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by Y. Ishiyama and J.H. Rainer



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RÉSUMÉ

Les auteurs examinent la base de calcul et la surcharge due aux séismes, y compris les facteurs entrant en jeu dans le calcul du cisaillement à la base, par exemple les zones sismiques, le contenu spectral des séismes, la détermination des fréquences, le comportement de la structure, le coefficient de priorité et le coefficient de fondation/sol. La méthode de répartition des forces dans le sens vertical, la torsion et les limites de la flèche horizontale des étages sont également présentées. Les similitudes et les différences entre les trois codes sont relevées. On s'est aperçu qu'en règle générale, les dispositions des codes des trois pays avaient des liens entre elles au niveau des diverses composantes. Le cisaillement à la base calculé pour la zone sismique à risque élevé de chaque pays s'est avéré le plus important dans le code japonais (BSLJ), et le moins important dans les recommandations du NEHRP américain; les forces sismiques décrites dans le code canadien (CNBC) sont légèrement supérieures à celles du NEHRP.

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# Comparison of seismic provisions of 1985 NBC of Canada, 1981 BSL of Japan and 1985 NEHRP of the USA

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ABSTRACT: The basis of design and the seismic load, including the factors that contribute to the base shear calculation, e.g. seismic zoning, seismic spectral content, period determination, structural behaviour, importance factor and soil/foundation factor, are examined. The method of distributing the forces in the vertical direction, torsion, storey drift limitation, etc. are also presented. Similarities and differences among the three codes are noted. It is found that, in general, the provisions of the three countries can be related to one another in terms of the various components. The base shear in the respective highest seismic zone is largest in the Japanese code (BSLJ) and lowest in the NEHRP recommendations of the U.S.A. ; seismic forces in the Canadian code (NBCC) fall slightly above those of NEHRP.

## 1 INTRODUCTION

Seismic resistant design in different countries has benefitted greatly from lessons learned of earthquake effects in other parts of the world. Similarly, codes developed in various countries have provided guidance and models to designers and code writers everywhere. Because of proximity and cultural and economic factors, Canadian seismic provisions have traditionally been modelled after the U.S. Codes. While the Japanese seismic code has had less direct influence on the development of the Canadian Seismic code, the active seismic history of Japan and the expertise and experience in earthquake engineering in Japan make a comparison of all three seismic codes desirable.

The National Building Code of Canada (NBCC)(National Research Council Canada 1985a, b) provides technical requirements for ensuring public safety in buildings and is a model code that can be adopted and then used in municipal bylaws or provincial building codes.

The Building Standard Law in Japan (BSLJ) has been in force since 1950 to safeguard the lives, health and property of the people and to increase the public welfare. The new aseismic design method (International Association for Earthquake Engineering 1984: 534-546) comprises the revised enforcement order, notifications and related regulations in force since 1981 under the Building Standard Law. The regulations were issued after a five-year national research project to develop new aseismic design methods and a three-year review.

The 1985 edition of the U.S. National Earthquake Hazards Reduction Project (NEHRP)(Building Seismic Safety Council 1985) is based on the document issued by the Applied Technology Council (1978) and contains the results of additional research and review process by the Building Seismic Safety Council. This edition is intended to serve as a source document for use by any interested member of the building community, and in particular for the development of seismic provisions throughout the U.S.A.

## 2 DESIGN PROCEDURE

The design procedure in NBCC consists of calculating the stresses in structural members caused by the load due to earthquakes and designing the members for stresses of various load combination of factored loads using limit states design (Table 1). Though working stress design is included in the NBCC, it is gradually being less used.

In the BSLJ design procedure the stresses on structural members caused by the load due to moderate earthquake motions are caluculated and the members designed for stresses of the load combinations of permanent load and seismic load using working stress design (Table 1). Furthermore, for buildings higher than 31 m and for irregular buildings calculation of the ultimate lateral shear strength of each storey above the ground is required and confirmed that it be not less than the specified ultimate lateral shear for severe earthquake motions. Flow charts of the various design requirements are given by Ishiyama (1985).

In NEHRP, ultimate strength design principles are utilized in specifying the load combinations (Table 1), and dead loads contain a portion of the velocity-related zonal acceleration coefficient $A_v$ (see 3.2) to account for the effects of vertical seismic motions.

Table 1. Load combinations for seismic design.

| | |
|---|---|
| NBCC | 1.25 D + 1.5 Q<br>0.85 D + 1.5 Q<br>1.25 D + 0.7(1.5 L + 1.5 Q) |
| BSLJ | D + L + Q<br>D + L + S + Q |
| NEHRP | (1.1 + 0.5 $A_v$)D + L + S ± Q<br>(0.9 - 0.5 $A_v$)D ± Q |

D = dead load, Q = seismic load, L = live load, S = snow load, $A_v$ = velocity-related zonal acceleration coefficient.

