Load factor calibration for the proposed 2005 edition of the National Building Code of Canada: Companion-action load combinations

F.M. Bartlett, H.P. Hong, and W. Zhou

Abstract: The 2005 edition of the National Building Code of Canada (NBCC) will adopt a companion-action format for load combinations and specify wind and snow loads based on their 50 year return period values. This paper presents the calibration of these factors, based on statistics for dead load, live load due to use and occupancy, snow load, and wind load, which are summarized in a companion paper. A target reliability index of approximately 3 for a design life of 50 years was adopted for consistency with the 1995 NBCC. The load combinations and load factors for strength and stability checks recommended for the 2005 NBCC were based on preliminary values from reliability analysis that were subsequently revised slightly to address major inconsistencies with past practice. The recommended load combinations and factors generally give factored load effects similar to those in the 1995 NBCC, but are up to 10% more severe for the combination of dead load plus snow load and are generally less severe for the combination of dead load, snow load, and live load due to use and occupancy. Load factors less than one are recommended for checking serviceability limit states involving specified snow and wind loads. Importance factors for various classifications of structure are also presented. Revisions to the commentaries of the NBCC are recommended that will provide guidance on dead load allowances for architectural and mechanical superimposed dead loads and cast-in-place cover slabs and toppings.

Key words: buildings, code calibration, companion action, dead loads, live loads, load combinations, load factors, reliability, safety, snow loads, wind loads.

Résumé : L'édition 2005 du Code national du bâtiment du Canada (CNBC) adoptera un format compagnon-action pour les combinaisons de charges et spécifiera les charges de vent et de neige selon leurs valeurs basées sur une période de retour de 50 ans. Cet article présente le calibrage de ces facteurs basé sur des statistiques pour les charges mortes, les charges vives causées par l’usage du bâtiment, les charges de neige et les charges de vent qui sont résumées dans un article accompagnant celui-ci. Un index de fiabilité cible d’environ 3 pour une durée de service de 50 ans a été adopté afin d’être compatible avec le CNBC 1995. Les combinaisons de charges et les facteurs de charges pour les vérifications de résistance et de stabilité recommandés pour le CNBC 2005 ont été basés sur des valeurs préliminaires provenant d’analyses de fiabilité qui ont été révisées par la suite afin d’adresser des incohérences majeures des pratiques passées. Les combinaisons et les facteurs de charges recommandés donnent généralement des effets similaires à ceux du CNBC 1995, mais sont jusqu’à 10 % plus sévères pour la combinaison des charges mortes et des charges de neige, et sont généralement moins sévères pour la combinaison des charges mortes, de neige et des charges vives causées par l’usage de bâtiment. Des facteurs de charges plus petits que un (1) sont recommandés pour la vérification des états limites d’utilisation impliquant des charges de neige et de vents spécifiées. Des facteurs d’importance pour diverses classes de structures sont aussi présentés. Des révisions aux commentaires du CNBC sont recommandées. Ces révisions guideront différentes allocations des charges mortes architecturales et mécaniques super-imposées et des dalles et recouvrements coulés sur place.

Mots clés : bâtiments, calibrage de codes, action compagnon, charges mortes, charges vives, combinaisons de charges, facteurs de charges, fiabilité, sécurité, charges de neige, charges de vent.


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Written discussion of this article is welcomed and will be received by the Editor until 31 August 2003.

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Introduction

This is the second of two papers summarizing the load factor calibration carried out for combinations of dead, live, wind, and snow loads to be specified in the proposed 2005 edition of the National Building Code of Canada (NBCC). Bias coefficients and coefficients of variation (CoV) for probability distributions representing dead, live, wind, and snow load effects were obtained from the literature and from data provided by the Engineering Climatology Section of the Canadian Meteorological Centre in Downsview, Ontario, as described in a companion paper (Bartlett et al. 2003).

In this paper, the calibration of load factors and load combinations for ultimate limit states is presented. Statistical parameters for resistances are summarized and used to compute reliability indices for ultimate limit states due to load combinations specified in the 1995 National Building Code of Canada (NBCC 1995). A preliminary set of companion-action load combinations that gives the same average reliability index is derived. The rationale for revising some of these values, based on comments received, to give the set of recommended load factors is presented, and the impact of these recommended load factors with respect to the 1995 NBCC criteria is summarized. Lastly, importance factors for different classifications of buildings and load factors for serviceability limit states (SLS) are presented.

