrete or masonry wall anchorage: Concrete and masonry walls shall be anchored to the roof and all floors that provide lateral support for the wall. The anchorage shall provide a direct connection between the walls and the roof or floor construction. The use of toe nailing or nails subject to withdrawal forces is not permitted. Wood ledgers shall not be subjected to cross grain bending or cross grain tension. The connections shall be capable of resisting a seismic lateral force of 1,000 times the effective peak velocity-related acceleration, (A_v), (pounds) per lineal foot of wall. Walls shall be designed to resist bending between anchors where the anchor spacing exceeds 4 feet.

As can be seen, the change that would be prompted by the adoption of B223-91 is fairly straightforward and the presentation of the change is simple.

B. Areas where A_v is less than 0.15 but greater than or equal to 0.10

The requirements for the same R-2 building to be constructed in an area where A_v is less than 0.15 but greater than or equal to 0.10 are more complicated in both sets of requirements.

1. <u>Seismic Forces Consideration and Distribution</u>

In addition to the requirements listed for the areas where A_v is less than 0.10 but greater than or equal to 0.05, both 1990 NBC and B223-91 have requirements for explicit consideration of seismic forces and their distribution. Methods for computing base shear, vertical and horizontal distribution of seismic forces, torsional moments, overturning and story drift are addressed. A comparison of these requirements follows.

Base Shear - 1990 NBC

Base shear is computed as:

$V = 2.5 A_v IKCSW$

Where:

A_v = *Coefficient representing effective peak velocity-related acceleration based on Figure* 1113.1

I = *Occupancy importance factor* ($I = 1.00$ *for residential structures*)

K = *Coefficient for horizontal force.* ($K = 2.00$ *for residential structures with bearing wall systems or building wall systems*)

C = *Coefficient for use with "S"*

S = *Soil factor from Section* 1113.4.6 & *Table* 1113.4.6 ($S_1 = 1.0$, $S_2 = 1.2$ *and* $S_3 = 1.5$)

W = *Dead load (for residential purposes -- dead load as defined in* 1104.0, *including partition loading)*

The coefficient "C" is computed as:

$$C = \frac{1}{15\sqrt{T}}$$

but its value is not required to exceed 0.12.

T = *Fundmental elastic period and is derived as follows for most residential types:*

$$T = 2\pi \sqrt{\frac{(\sum_{i=1}^{n} w_i \sigma_i^2)}{(g \sum_{i=1}^{n} f_i \sigma_i)}}$$

Where:

w_i = *Portion of W located at or assigned to level i*

σ_i = *Deflection at level i relative to base due to lateral forces*

g = *Acceleration due to gravity*

f_i = *Distributed portion of a total lateral force at level i*

Base Shear -- B223-91

B223-91 proposes computation of base shear as follows:

$V = C_S W$

Where:
C_S = *Seismic coefficient*
W = *Total dead load and "applicable portions of other loads"*

Three alternate methods of calculating the Seisic coefficient are offered:

$$C_s = \frac{1.2\ A_v\ S}{R\ T^{2/3}}$$

Can be used when the fundamental period (T) of the building is computed.

However, the Seismic design coefficient need not exceed:

$$C_s = \frac{2.5\ A_a}{R}$$

When the peak acceleration (A_a) is greater than or equal to 0.30, the following formulation must be used:

$$C_s = \frac{2\ A_a}{R}$$

Where:
A_a = *Effective peak acceleration*
A_v = *Effective peak velocity-related acceleration*
S = *Coefficient for soil profile characteristics*
R = *Response modification factor*
T = *Fundamental period of the building*

The fundamental moment for buildings built with either bearing wall systems or building frame systems is calculated as:

$$T_a = \frac{0.05\ h_n}{\sqrt{L}}$$

Where:
h_n = *building height*
L = *Overall length of building at base in direction being considered*

Vertical Distribution of Seismic Force -- 1990 NBC

In the 1990 Edition of the NBC, the imposed lateral forces are distributed over the height of the building in accordance with:

$$V = F_t + \sum_{i=1}^{n} F_i$$

Where:

$F_t = 0.07TV$

and

V = *Total lateral force or shear at the base*

F_t = *The portion of V concentrated at the top in addition to* F_n

F_i = *Lateral force applied to level i*

T = *Fundamental elastic period of vibration of the building*

"The maximum required value of F_t shall be 0.25V. When T is 0.7 second or less, the minimum required value of F_t shall be zero. The remaining portion of the total base shear (V) shall be distributed over the height of the structure, including level n, according to the formula:"

$$F_x = (V-F_t)w_x h_x \div \sum_{i=1}^{n} w_i h_i$$

Where:

F_x = *Lateral force applied to level x*

w_x *and* w_i = *Portion of W located at or assigned to level x*

h_x *and* h_i = *height above base to level x*

"At each level designated as x, the force (F_x) shall be applied over the area of the building in accordance with the mass distribution on that level".

Vertical Distribtution of Seismic Force -- B223-91

B223-91 proposed that the vertical distribution of lateral force (F_x) at any level be determined as follows:

$$F_X = C_{VX} V$$

$$C_{VX} = \frac{w_X h_x^k}{\sum_{i=1}^{n} w_i h_i^k}$$

C_{VX} = *Vertical distribution factor*
V = *Total design lateral force or shear at base*

w_i *and* w_x = *portion of gravity load (W) located or assigned to level i or x*

h_i *and* h_x = *Height from base to level i or x*

k = *Building-period related exponent*
k = 1 *for buildings having a period of* 0.5 *seconds or less.*
k = 2 *for buildings having a period of* 2.5 *or more.*
k = *a linearly interpolated value between* 1 *and* 2 *for buildings having a period between* 0.5 *and* 2.5

Distribution of Horizontal Shear -- 1990 NBC

Distribution of horizontal shear is addressed in Section 1113.5.4 of the 1990 edition of the NBC as follows:

> *"Total shear in any horizontal plane shall be distributed to the various elements of the lateral force-resisting system in proportion to their rigidities, considering the rigidity of the horizontal bracing system or diaphragm. Rigid elements incorporated into the building which are not assumed to be part of the lateral force-resisting system shall be permitted if their effect on the action of the system is considered and provided for in the design."*

Distribution of Horizontal Shear -- B223-91

In Section 1113.4.3 of B223-91, the horizontal shear distribution in any story (V_x) is calculated as:

$$V_x = \sum_{i-1}^{n} F_i$$

Where:
F_i = *portion of seismic base shear induced at level i*

It continues:

> *"The seismic design story shear, (V_x), shall be distributed to the various vertical elements of the seismic resisting system in the story under consideration based on the relative lateral stiffnesses of the vertical resisting elements and the diaphragm."*

Torsional Moments - 1990 NBC

Horizontal torsional moments are addressed in Section 1113.5.5 of the 1990 NBC as follows:

> *"The design shall provide for the torsional moment resulting from the locations of the building masses plus the torsional moments caused by assumed displacement of the mass each way from its actual location by a distance equal to 5 percent of the dimension of the building perpendicular to the direction of the applied forces."*

Torsional Moments - B223-91

Section 1113.4.31 of B223-91 relates:

> *"The design shall include the torsional moment (M_t) resulting from the location of the building masses plus the accidental torsional moments (M_{ta}) caused by assumed displacement of the mass each way from its actual location by a distance equal to 5 percent of the dimension of the building perpendicular to the direction of the applied forces."*

The text of B223-91 continues with coverage of torsional irregularities. Irregularities are not considered for the purposes of this examination.

Overturning -- 1990 NBC

The 1990 edition of the NBC required that every building be designed to resist the overturning effect of earthquakes. The overturning moment at each story is calculated as follows:

$$M_x = \frac{F_t(h_n - h_x)}{\sum_{i=x}^{n} F_i(h_i - h_x)}$$

Where:
F_t = *Portion of V considered concentrated at top of structure*
F_i = *Lateral forces applied to level i*

h_n
&
h_x = *Height above base to level n, x, i*
&
h_i

"The increment of overturning moment at each story shall be distributed to the resisting elements in the same proportion as the distribution of the horizontal shears..."