## 3 SEISMIC LOAD

### 3.1 Base shear coefficient

The base shear coefficient $C_B$ for NBCC:

$$C_B = v\ S\ K\ I\ F \tag{1}$$

where v is zonal velocity ratio (see 3.2), S seismic response factor (see 3.3), K numerical coefficient for structural behaviour (see 3.5), I importance factor (see 3.6), F foundation factor (see 3.7).

In BSLJ, the base shear coefficient for moderate earthquake motions:

$$C_B = Z\ R_t\ C_0 \tag{2a}$$

where Z is zoning coefficient (see 3.2), $R_t$ design spectral coefficient (see 3.3), $C_0$ standard shear coefficient = 0.2 (see 3.2).

For severe earthquake motions:

$$C_B = D_s\ F_{es}\ Z\ R_t\ C_0 \tag{2b}$$

where $D_s$ is structural coefficient (see 3.5), $F_{es}$ shape factor = $F_e\ F_s$ (see 3.10) and $C_0$ = 1.0.

For NEHRP:

$$C_B = \frac{1.2\ A_v\ S'}{R\ T^{2/3}} \leq \frac{2.5{*}A_a}{R} \tag{3}$$

where S' is soil factor (see 3.7), R response modification factor (see 3.5), T fundamental period (see 3.4), $A_a$ effective peak acceleration coefficient (see 3.2). (* or 2.0, see 3.3.)

The factors included in Eqs.(1)-(3) are shown in Table 2.

Table 2. Comparison of factors

| Effect | NBCC | BSLJ | NEHRP |
|---|---|---|---|
| Seismic hazard | v | Z $C_0$ | $A_a$,$A_v$ |
| Spectral content | S | $R_t$ | $2.5/T^{2/3}$* |
| Structural behaviour | K | $D_s\ F_{es}$ | R |
| Importance | I | - | ** |
| Soil/foundation | F | $R_t$ | S' |

* see 3.3 and Fig. 6, ** importance is expressed by seismic hazard exposure groups and seismic performance categories.

### 3.2 Seismic zoning

The seismic zoning maps in NBCC (Figs. 1a, b) (Heidebrecht, et al. 1983) give zones derived from the peak ground acceleration (the parameter that is governed by the effect of near field earthquakes), and the other gives zones derived from peak ground velocity (mainly governed by far earthquakes). The probability of exceedance that corresponds to these peak ground motion parameters is 10% in 50 years. The velocity-related seismic zone $Z_v$ (Fig. 1b), and the corresponding zonal velocity ratio v govern mainly the longer period structures or higher buildings. Fig. 1a gives the acceleration-related seismic zone $Z_a$ which governs mainly the shorter period or lower buildings. The effect of $Z_a$ and $Z_v$ are combined into the seismic response factor S (see 3.3 and Fig. 4).

The seismic zoning map in BSLJ (Fig. 2) only indicates relative seismicity, dividing Japan into four zones. The seismic zoning coefficient Z is 1.0, 0.9, 0.8 and 0.7 from highest seismicity zones to the lower seismicity zones. It is not

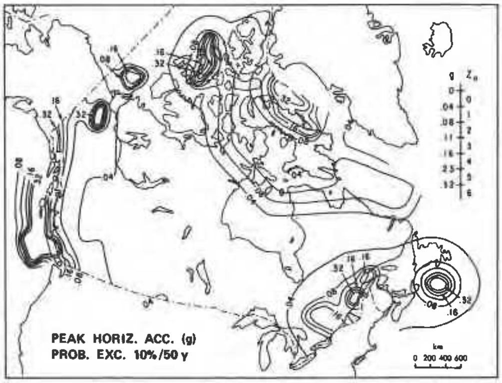

Fig. 1a Acceleration-related seismic zone $Z_a$ (NBCC)

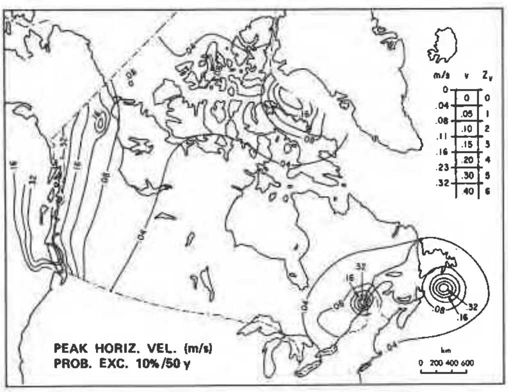

Fig. 1b Velocity-related seismic zone $Z_v$ (NBCC)