Bias coefficients and coefficients of variation for probability distributions representing the resistance of steel, concrete, and wood components were obtained from the literature, including recent studies representing current structural steel and concrete production. The calibration was carried out using the statistics for structural steel shown in Table 1, although similar results could be obtained if concrete or wood resistance statistics are considered (Bartlett et al. 2001).

Reliability indices for the 1995 NBCC

The first step of the calibration process was to determine reliability indices, $\beta$, for structural members designed using the current (1995) edition of the NBCC for combinations involving dead load plus a single type of transient load. In the 1995 NBCC, snow load and load due to use and occupancy are classified together in the single category of live load. Thus, for example, designers consider snow on a roof and occupancy load on floors acting simultaneously at their maximum lifetime values when proportioning a column that supports both a roof and floors. It is very unlikely, however, that this combination of maximum values would occur simultaneously because snow load and occupancy load are statistically independent (i.e., uncorrelated). Therefore, separate cases of (i) dead load plus (i.e., acting simultaneously with) only live load due to use and occupancy, and (ii) dead load plus only snow load were considered.

Figure 1 indicates the reliability indices for steel components, obtained using the first-order reliability method (FORM) (Rackwitz and Fiessler 1978; Madsen et al. 1986) and resistance parameters corresponding to the values for steel shown in Table 1. The values obtained are consistent for the combinations of dead load plus live load due to use and occupancy and dead load plus wind load. The reliability index approaches 3.0 if only live load is present or 2.8 if only wind load is present. Reliability indices for the combination of dead load plus snow load are lower; to increase the reliability index for this combination to even 2.8, it is necessary to increase the snow load factor from 1.5 to about 1.85.

Reliability indices for steel components resisting a combination of dead load ($D$), live (occupancy) load ($L$), and wind load ($W$) are shown in Fig. 2a for a 50 year design life. Only parts of the curves are shown because the combination $1.25D + 0.7(1.5L + 1.5W)$ governs the design only when $3/7 \leq LW \leq 7/3$. Thus, for example, for $W/D = 0.5$, $1.25D + 1.5L$ governs for $L/D \geq 1.17$ and $1.25D + 1.5W$ governs for $L/D \leq 0.21$. The reliability indices shown in Fig. 2a vary markedly, but the minimum values generally exceed 3.0. Similarly, Fig. 2b shows the 1995 NBCC reliability indices for steel components resisting the combination of dead load, live load, and snow load. The reliability indices are typically quite high because the 1995 NBCC definition of live load that includes both snow load and use and occupancy load acting concurrently at their maximum values is conservative. For elements such as columns that may support a roof with snow load plus floors with use and occupancy load, this conservatism compensates for the low reliability index for the case shown in Fig. 1 where snow load dominates. Figure 2c shows the 1995 NBCC reliability indices for steel components resisting the combination of dead load, wind load, and snow load. Typically, the reliability index exceeds 3, though it falls to 2.5 for the cases where snow load dominates.

Based on these findings, a target reliability index of approximately 3 for a 50 year design life was adopted for calibration of the factored load combinations in the 2005 NBCC, with a minimum value of 2.8 for combinations involving only wind or snow loads.

Table 1. Statistical parameters for material resistances.

<table>
<thead>
<tr>
<th>Resistance type</th>
<th>Bias</th>
<th>CoV</th>
<th>Distribution type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural steel</td>
<td>1.17</td>
<td>0.108</td>
<td>Log-normal</td>
</tr>
<tr>
<td>Concrete in compression</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cast-in-place concrete</td>
<td>1.16–1.41</td>
<td>0.229</td>
<td>Log-normal</td>
</tr>
<tr>
<td>Precast in CSA-certified plants</td>
<td>1.19–1.45</td>
<td>0.213</td>
<td>Log-normal</td>
</tr>
<tr>
<td>Wood</td>
<td>1.66</td>
<td>0.230</td>
<td>Weibull</td>
</tr>
</tbody>
</table>

Fig. 1. The 1995 NBCC reliability indices for steel components resisting dead load plus a single transient load.
Calculated load combinations and factors for the 2005 NBCC

The determination of load combinations and load factors for the 2005 NBCC was carried out in two phases. In the first phase, values were determined that provide more uniform values of reliability index for a range of ratios of load types. In the second phase, these factors were reviewed and adjusted, based on comments received, to address major inconsistencies with past practice. The calculated load combinations and load factors are presented in this section, and the revised values recommended for the 2005 NBCC are presented in the next section.