In discussing the distribution of overturning moments the text relates:

"Where other vertical members are provided which are capable of partially resisting the overturning moments, a redistribution to these members shall be permitted if framing members of sufficient strength and stiffness to transmit the required loads are provided. Where a vertical resisting element is discontinuous, the overturning moment carried by the lowest story of that element shall be carried down as a load to the foundation."

Overturning -- B223-91

B223-91 requires that buildings be tested to resist overturning . For any level x, the overturning moment must be determined in the following manner.

$$M_x = \tau \sum_{i=x}^{i} F_i (h_i - h_x)$$

Where:

F_i = *Portion of the seismic base shear (V) induced at level i*

h_i

And = *Height base to level i or x*

h_x

τ = 1.0 *for top* 10 *stories*

= 0.8 *for* 20*th story from top and below*

In addressing overturning, Section 1113.4.4 relates:

> *"At any story, the increment of overturning moment in the story under consideration shall be distributed to the various vertical resisting element in the same proportion as the distribution of the horizontal shears to those elements."*

Story Drift -- 1990 NBC

Section 1113.7 relates the following:

"Lateral deflections or drift of a story relative to adjacent stories, including any portions thereof caused by deflection of horizontal resisting elements, shall not exceed 0.005 times the story height (0.0025 in buildings with unreinforced masonry) unless it can be demonstrated that greater deformation can be tolerated. The horizontal displacement calculated from the application of the lateral forces shall be multiplied by 1/K to obtain the drift. The ratio 1/K shall not be less than 1.0. All portions of structures shall be designed and constructed to act as an integral unit in resisting horizontal forces unless separated structurally by a distance sufficient to avoid contact under deflection from seismic action."

Story Drift -- B223-91

Section 1113.4.5.1 relates the following:

"The design story drift, (Δ), shall be computed as the difference of the deflections at the top and bottom of the story under consideration. The deflections of level x at the center of the mass (δ) shall be determined in accordance with the following formula:"

$$\delta_x = C_d \delta_{xe}$$

Where:
C_d = *Deflection amplification factor from Table* 1113.3.3
δ = *Deflections determined by inelastic analysis*

"The elastic analysis of the seismic resisting system shall be made using the required seismic design forces of Section 1113.4.2.

For determining compliance with the story drift limitations of Section 1113.3.7, the deflections of level x at the center of mass (δ) shall be calculated as required in this section. For purposes of this drift analysis only, it is permissible to use the computed fundamental period, (T), of the building without the upper bound limitation specified in Sections 1113.4.1.2 when determining drift level seismic design forces..

Where applicable, the design story drift (Δ) shall be increased by the incremental factor relating to the P-delta effects as determined in Section 1113.4.5.2."

In further addressing the P-Delta effect, Section 1113.4.5.2 relates:

"P-Delta effects on story shears and moments , the resulting member forces and moments, and the story drifts induced by these effects are not required to be considered when the stability coefficient, (θ), as determined by the following formula, is equal to or less than 0.10:

$$\theta = \frac{P_x \Delta}{V_x h_{sx} C_d}$$

Where:
P_x = *Total unfactored vertical design load at story x*
Δ = *Design story drift*
V_x = *Seismic design story shear acting in story x*
h_{sx} = *story height below level x*
C_d = *Deflection amplification factor in Table* 1113.3.3

When the stability coefficient (θ) exceeds 0.10 for any story, the P-delta effects on story drifts, shears, member forces, for the entire building are to be determined by a properly substantiated analysis.

The increase in story shears and moments resulting from the increase in story drift shall be added to the corresponding quantities determined without considerations of *the P-delta effect."*

Other sections provide means of computation of the values for the variables used in the above computations.