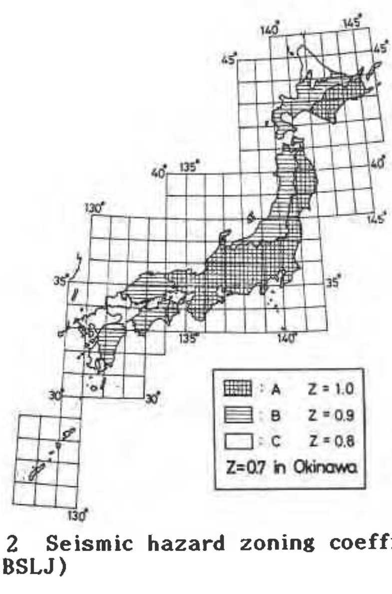

Fig. 2 Seismic hazard zoning coefficient Z (BSLJ)

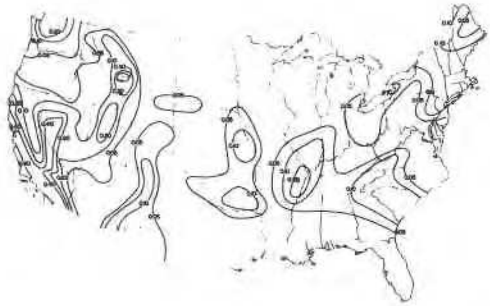
Fig. 3a Contour map for effective peak acceleration (NEHRP)


Fig. 3b Contour map for effective peak velocity-related acceleration (NEHRP)

explained how these values are related to acceleration or to velocity nor is the return period specifically stated. Comparing this map to the seismic contour lines by Japanese researchers (Hattori 1976, 1977), the map seems to be related not only to the statistical seismicity but also to the engineering experience that has been employed in Japan.

By means of the standard shear coefficient $C_0$, two levels of seismic risk are addressed: $C_0$ = 0.2 for moderate earthquake motions and 1.0 for severe earthquake motions. This is interpreted as follows. Moderate earthquake motions would occur several times during the use of the buildings, and the maximum acceleration at the ground surface becomes 0.08 to 0.1 g. The response of low-rise buildings may reach 0.2 g considering a dynamic amplification of 2.0 to 2.5. Severe earthquake motions would occur perhaps once during the use of the buildings, the maximum ground acceleration at the ground surface may reach 0.33 to 0.4 g, and the elastic response of low-rise buildings may become 1 g considering a dynamic amplification of 2.5 to 3. The 1 g force is too large for the economic design of usual buildings and therefore is reduced by $D_s$ which varies from 0.25 to 0.55. This takes into account the energy absorbing capacity, i.e. the ductility and the damping of structures (see 3.5).

The seismic hazard calculations for NEHRP also employ historical seismic data as well as knowledge of geologic zones for which a maximum plausible earthquake can be postulated. The ground motion acceleration that has 10% chance of exceedance in 50 years was chosen as the basis for the map. NEHRP employs an effective peak acceleration EPA that is derived from the 5% damped response spectrum in the 0.1 to 0.5 s period range. In addition to EPA, an "effective peak velocity" EPV was derived by setting EPV = 12 in./s (30 cm/s) for EPA = 0.40 g, and then halving the EPV for successive 80-mile (130 km) increment in distance. For eastern and mid-western U.S., the second halving was carried out at a 160-mile (260 km) distance since longer period waves have been found to attenuate less rapidly there. From the contour maps of EPA and EPV, two zoning maps were derived, one for EPA applicable to short-period structures, and for EPV applicable to moderate- to long-period structures (Figs. 3a, b). The zone boundaries for EPA and EPV with values given in Table 3 form the seven map areas (or seismic zones) along county boundaries, together with an assigned "Seismicity Index." Also given in Table 3 for each map area are the numerical coefficients $A_a$ and $A_v$, corresponding to EPA and EPV, respectively, for use in the lateral force calculation. Table 3 also shows the zones and zonal ratios for NBCC.

The seismic zoning maps for NEHRP and NBCC are seen to be based on similar principles. Some differences exist, however, since NBCC is based on peak acceleration and NEHRP on "effective peak acceleration," and the velocity-related maps were derived slightly differently. Despite these differences, a reasonable continuity in seismic zoning has now been achieved across the Canada-U.S. border, where previous versions gave major discrepancies (Uzumeri et al. 1978).

As was demonstrated above, the BSLJ zoning map can be interpreted to represent 0.33 to 0.40 g of design ground acceleration in the highest seismic zone. This is comparable to that of the highest zone in NBCC and NEHRP, i.e. 0.40 g. However, the further subdivision of zones occurs in the ratio of 0.9, 0.8 and 0.7 for BSLJ, and 0.75, 0.50, 0.375 etc. for NBCC and NEHRP.