Ultimate limit state load combinations and load factors corresponding to 1 in 50 year specified loads are presented in Table 2. The symbols for the various types of load effects are $D$ for dead load, $L$ for live load due to use and occupancy, $S$ for the specified 1 in 50 year snow load, and $W$ for the 1 in 50 year wind load. A new combination involving dead load only was introduced for consistency with other standards, including ASCE7-98 (ASCE 2000).

Reliability indices, calculated for steel components for these various load combinations using FORM (Rackwitz and Fiessler 1978; Madsen et al. 1986), are shown in Figs. 3 and 4. The reliability indices obtained are uniform and consistently achieve the target value of approximately 3 and exceed the minimum value of 2.8.

Recommended load combinations and factors for the 2005 NBCC

The final recommended load combinations and factors involving snow and wind loads are presented in Table 3. Two extra load types that were not calibrated in this study are included, namely $H$, representing horizontal earth load due to earth pressure including groundwater, and $T$, representing load due to restraint of long-term deformations. A number of notes will be included in the 2005 NBCC but are not included in Table 3 concerning areas accessible to pedestrian or vehicular traffic; consideration of loads due to restraint of short- and long-term deformations; anchorage for uplift; and the dead load factor for soils, superimposed earth, plants, and trees. The reasons for revision of the values shown in Table 2 are briefly described in the sections that follow.

Dead load factor

The initial proposal to reduce the dead load factor from 1.25 to 1.2 was criticized by members of the Task Group on Snow and Wind Loads, the Canadian Standards Association (CSA) Technical Committee for Reinforced Concrete Design, and others. In particular, concerns were raised that the dead load factor for superimposed dead load, particularly mechanical and architectural dead load, should not be reduced. It was therefore proposed to simply maintain the 1.25 dead load factor for load combinations involving wind, live, or snow loads.

It was suggested that commentary material be included to alert the designer to certain types of dead load that can easily be underestimated. For example, the dead load of cast-in-place toppings or the cover slab of a composite beam is sensitive to the camber and deflection of the supporting members (Bartlett et al. 2003). Guidance concerning suitable dead load allowances to cover the more uncertain types of dead load would be appropriate.

Accuracy of analysis for dead load effects

Questions were also raised about the accuracy of the dead load analysis, particularly concerning the tributary areas determined for columns. Commentary G “tributary areas” of the 1995 NBCC allows the lines of zero shear to be taken
half way between the column lines for buildings with regular bays. This is an acceptable assumption for a building with beam–column connections that do not transfer significant moments as the ultimate limit state is reached. For a building with moment-resisting connections, this is an acceptable approximation for columns located at least two bays away from the edge of a floor, but gives unconservative results for the first line of interior columns and conservative results for edge and corner columns.

To resolve this it is necessary to locate the line of zero shear in the end bay of a building with moment-resisting beam–column connections. For linear–elastic response, the location of the line of zero shear depends on the relative rotational stiffness of the supports, which can vary markedly. If a full plastic mechanism develops, however, the line of zero shear corresponds to the location of the central plastic hinge, and so depends only on the relative bending moment resistances at midspan and both ends. It can be shown that the distance from the interior support to the line of zero shear, kl, is

\[ kl = \frac{1 - \sqrt{(\eta + \kappa)(\kappa + 1) - (\eta + \kappa)}}{(1 - \eta)} \]

where \( k \) is the fraction of the exterior span length that is tributary to the interior column, \( l \) is the span length, \( \eta \) is the ratio of the moment capacities at the exterior and interior supports, and \( \kappa \) is the ratio of the moment capacity at midspan to that at the interior support. The ranges of these parameters are as follows: \( 0 \leq \eta \leq 1 \) and \( 0.5 \leq \kappa \leq 1 \). In Table 4, the \( k \) values calculated for these ranges are summa-

Table 2. Calculated ultimate limit state load combinations corresponding to 1 in 50 year specified loads.