Table 1113.3.3 of B223-91 indicates that the response modification factor (R) is 6 1/2 for light framed walls with shear panels and the deflection amplification factor (C_d) is 4 for buildings with bearing wall systems. For building frame systems the values are 5 and 4 1/2. Other governing requirements in Section 1113.3 include Section 1113.3.1 (Site Coefficient), its accompanying Table 1113.3.1 and Section 1113.3.2 (Soil-Structure Interaction). The former section and table allow the determinations of the Site Coefficient based on soil properties. The table lists 4 soil types along with a description of the characteristics of each and the value of each Site Coefficient. The types and their values are S_1 - 1.0, S_2 - 1.2, S_3 - 1.5 and S_4 - 2.0. Where the soil type can not be determined sufficiently, a value of 2.0 must be used. Section 1113.3.2 allows the modification of base shear, story shears, overturning moments and deflections using approved procedures to account for the effects of interaction.

Section 1113.4.6 and Table 1113.4.6 relate soil information in the 1990 NBC. Three soil categories are used: S_1 - 1.0, S_2 - 1.2 and S_3 - 1.5. If the characteristics can not be determined sufficiently, the value of either S_2 or S_3 that yields the largest value of CS must be used.

2. Design, Detailing and Structural Components

Other sections of both sets of code deal with issues related to the materials, components and the design of buildings to seismic requirements.

Requirements in Section 1113.3.6 of B223-91 are devoted to Design, Detailing Requirements and Structural Component Load Effects. In addition to Sections 1113.3.6.1.1 and 1113.3.6.1.2, R-2 buildings constructed where A_v is greater than or equal to 0.10 but less than 0.15, must comply with Sections 1113.3.6.2 and 1113.3.6.3. For the purpose of this examination, plan irregularities are not considered. Since the sole entry under Section

1113.3.6.3 is devoted to plan irregularity, this section is disregarded.

Section 1113.3.6.2.1 addresses materials and requires that materials and systems made up of those materials must comply with code requirements.

Section 1113.3.6.2.2 contains the seismic requirements for openings:

> *"Where openings occur in shear walls, diaphragms, or other plate type elements, the edges of the openings shall be designed to transfer the stresses into the structure. The edge chord shall extend into the body of the wall or diaphragm a distance sufficient to develop the stress of the chord member."*

Requirements for materials and openings are not explicitly addressed in Article 11 of the 1990 NBC.

Orthogonal Effects are the subject of Section 1113.3.6.2.3 in B223-91.

> *"The design seismic forces shall be applied separately in each of two orthogonal directions."*

The 1990 NBC contains similar requirements in Section 1113.4 where it stipulates that:

> *" Except as provided for in Sections 1113.8 and 1113.10, every structure shall be designed and constructed to resist minimum total lateral seismic forces assumed to act nonconcurrently in the direction of each of the main axes of the structure in accordance with the following formula: "*

$$V = 2.5A_v IKCSW$$

Section 1113.3.6.2.5 of B223-91 requires that the design of a building must comply with Section 1102.2 for progressive collapse. Although, the NBC seismic requirements found in

Article 11 do not address progressive collapse, since the requirements were contained in another part of the section of the 1990 code, this reference appears to have no impact.

Section 1113.3.6.2.6 in B223-91 addresses collector elements:

> "Collector elements shall be provided that are capable of transferring the seismic forces originating in other portions of the building to the element providing the resistance to those forces."

This section is followed by the requirements for diaphragms in Section 1113.3.6.2.7.

> *"The deflection in the plane of the diaphragm, as determined by engineering analysis, shall not exceed the permissible deflection of the attached elements. Permissible deflection shall be that deflection which will permit the attached element to maintain its structural integrity under the individual loading and continue to support the prescribed loads.*
>
> *Floor and roof diaphragms shall be designed to resist the following seismic forces: A minimum force equal to 50% the effective peak velocity related acceleration, (A_v), times the weight of the diaphragm and other elements of the building attached thereto plus the portion of the seismic shear force at that level, (V_x), required to be transferred to the components of the vertical seismic resisting system because of offsets or changes in stiffness of the vertical components above and below the diaphragm.*
>
> *Diaphragms shall provide for both the shear and bending stresses resulting form these forces. Diaphragms shall have ties or struts to distribute the wall anchorage forces into the diaphragm. Diaphragm connection shall be positive, mechanical type connections."*