### 3.3 Spectral content

The spectral content of the design earthquake as a function of the fundamental period of the building is reflected in the seismic response factor S (Fig. 4) in NBCC. The factor is constant for shorter periods or lower buildings and decreases inversely in proportion to the square root of the fundamental period for longer or higher buildings. The curves for these two regions are connected by straight lines.

In BSLJ, the design spectral coefficient $R_t$ (Fig. 5) is constant ($R_t = 1$) for $T < T_c$, where $T_c$ is the critical period whose value is 0.4, 0.6 or 0.8 s, depending on the soil profile. $R_t$ decreases hyperbolically according to $R_t = 1.6\ T_c/T$ for $T > 2\ T_c$, which corresponds to a constant velocity response for longer periods. For $T_c < T < 2\ T_c$ the curves are smoothly connected by parabolas. The smooth curve avoids the drastic change of design base shear which occurs in specified design spectra where sharp corners are present. This appears appropriate since in most cases the fundamental period is only estimated by empirical formulae.

The parameters to account for spectral

Table 3. NEHRP and NBCC seismic zones

| NEHRP | | | | NBCC | | |
|---|---|---|---|---|---|---|
| Map Area | Coefficient $A_a$ | Coefficient $A_v$ | Seismicity Index | Seismic Zone $Z_a$. $Z_v$ | Acceleration Ratio a | Velocity Ratio v |
| 7 | 0.40 | 0.40 | 4 | 6 | 0.40 | 0.40 |
| 6 | 0.30 | 0.30 | 4 | 5 | 0.30 | 0.30 |
| 5 | 0.20 | 0.20 | 4 | 4 | 0.20 | 0.20 |
| 4 | 0.15 | 0.15 | 3 | 3 | 0.15 | 0.15 |
| 3 | 0.10 | 0.10 | 2 | 2 | 0.10 | 0.10 |
| 2 | 0.05 | 0.05 | 2 | 1 | 0.05 | 0.05 |
| 1 | 0.05 | 0.05 | 1 | 0 | 0 | 0 |

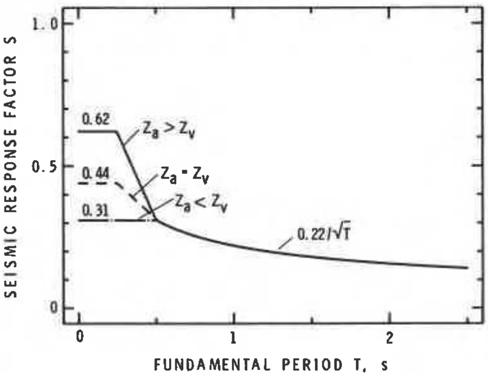


Fig. 4 Seismic response factor S (NBCC)

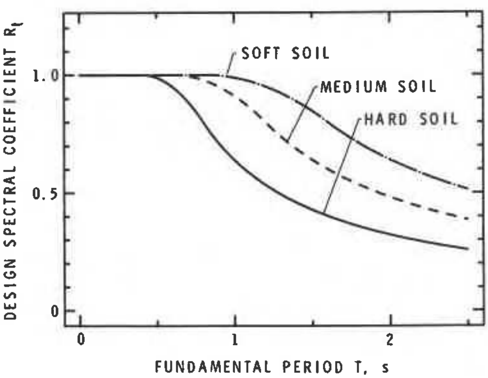


Fig. 5 Design spectral coefficient $R_t$ (BSLJ)

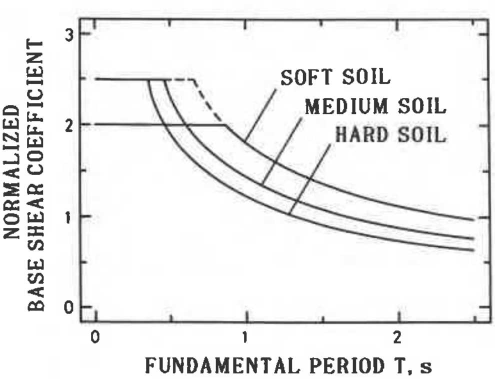


Fig. 6 Normalized base shear coefficient to account for spectral content (NEHRP)

content in NEHRP are: $1.2\ S'/T^{2/3} < 2.5\ A_a/A_v$, or $< 2.0\ A_a/A_v$ for soil profile type $S_3$ in areas where $A_a > 0.30$. This is shown in Fig. 6 assuming $A_a = A_v$. These exprssions are used directly to define a response spectrum for modal analysis. The factors 2.5 and 2.0 are thus response amplification factors relative to the ground motion parameters $A_a$ and $A_v$.

### 3.4 Estimation of fundamental period

The methods of calculating estimates for the natural periods of buildings in the three codes are given in Table 4.