<table>
<thead>
<tr>
<th>Load combination</th>
<th>Principal load</th>
<th>Factored load combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dead</td>
<td>1.35D</td>
</tr>
<tr>
<td>2</td>
<td>Dead + live</td>
<td>1.20D + 1.5L + (0.2W or 0.25S)</td>
</tr>
<tr>
<td>3</td>
<td>Dead + snow</td>
<td>1.20D + 1.7S + (0.3L or 0.2W)</td>
</tr>
<tr>
<td>4</td>
<td>Dead + wind</td>
<td>1.20D + 1.35W + (0.3L or 0.25S)</td>
</tr>
<tr>
<td>5</td>
<td>Dead counteracting L, S, or W</td>
<td>0.90D + (1.5L or 1.7S or 1.35W)</td>
</tr>
</tbody>
</table>

Fig. 3. Reliability indices for dead load plus single transient load.

Fig. 4. Reliability indices for (a) dead load, live load, and wind load combinations; (b) dead load, live load, and snow load combinations; and (c) dead load, snow load, and wind load combinations.
Table 3. Proposed ultimate limit state load combinations corresponding to 1 in 50 year specified loads.

<table>
<thead>
<tr>
<th>Load combination</th>
<th>Principal load</th>
<th>Factored load combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dead</td>
<td>$1.4D + 1.0T$</td>
</tr>
<tr>
<td>2</td>
<td>Dead + live</td>
<td>$1.25D + 1.5L + (0.4W or 0.5S) + 1.5H + 1.0T$</td>
</tr>
<tr>
<td>3</td>
<td>Dead + snow</td>
<td>$1.25D + 1.5S + (0.5L or 0.4W) + 1.5H + 1.0T$</td>
</tr>
<tr>
<td>4</td>
<td>Dead + wind</td>
<td>$1.25D + 1.35W + (0.5L or 0.5S) + 1.5H + 1.0T$</td>
</tr>
<tr>
<td>5</td>
<td>Dead counteracting $L, S,$ or $W$</td>
<td>$0.9D + (1.5H or 1.5L or 1.5S or 1.35W)$</td>
</tr>
</tbody>
</table>

Note: In load combinations 2 and 5, a live load factor of 1.25 may be used for liquids in tanks. In load combinations 3 and 4, a companion load factor of 0.5 shall be 1.0 for storage occupancies, and the factored companion live load shall not be less than the sustained live load, $L_o$.

Table 4. Fraction $k$ of the exterior span length tributary to interior column.

<table>
<thead>
<tr>
<th>$\eta$</th>
<th>$\kappa$</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.634</td>
<td>0.620</td>
<td>0.609</td>
<td>0.600</td>
<td>0.592</td>
<td>0.586</td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>0.613</td>
<td>0.602</td>
<td>0.593</td>
<td>0.586</td>
<td>0.580</td>
<td>0.574</td>
<td></td>
</tr>
<tr>
<td>0.2</td>
<td>0.594</td>
<td>0.586</td>
<td>0.579</td>
<td>0.573</td>
<td>0.568</td>
<td>0.564</td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>0.578</td>
<td>0.571</td>
<td>0.566</td>
<td>0.561</td>
<td>0.557</td>
<td>0.554</td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td>0.564</td>
<td>0.558</td>
<td>0.554</td>
<td>0.551</td>
<td>0.547</td>
<td>0.544</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>0.551</td>
<td>0.547</td>
<td>0.543</td>
<td>0.541</td>
<td>0.538</td>
<td>0.536</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>0.539</td>
<td>0.536</td>
<td>0.533</td>
<td>0.531</td>
<td>0.530</td>
<td>0.528</td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td>0.528</td>
<td>0.526</td>
<td>0.524</td>
<td>0.523</td>
<td>0.521</td>
<td>0.520</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>0.518</td>
<td>0.517</td>
<td>0.516</td>
<td>0.515</td>
<td>0.514</td>
<td>0.513</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>0.509</td>
<td>0.508</td>
<td>0.508</td>
<td>0.507</td>
<td>0.507</td>
<td>0.506</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>0.500</td>
<td>0.500</td>
<td>0.500</td>
<td>0.500</td>
<td>0.500</td>
<td>0.500</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5 shows a floor plan of a simple building with lines of zero shear located midway between column lines of interior spans and at 0.55/ from the interior column of exterior spans. Tributary areas for corner, edge, first interior–corner, first interior–edge, and interior columns are summarized in Table 5. The ratio of the actual tributary area to that one would calculate using the provisions of commentary G ranges from 0.81 for a corner column to 1.10 for the first interior–corner column. Excluding the corner column, the bias of the tributary area is 1.0 and the CoV is 0.081; if it is included, the bias is 0.968 and the CoV is 0.109.