Section 1113.5.6 in the 1990 NBC provides the following on diaphragms and collectors:

"Floor and roof diaphragms and collectors shall be designed to resist the forces determined in accordance with the formula:"

$$F_{px} = \left(\sum_{i=x}^{n} F_i \div \sum_{i=x}^{n} w_i \right) w_{px}$$

Where:

F_{px} *is not required to exceed* $0.75 A_v I w_{px}$

and

F_{px} *=Force on floor diaphragms and collectors*

F_i *= Lateral forces applied to level i*

w_i *= portion of W located at or assigned to level i*

w_{px} *= Weight of floor or roof diaphragms and collectors and elements tributary thereto at level x plus 25 percent of the floor live load*

"The force F_{px} *is not required to exceed 0.75* $A_v I w_{px}$.

Where the diaphragm is required to transfer lateral forces from the vertical resisting elements above the diaphragm to other vertical resisting elements below the diaphragm, due either to offsets in the placement of the elements or to changes in stiffness in the vertical elements, these forces shall be added to the value determined for F_{px}. *However, the lateral force on the diaphragms shall not be less than 0.35* $A_v I w_{px}$.

Diaphragms providing lateral support to concrete or masonry walls shall have continuous ties between diaphragm chords to distribute into the diaphragm the anchorage forces specified in this section. Chords added to form subdiaphragms to transmit the anchorage forces to the main crossties shall be permitted. Diaphragm deformations shall be considered in the design of the supported walls."

The design of bearing walls is addressed in Section 1113.3.6.2.8 of B223-91.

> *"Exterior and interior bearing walls and their anchorage shall be designed for a force of the effective peak velocity related acceleration, (A_v), times the weight of the wall, normal to the surface with a minimum force of 10% of the weight of the wall. Interconnection of wall elements and connections to supporting framing systems shall have sufficient ductility, rotational capacity, or sufficient strength to resist shrinkage, thermal changes, and differential foundation settlement when combined with seismic forces.*

Section 1113.10 of the 1990 NBC addresses lateral forces on elements of structures and nonstructural components. This language also pertains to bearing walls.

> *"Parts or portions of buildings or structures, nonstructural components and anchorage of such components to the main structural system shall be designed for lateral forces in accordance with the following formula:*
>
> $$F_p = 2.5\ A_v I C_p W_p$$
>
> *The values of C_p are set forth in Table 1113.10. The value of I shall be as set forth in Table 1113.1. ... The distribution of these forces shall be in accordance with the gravity loads pertaining thereto."*

Table 1113.10 in the 1990 edition of the NBC indicates that the value of C_p normal to flat surfaces in exterior and interior bearing walls is 0.3.

It must be noted that although the requirements in Section 1113.10 and Table 1113.10 were to remain in place, the above change modified its impact on load-bearing walls. Since this section along with its companion table are unchanged, its effect on other components regulated through this section are unaffected.

Section 1113.5.2 of the 1990 NBC addresses setbacks.

"Buildings having setbacks wherein the plan dimension of the tower in each directions is at least 75 percent of the corresponding plan dimension of the lower part shall be considered as uniform buildings without setbacks, provided that other irregularities as defined in this section do not exist."

Item 3 (Vertical Geometric Irregularity) of Table 1113.3.4.2 addresses the setback issue.

"Vertical geometric irregularity shall be considered to exist where the horizontal dimension of the lateral force-resisting system in any story is more than 130% of that in an adjacent story."

The 130 percent figure, when used to characterize the dimension of a lower story based on the dimension of the upper story, could be reformulated to characterize the dimension of the upper story as 77 percent of that of the lower story. However, this is irrelevant since Item 3 pertains only to buildings in SPC D or E. For the purpose of this examination, plan and vertical structural irregularities have been ignored.