Table 4. Summary of period estimates

| Code | Moment resistant frames | Other buildings |
|---|---|---|
| NBCC | $T = 0.1\ N$ | $T = 0.09\ h/\sqrt{D}$ |
| NEHRP | $T = C_T\ H^{3/4}$<br>$C_T = 0.035$ (steel)<br>$C_T = 0.030$ (concrete) | $T = 0.05\ H/\sqrt{L}$ |
| BSLJ | $T = h(0.02+0.01\alpha)$<br>$= 0.02\ h$ (concrete)<br>$= 0.03\ h$ (steel) | |

$\alpha$ = ratio of height of steel on concrete structure; H = height (ft.); L = length (ft.); h = height (m); D = dimension of force resisting system (m); N = no. of storeys.

All three codes permit the period T' to be calculated by more refined methods but the permissible deviation from Table 4 is limited. In the NBCC, $T' \leqq 1.2\ T$; for NEHRP, $T' \leqq 1.2\ T$ in map area 7 and increases to $T' \leqq 1.7\ T$ in map area 2; for BSLJ, the base shear with T' should not be less than 0.75 base shear with T, but requires a proportionate increase in top lateral force on the building.

Fig. 7 shows the comparison of fundamental periods calculated by the formulae in Table 4. All formulae indicate the fact that the higher the building, the longer the fundamental period. However, the large divergence in Fig. 7 may also indicate that precise estimation of the fundamental period is impossible by using a simple formula with only a few parameters in it.

### 3.5 Structural behaviour

The numerical coefficient K in NBCC modifies the seismic design load depending on the material and type of construction, damping, ductility, and/or energy-absorptive capacity.

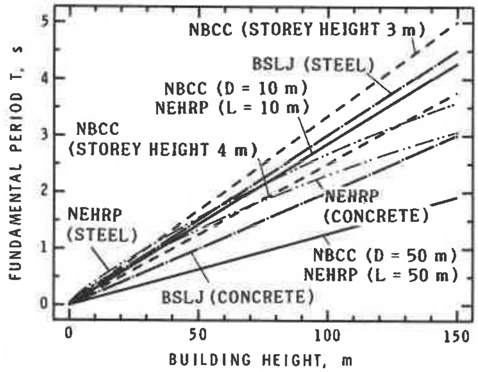


Fig. 7 Comparison of period calculations (NBCC, BSLJ and NEHRP)

The performance of various types of structure is expressed in NEHRP by the seismic response modification coefficient R in the denominator of the base shear calculation. Five categories of structures are recognized: bearing wall systems, building frame systems, moment resisting frames, dual systems, and inverted pendulums. These are then further subdivided depending on the type of vertical element to resist the lateral seismic forces. The correspondence between K of NBCC and R of ATC-3 (the forerunner to NEHRP) has been demonstrated by Rainer (1987).

In BSLJ, the building should be in the elastic range when subjected to moderate earthquake motions. Therefore, the energy-absorbing capacity is not taken into account in the case of the standard shear coefficient $C_0$ = 0.2 (see Eq. (2a)).

In the case of severe earthquake motions, the building will sustain inelastic response. For this case BSLJ requires that the ultimate lateral shear strength of each storey not be less than the specified ultimate lateral shear in which $C_0$ = 1.0 (see Eq. (2b)).

It can be seen that the ratio of the most ductile structure (K = 0.7) to the usual structure (K = 1.3) in NBCC is approximately 0.5 and the ratio of $D_s$ = 0.25 to $D_s$ = 0.55 in BSLJ is almost the same. This is also the case for NEHRP, for R = 7 to 8 (most ductile) and R = 3.5 to 4.5 (ordinary reinforced concrete or masonry). The inverse of $D_s$ in BSLJ corresponds to R in NEHRP. In absolute terms, the force reduction factors implied by $D_s$ in BSLJ are 1/0.25 = 4.0 for the most ductile buildings, and 1/0.55 = 1.8 for regular types. The corresponding values in the NBCC can be shown to be 6.5 for ductile frames and 3.5 for ordinary reinforced concrete buildings, assuming a load factor of 1.0 (Rainer 1987). Thus Japanese code permits force reduction factors that are only about one half or less than those in NEHRP for similar ground motion parameters. The NBCC force reduction factors are only slightly smaller than those of NEHRP. These differences in the force reduction factors carry forward into the base shesr comparison (see 3.11).

### 3.6 Importance factor

The importance factor I in NBCC is 1.3 for all post-disaster buildings and schools and 1.0 for all other buildings.

BSLJ does not include an importance factor because BSLJ stipulates the minimum standard applicable for all buildings.

In NEHRP the importance of a building is accounted for by the Seismic Performance Categories and the Seismic Hazard Exposure Groups. The former depends on the seismic zone under consideration.