Clearly the provisions of commentary G are approximate. For the worst case, the analysis bias is 1.103 and the CoV (calculated from the data in Table 4) is 0.045. If a column carries 10 floors of concrete slabs with dead load bias of 1.03 and a CoV of 0.08/(10)1/2 = 0.025 and the CoV of 0.05 for load modelling error is included, then the axial dead load has a bias of 1.14 and a CoV of 0.073. The high bias requires a dead load factor in the order of 1.3. For the average case, the analysis bias is 1.0 and the CoV is 0.094, which for the column carrying 10 floors of slabs corresponds to a dead load factor in the order of 1.22.

Commentary G “Tributary Areas” of the 1995 NBCC therefore requires revision because the method for computing tributary areas (and hence column axial loads) is conservative for first interior–corner column in structure with moment-resisting joints such as a typical reinforced concrete building. The commentary could be revised to state that, if the beam–column connections are moment resisting, the tributary area for an end bay should be distributed 45% to the exterior column and 55% to the first interior column.

Load combination 1, with the dead load as the principal action, was also a subject of some discussion. It governs only for elements such as columns in multiple-storey buildings that have ratios of nominal live load to nominal dead load less than 0.10. The general consensus of the Task Group on Snow and Wind Loads, however, was to include it in the set of load combinations with a dead load factor of 1.4.

Snow load factor

Figure 1 indicates that, for components designed using the 1995 NBCC, the reliability index is less when the load is predominantly snow than when the load is predominantly live (use and occupancy) or wind. This difference is due to...
the large variability of the snow load, which is directly attributable to the transformation of load-to-load effect that has a CoV of 0.42 (Bartlett et al. 2003). The significant research effort necessary to more accurately quantify the load-to-load effect transformation factor is beyond the scope of the current investigation.

Members of the Task Group on Snow and Wind Loads were surveyed concerning the apparent low reliability index obtained for snow load using criteria in the 1995 NBCC. Some respondents that snow load was a common cause of roof collapses in Canada and that the load factors should be increased. Others observed that roof collapses are often due to human errors, including design errors (failing to account for snow drifting, failing to provide proper bracing to compression members) and construction errors (poor welding, poor connection or bracing of wood truss web members). Concerns were also expressed that, because the 2005 NBCC will consider snow load as a separate load from live load due to use and occupancy, components that support floors and roofs will require less resistance than that required by the 1995 NBCC provisions. If the snow load factor is increased to 1.7, as the calibration suggests, and the specified snow load is based on a 50 year return period instead of a 30 year return period, the ratio of the new factored snow load to that in the 1995 NBCC is 1.7 × 1.1/1.5 = 1.25. A 25% increase in factored snow load seemed too large, and so it was proposed that the snow load factor be maintained at 1.5. The specified snow load will increase by approximately 10% due the change of return period from 30 years to 50 years.

Companion-action factors for live, wind, and snow loads

The companion-action factors for live, wind, and snow loads shown in Table 2 also required reconsideration. The factors for live load, when it is a companion action, approximate the sustained fraction of the live load. The live load was modelled as a simple pulse without considering sustained and transient components (Bartlett et al. 2003), which is slightly unconservative for this case. The sustained portion of the live load does not reduce significantly for large tributary areas, but the design live load can be reduced markedly. To address this, the factors for the companion-action live load were increased from 0.3 to 0.5. Also, a note was added to ensure that the factored companion-action live load is not less than the sustained component of the live load.

The load factors for snow and wind loads, when they are companion actions, have been derived assuming these loads are statistically independent. This assumption may be unconservative, so the factors shown in Table 3 are double the values shown in Table 2.