Section 1113.9 in the 1990 NBC is devoted to structural systems and states:

"The design of structural systems shall comply with the applicable provisions of Sections 1113.9.1 through 1113.9.6. Reinforced concrete members shall comply with the applicable provision of Chapter 21 of ACI 318 listed in Appendix A as specified in this section and Section 1501.0.

Except where specifically prohibited in this section, where the framing systems along two orthogonal axes are different, the K factor appropriate for each direction shall be used. In Seismic Zone 3 or 4 where a structure has a bearing wall system in only one direction, the K factor used for design in the orthogonal direction shall not be less than that used for the bearing wall system."

Section 1113.9.1 - Bearing wall systems:

"Bearing wall systems shall use shear walls or braced frames as vertical elements for resistance to lateral seismic force. Horizontal elements of the seismic force-resisting system shall be diaphragms or trusses. The factor K depends on the type of lateral force-resisting element, as shown in Table 1113.4.3."

Section 1113.9.2 - Building-frame systems:

"Building-frame systems designed using a factor K=1.0 shall have an essentially complete space frame that conforms to AISC Specification for Structural Steel Buildings -- Allowable Stress Design and Plastic Design or ACI 318 listed in Appendix A and that supports all gravity loads and shall have shear walls or braced frames to resist the earthquake lateral force.

Section 1113.3.6.2.1 in B223-91 provides a more general approach to, but comparable handling of, the reinforced concrete requirements referred to in the first paragraph of 1113.9 of the 1990 NBC. This section implicitly references the reinforced concrete requirements contained elsewhere in the code.

Only two sections -- 1113.9.1 and 1113.9.2 -- of the six referenced sections (i.e. 1113.9.1 through 1113.9.6) pertain to the structural framing approaches commonly used in low-rise residential construction.

The effect of the referenced values of "K" enter through computation of base shear presented earlier in this examination. Its value, based on Table 1113.4.3, for the most commonly used arrangements of lateral force-resisting elements are as follows:

Bearing wall systems

1, 2 or 3-story light wood frame walls --1.0

reinforced concrete shear walls -- 1.33

Building framing system

shear walls -- 1.0

The reference to the required use of shear walls (or braced frames) reflects the most commonly used seismic load-resisting system in low-rise residential construction and is similarly referenced in Table 1113.3.3.

3. Plans and Design Data

The requirements under Section 1113.1.3 of the 1990 NBC address the subjects of plans and design data:

"Where earthquake loads are applicable, a brief statement of the items indicated in Sections 1113.1.3.1 through 1113.1.3.3 shall be included with each set of plans filed.

1113.1.3.1 Dead and live loads:
A summation of the dead and, where applicable, live loads of the building, floor by floor, which was used in figuring the shear for which the building is designed, shall be submitted.

1113.1.3.2 Bracing:
A brief description of the bracing system used, the manner in which the designer expects such system to act and a clear statement of any assumption used, shall be submitted. Assumptions as to location of all points of counter-flexure in members shall be stated.

1113.1.3.3 Sample calculations:
Sample calculations of a typical bent or the equivalent shall be submitted"

Section 1113.1.1 in B223-91 provides requirements on design data:

"Where earthquake loads are applicable, the following design data shall be indicated on the design drawings:

1. The peak velocity related acceleration, (A_v), according to Section 1113.1.4.

2. The peak acceleration, (A_a), according to Section 1113.1.4.

3. The seismic hazard exposure group according to Section 1113.1.5.

4. The Seismic Performance Category according to Section 1113.1.7.

5. The soil profile type according to Table 1113.3.1.

6. The basic structural system and seismic resisting system according to Table 1113.3.3.

7. The response modification factor, (R), and the deflection amplification factor, ($C_{d)}$) according to Table 1113.3.3.

8. The analysis procedure utilized in accordance with Section 1113.4 or 1113.5 as applicable."

Section 1113.1.4 of the 1990 NBC is devoted to stress increases:

"Except where specifically prohibited by this section and Section 1113.11.5, the requirements of this section presume that allowable stresses are increased by one-third for earthquake loads. However, this increase shall not be permitted in conjunction with any decrease in total load effect taken in accordance with Section 1114.0."