### 3.7 Effect of soil profile and foundation

The foundation factor F for NBCC is 1.0 for very dense, stiff and hard soils, 1.3 for medium soils, and 1.5 for loose and soft soils, except F S < 0.44 where $Z_a < Z_v$, and F S < 0.62 where $Z_a > Z_v$.

BSLJ does not explicitly stipulate soil or foundation factors, but the design response spectrum (Fig.5) indicates the factor can be calibrated as 1.0 for hard soils, 1.5 for medium soils and 2.0 for soft soils.

In the NEHRP recommendations, the soil profile coefficient S' is 1.0 for stiff soils and rock, 1.2 for soils of intermediate stiffness and depth, and 1.5 for soft and deep deposits.

### 3.8 Weight of the building

NBCC stipulates that the weight of the building (for calculation of the seismic force) includes dead load (weight of all permanent structural and non-structural components of a building) plus 25% of the design snow load, 60% of the storage load for areas used for storage and the full contents of any tanks.

BSLJ specifies that the weight of the building include dead load plus applicable portion of live load and snow load (in the case of heavy snow district). The applicable portion is 0.6 kN/m² for residential rooms and 0.8 kN/m² for offices which correspond to about one-third of the design live load for floor slabs.

The weight in NEHRP includes the following: dead weight of the structure, partition and permanent equipment including operating contents, a minimum of 25% of floor live load for storage buildings, the effective snow load.

The inclusion of the live load in BSLJ is the only major difference between the calculation of the weight of the building compared to NBCC and NEHRP. The applicable contribution of the live load to the total weight of the building may be from 5 to 10% of the total weight.

### 3.9 Distribution of seismic load

In NBCC, the base shear V is distributed as follows: a portion $F_t$ of the base shear is assumed to be concentrated at the top of the building and is given by:

$$F_t = 0.004\ V\ (h/D)^2 < 0.15\ V \qquad (4a)$$

$$F_t = 0 \qquad \text{for } h/D < 3 \qquad (4b)$$

The reminder is distributed by:

$$F_x = (V - F_t)\frac{w_x\ h_x}{\Sigma\ w_i\ h_i} \qquad (5)$$

where $w_x$ is the portion of weight located at level x, $h_x$ is the height above base to level x and the summation is from i = 1 to N.

In BSLJ, the lateral seismic shear coefficient given for each storey is calculated by multiplying the base shear coefficient and the lateral shear distribution factor $A_i$ which is given by:

$$A_i = 1 + \left(\frac{1}{\sqrt{\alpha_i}} - \alpha_i\right)\frac{2T}{1 + 3T} \qquad (6)$$

where $\alpha_i$ is the normalized weight and is defined as the weight above level i divided by the total weight of the building above the ground.

The lateral seismic force $F_x$ at level x in NEHRP is as follows:

$$F_x = \frac{w_x\ h_x^k}{\Sigma\ w_i\ h_i^k} \qquad (7)$$

where k is an exponent related to the building period: k = 1 for T < 0.5 s, k = 2 for T > 2.5 s, linear interpolation between T = 0.5 and 2.5 s.

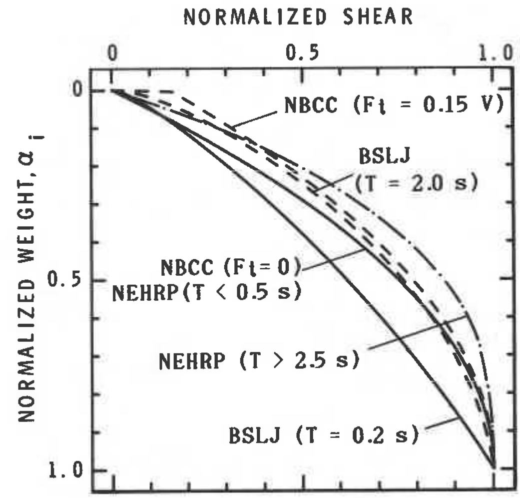


Fig. 8 Shear distributions for NBCC, BSLJ and NEHRP

A comparison of the shear distribution of the three codes normalized by the base shear is presented in Fig. 8, assuming that the mass is uniformly distributed along the height of the building.

An extensive parameter study for lateral load variation has been presented by Ishiyama (1986).

### 3.10 Torsion

In NBCC, the torsional effect is considered by the torsional moment $M_{tx}$ in each storey using:

$$M_{tx} = (F_t + \Sigma\ F_i)\ e_x \qquad (8)$$

where $e_x$ is design eccentricity at level x and is computed by one of the following, whichever provides the greater stresses, and the summation is from i = x to N:

$$e_x = 1.5\ e + 0.10\ D_n \qquad (9a)$$

$$e_x = 0.5\ e - 0.10\ D_n \qquad (9b)$$

where e is distance between the location of the resultant of all forces at and above the level and the centre of stiffness at the level, and Dn is the dimension of the building in the direction of the computed eccentricity.