Impact of proposed load combinations for design at ultimate limit states

The impact of the proposed load combinations, shown in Table 3, was investigated by computing ratios of the factored load effect for the proposed load factors to those obtained using the factors in the 1995 NBCC:

\[
R = \left( \frac{\text{Proposed factored demand}}{\text{1995 NBCC factored demand}} \right)_{\alpha \psi}
\]

In this equation, the symbols \( \alpha \) (with subscripts) represent load factors, \( D \) is the specified dead load effect, and \( S_i \) represent specified load effects due to transient load type \( i \). The symbol \( \psi \) is the load combination factor in the 1995 NBCC, which is equal to 1.0 when snow and live (use and occupancy) or wind loads only are considered and 0.7 when the combination of snow, live, and wind loads is considered.

Figure 6 shows the ratios for the simple combinations of dead and live loads, dead and wind loads, and dead and snow loads as a function of the ratio of transient load to dead load. The factored load effect for the proposed factors is exactly equivalent to that in the 1995 NBCC for dead and live loads, up to 2% more severe than that in the 1995 NBCC for dead and wind loads, and up to 6% more severe than that in the 1995 NBCC for dead and snow loads.

Figure 7a shows the impact of the proposed load factor for the combination of dead, live, and snow loads. For cases where the ratio of live load to dead load is low, the proposed criteria give larger factored demands than the 1995 NBCC criteria. For the vast majority of cases, however, the new criteria will give smaller demands than the 1995 NBCC criteria because they recognize the insignificant probability of extreme snow and live (use and occupancy) loads occurring simultaneously. This essential distinction has been widely adopted in American standards based on the 1980 National Bureau of Standards report (Ellingwood et al. 1980).

Figure 7b shows the impact of the proposed load factors for the combination of dead, live, and wind loads. The ratios defined by eq. [2] exhibit sharp kinks because the numerator
is the maximum of values from two load combinations and the denominator is the maximum of values from three load combinations. On average, the new factored demands for these combinations are approximately 4% larger than those from the 1995 NBCC. Similarly, Fig. 7c shows the impact of the proposed load factors for the combination of dead, snow, and wind loads. On average, the new factored demands are 8% higher than those from the 1995 NBCC.

Importance factors based on building classification

Because the bias and CoV of snow load are similar to those of wind load (Bartlett et al. 2003), a common set of importance factors seemed appropriate. As described in the companion paper, the 1995 NBCC provisions that require a post-disaster building to be designed for the 1 in 100 year wind load effectively correspond to an importance factor that ranges from 1.14 to 1.26, with a mean value of 1.21. The consensus of the Task Group on Snow and Wind Loads was that rounding the mean value of 1.21 down gave a value, 1.2, that was too small and so 1.25 was proposed. Preliminary values of importance factors derived in this way for snow or wind load are shown in Table 6.

Load combinations and load factors for serviceability limit states

Serviceability limit state load combinations and load factors are a challenge to calculate because the consequences of attaining a serviceability limit state can be quite variable. Reliability indices for serviceability have been defined for the calibration of serviceability load combinations used for design of the Confederation Bridge (MacGregor et al. 1997). The extension of this methodology to a broader population of structures constructed of different materials seems difficult, however, given the diversity of possible serviceability concerns.

There may also be a need to distinguish between serviceability limit states that permanently change the properties of the structure, such as cracking of prestressed concrete beams, and those that do not, such as instantaneous deflections. This distinction is made complicated because, for ex-

**Table 6. Importance factors for snow or wind load.**

<table>
<thead>
<tr>
<th>Importance category</th>
<th>Importance factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>I: low</td>
<td>0.80</td>
</tr>
<tr>
<td>II: normal</td>
<td>1.00</td>
</tr>
<tr>
<td>III: high</td>
<td>1.10–1.15</td>
</tr>
<tr>
<td>IV: post-disaster</td>
<td>1.25</td>
</tr>
</tbody>
</table>
ample, sustained load deflections may result in permanent sag but do not weaken (or change the properties of) the structure.

The load level used to check serviceability limit states depends on the consequences of the limit state occurring. For example, the wind load used to check lateral deflection of a telecommunications tower should be relatively severe if small deflections cause the telecommunication network to fail. It would be unrealistic to check lateral deflections of other structures using the same severe wind load because the consequence of any loss of function would probably be less.