Section 1113.1.5 addresses combined vertical and horizontal forces:

"In computing the effect of seismic forces in combination with vertical loads, gravity load stresses induced in members by dead load plus design live load, except roof live load, shall be considered. Consideration shall also be given to minimum gravity loads acting in combination with lateral forces."

EXAMINATION OF R26-94

1. Define the problem

   a. Choose a scope and perspective

The scope of this analysis is proposed code change no. R26-94 to the *Council of American Building Officials (CABO) One and Two Family Dwelling Code* that involves changing Section R-303--Footings. The proposed change, presented in the *1994 Proposed Changes to the CABO Codes*, provides for an internationally recognized alternative method of protecting foundations against frost heave. This nationwide code change would allow builders to construct frost protected footings in cold climates above the natural frost depth line. Cold climates for frost protected footings are regions where the air freezing index is 1,500 degree-days (Fahrenheit) or higher, or approximately the northern third of the United States.

The perspective of this analysis is that of the home builder.

b. Determine the time period for the analysis

The time period for this analysis is the current year, 1994.

c. Describe the code change

The types of housing affected by this change are single and multiple family dwellings as distinguished by the *CABO One and Two Family Dwelling Code.* The anticipated physical impact will be on the foundation of each structure. The code change will basically allow the bottom of footings for heated buildings to be located above the frost line where protected by insulating the foundation with Type IV extruded polystyrene insulation.

The housing affected by this code change may have different types of foundations. These will be either slab-on-grade, crawl space, or basement type foundations. Each will need to be analyzed separately.

For slab-on-grade foundations, the thickened edge of the slab will not have to extend below the frost line. Less excavation to the proper depth and less concrete will be required for the footing. An increase in excavation will be required to place the horizontal insulation. Also, an increase in material costs will result from the need to provide insulation.

For crawl space foundations, the bottom of the footing or grade beam will not need to extend below the frost line. Less excavation to the proper depth and less concrete will be required for the footing. Instead of a first floor constructed of floor joists, girders, posts, and subflooring material, a concrete floor will be installed on grade. Utilities such as electric and water will be installed in or under the floor slab, rather than in the crawl space area. Planning of the utilities will take place early in the construction in order to provide stubup locations before the concrete is cast for the slab-on-grade. An increase in excavation will be required to place the horizontal insulation. Also, an increase in material costs will result from the need to provide insulation.

For basement foundations, the basement may be eliminated completely by using a frost protected footing. Costs will be saved for excavating the basement, providing the basement floor and walls, and the first floor joists, girders, posts, and subflooring material. Costs will be added for the concrete slab-on-grade, insulation, and excavation costs resulting from the installation of the horizontal insulation. Utilities such as electric and water will be installed in or under the floor slab, rather than in the basement. Planning of the utilities will take place early in construction in order to provide stubup locations before the concrete is cast for the slab-on-grade. If the basement is not intended to be used for living space or storage, a direct comparison of a basement house to a frost protected footing house of the same size may be made. However, if a basement house is planned to be used for living space or storage, this will complicate a cost analysis because the function will be different for the two houses. It will not be feasible to enlarge the floor plan of the house, because it will represent a fundamentally different house than the one with a basement.

d. Select representative cases and develop designs for each

Three prototype houses will be selected to typify the impact of the code change. Each house will have one of the foundations discussed above-- slab-on-grade, crawl space, or basement so that each type of foundation is represented. Each house will be compared to a frost protected footing type foundation as proposed in CABO Code Change No. R26-94. An average northern air freezing index of 2,500 will be used for all three houses. For the basement house, consideration will also need to be made on the impact of the reduced living space. The most typical foundation found in the northern United States is the crawl space and basement. The slab-on-grade foundation is included even though they are less popular in these regions.

Designs may be developed for the frost protected footings based on the code change. Given the foundations of the existing prototype houses, it will be rather easy to design the frost protected footings for each house. Foundation plans will be prepared for each of the three houses using the traditional footings, and one additional foundation plan will be prepared using frost protected footings for each house.

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