A dynamic analysis is required for cases where the centroid of mass and the centre of stiffness of the floors do not lie approximately in a vertical line.

In BSLJ, the design eccentricity is equal to the computed eccentricity without considering the accidental torsion. Instead, the eccentricity of stiffness $R_e$ of each storey is restricted to be less than 0.15:

$$R_e = e/r_e < 0.15 \quad (10)$$

where $r_e$ is elastic radius which is defined as the square root of the torsional stiffness divided by the lateral stiffness.

In case $R_e$ exceeds 0.15, the ultimate lateral shear strength of each storey must be calculated and it must be confirmed to be not less than the specified ultimate shear as increased by the factor of $F_e$, 1.0 to 1.5, taking into account the value of $R_e$. If torsional motion occurs, structural members in the transverse direction will also affect the movement. This can be taken into account to a certain extent by the introduction of the elastic radius. The specified ultimate shear is also increased by the shape factor $F_s$, 1.0 to 1.5, in case variation of lateral stiffness is less than 0.6 (see Eq. (2b) and Ishiyama 1985).

The NEHRP recommendations for torsion provide for an increase or decrease of eccentricity ("accidental eccentricity") of 0.05 times the dimension of the building in the direction of the applied forces. In NBCC notation, this would correspond to:

$$e_x = e \pm 0.05\, Dn \quad (11)$$

### 3.11 Comparison of base shear coefficients

A comparison of base shear coefficients among different codes has to take account for all the respective requirements. This can in practice only be done for individual buildings, and even then is a difficult task. It is instructive, however, to examine the broad variations in base shear coefficients, taking for each code a particular type of building and seismic risk zone. All other variables such as period calculation, weight, importance and soil factors are assumed constant or comparable. The NBCC base shear coefficients also need to be multiplied by 1.5 to bring them to the same ultimate design load basis as BSLJ and NEHRP (see Table 1). Thus for the most energy absorbent category and highest seismic risk zone, the comparison of base shear coefficients for NBCC, BSLJ and NEHRP is shown in Fig. 9. The BSLJ is shown to specify base shear coefficients about twice as large as NEHRP at the low period end while those of NBCC are midway

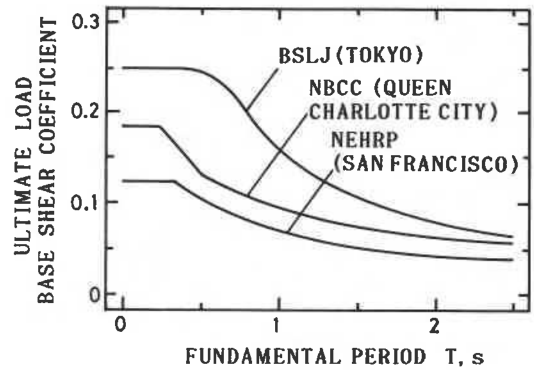


Fig. 9 Comparison of base shear coefficients applicable to the highest seismic zones of NBCC, BSLJ and NEHRP

between the other two codes.

## 4 OTHER CONSIDERATIONS

### 4.1 Storey drift limitation

NBCC gives no absolute value of storey drift limitation. However, it says "storey drift shall be considered in accordance with accepted practice," and the commentary (National Research Council Canada 1985b) recommends storey drift limitation to be 1/200 times the storey height, using the specified loads. The drift obtained from elastic analysis is multiplied by 3 to give more realistic values of anticipated deflection taking into account inelastic deformations. To prevent collision of buildings, adjacent structures are separated by twice their individual deflections if they are not connected to each other.

BSLJ restricts the storey drift calculated for the moderate earthquake motions ($C_0$ = 0.2) not to exceed 1/200 of the storey height. This can be increased to 1/120 if the non-structural members will not sustain severe damage. It is not required to calculate the storey drift caused by severe earthquake motions.

Both storey drift and P-Delta effects are explicitly specified by NEHRP. The design storey drift $\Delta$ is calculated as the difference in deflection $\delta_x$ at level x, where:

$$\delta_x = C_d\, \delta_{xe} \quad (12)$$

and $\delta_{xe}$ is the deflection from an elastic analysis due to the prescribed seismic design forces and $C_d$ is a deflection amplification factor that is related to the type of structure. $C_d$ is similar but not always the same in value as the response modification coefficient R. Thus for very ductile building R is large, 6 to 8, and $C_d$ is also large, 4.5 to 6.5. This gives recognition to the varying degrees of deformations expected from buildings having different degrees of ductile behaviour. The allowable storey drift $\Delta_a$ depends on the Seismic Hazard Exposure Group and is 0.010 $h_{sx}$ for group III (essential buildings) and 0.015 $h_{sx}$ for others; $h_{sx}$ is the storey height below level x.