Past editions of the NBCC have required structures to be checked for deflection and vibration due to wind load for the 1 in 10 year reference pressure. The ratio of the 1 in 10 year specified load to the 1 in 50 year load can be derived (e.g., Bartlett et al. 2001). Ratios of the 1 in 10 year reference pressure to the 1 in 50 year reference pressure vary from 0.82 to 0.71. From Fig. 5 of the companion paper, the SLS load factor applied to the 1 in 50 year specified pressure should be about 0.75 for this range of CoV values.

There are no proposals to change the magnitudes of specified live load due to use and occupancy. Thus the SLS load factors for live load need not change.

Specified snow loads corresponding to the 1 in 50 year values are approximately 10% larger than those corresponding to the 1 in 30 year values. The SLS load factor applied to the specified snow load should therefore be 0.9.

For long-term deflections and settlement, it seems appropriate to consider only the sustained portion of the live load. Snow load is tricky here: the sustained snow load in many parts of southern Canada seems light but could be more substantial in northern Canada. Long-term deflection due to the combination of snow load and live load due to use and occupancy has often governed the design of wood components. Two companion-action-based load combinations for snow load and live load due to use and occupancy are therefore proposed: $S + L_S$, where $L_S$ is the sustained portion of the live load; and $L + 0.35$. The 0.3 companion-action load factor for snow approximates the 0.25 companion-action factor shown for load combination 2 in Table 2 increased by the factor 1/0.9 to account for the SLS factor applied to the specified snow load.

**Summary and conclusions**

This paper has summarized the calibration of companion-action load factors for combinations of dead, live, wind, and snow loads specified in the 2005 edition of the National Building Code of Canada. The recommended load factors and load combinations for ultimate limit states are shown in Table 3, and the recommended importance factors for various classifications of structure are shown in Table 6.

The proposed load combinations and load factors give a more uniform reliability than the load factors and load combinations in the 1995 NBCC for a range of applied loads. The basic dead load plus live load combination is generally less severe than that in the 1995 NBCC, and the dead load plus wind load plus live load and dead load plus wind load plus snow load combinations are slightly more severe.

For checking deflections and other serviceability limit states, SLS factors of 0.75 for wind load and 0.90 for snow load are proposed. These SLS factors give specified loads that are consistent, on average, with the 1 in 10 year wind velocity pressure and 1 in 30 year snow load used to check serviceability in the 1995 NBCC. For components that resist live load due to use and occupancy and snow load, serviceability limit states should be checked using the combinations $L + 0.35$ and $S + L_S$.

Revisions to the commentaries are recommended to provide guidance on estimating dead load allowances for circumstances where the dead load is uncertain. Concerns have been raised about architectural and mechanical superimposed dead load, and the dead load of cast-in-place toppings and cover slabs that may be sensitive to the camber and deflection of the supporting members.

The commentary on tributary areas requires revision. The method for computing tributary areas (and hence column axial loads) is conservative for first interior – corner column in structures with moment-resisting joints such as a typical reinforced concrete building. The commentary could be revised to indicate that, if the beam–column connections are moment resisting, the tributary area for an end bay should be distributed 45% to the exterior column and 55% to the first interior column.

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**References**

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List of symbols

- $a$, $b$ center-to-center spacing of column in orthogonal direction
- CoV coefficient of variation
- $D$ effect due to dead load
- $H$ horizontal earth load due to earth pressure
- $I_S$, $I_W$ importance factors
- $k$ fraction of exterior span that is tributary to interior column
- $l$ span length
- $L$ effect due to live load due to use and occupancy
- $L_S$ sustained portion of live load
- $R$ ratio of factored demand for proposed loads and load factors to that from the 1995 NBCC
- $S$ effect due to 1 in 50 year snow load
- $S_i$ specified load effects due to transient load type $i$
- $T$ load due to restraint of long-term deformations
- $W$ effect due to 1 in 50 year wind load
- $\alpha$ load factor
- $\beta$ reliability index
- $\eta$ ratio of moment capacity at exterior support to moment capacity at interior support
- $\kappa$ ratio of the moment capacity at midspan to the moment capacity at the interior support
- $\psi$ load combination factor in the 1995 NBCC