P-Delta effects need to be considered when the stability coefficient $\theta$ exceeds 0.10:

$$\theta = P_x \, \Delta/(V_x \, h_{sx} \, C_d) \qquad (13)$$

where $P_x$ is the total unfactored vertical design load at and above level x.

## 4.2 Overturning moment reduction coefficient

NBCC allows a reduction of overturning moment at the base by a reduction coefficient J that varies from J = 1.0 for T < 0.5 s to J = 0.8 for T > 1.5 s.

BSLJ does not allow a reduction of the overturning moment at any level.

The overturning moment reduction factor $\kappa$ in NEHRP is similar to that of NBCC, except that it is based on the number of storeys:

$\kappa$ = 1.0 for top 10 storeys;
= 0.8 for the 20th storey from top and below;
= value between 1.0 and 0.8 linearly interpolated between 10th and 20th storey below top.

The foundation of all buildings, except for inverted pendulum structures, may be designed with $\kappa$ = 0.75.

## 4.3 Dynamic analysis

In NBCC, a dynamic analysis is required in some cases when irregular torsional behaviour is expected, as explained in 3.10. The so-called "modal analysis" which can estimate the response of the building in a stochastic manner using a given spectrum (taking the square root of the sum of the squares, SRSS) can also be applied to determine the distribution of shear along the height of the building. However, the base shear itself as obtained by this method is not intended to be used for purposes of design.

In BSLJ, the fundamental period of the building can also be calculated by using an accepted method of dynamics. Then the design spectral coefficient Rt can be obtained from Fig. 5 provided Rt is not less than 0.75 times the original Rt using T in Table 4. The shear distribution factor Ai is then calculated by using T obtained from the dynamic analysis. The shear distribution can also be determined by SRSS using Rt as an acceleration response spectrum or by using any other dynamic analyses including linear and non-linear time history analyses.

Because BSLJ applies only to buildings less than 60 m in height, dynamic analyses (including usually non-linear time history analysis) are required for all buildings higher than 60 m and the approval of the Minister of Construction must be obtained.

The modal analysis procedure in NEHRP uses the same ground motion parameters $A_a$ and $A_v$ and base shear coefficient $C_s$ as the equivalent lateral force procedure, or static method, with minor exceptions. Modal forces are computed and then treated similarly as in the static method. Deflections and drifts calculated from the modal analysis method are augmented by the deflection amplification factor $C_d$. Limits are provided for permissible variations of the period T' of the fundamental mode from T calculated by the simplified formulae in Table 4.

## 4.4 Soil-structure interaction

Neither NBCC nor BSLJ have provisions for considering the effect of soil-structure interaction in practical design. NEHRP, however, includes a method for considering this effect. Both the changes in period and in effective damping are considered in the equivalent lateral force method as well as the modal analysis procedure. This results in reduced base shear, lateral force, and overturning moments, but may increase the computed values of the lateral displacements and P-Delta effect.

# 5 SUMMARY AND CONCLUSIONS

The main factors which constitute the seismic load provisions of the National Building Code of Canada (NBCC), the Japanese seismic code (BSLJ) and the U.S. NEHRP Recommended Provisions have been presented and compared. While the three codes differ in detail, they have essential common features and are comparable in the distribution of lateral shears in the respective highest risk zones. The NBCC provisions are quite similar to the NEHRP recommendations, since the forerunner of the NEHRP, the ATC-3 provisions, served as an inspiration to the 1985 NBCC seismic code.

The Canadian code (NBCC) and the U.S. NEHRP recommendations are mainly based on limit state design whereas the Japanese code (BSLJ) is based on working stress design and ultimate strength.

All three codes include the effect of seismic risk, spectral contents, structural behaviour (energy absorption capacity) and soil/foundation effects for seismic load. The importance of a building is included in NBCC and NEHRP but not in BSLJ.

The other effects that have been compared include torsion, storey drift limitation, overturning moment reduction, and dynamic analysis.

A comparison of base shear coefficients among the three codes, taking into account a limited set of parameters, shows that for the structures with the highest energy absorption located in the highest risk zones in respective countries, the Japanese code (BSLJ) gives a base shear coefficient that is more than twice as large than that of NEHRP; NBCC lies halfway between these two codes.

Although these three codes have introduced up-to-date knowledge of seismology and earthquake engineering, design and construction practices, there seems to be room for improvement, not only through developments from future research and practice, but also in utilizing fully the state of present knowledge.

Future improvements for codification should be carried out in the areas of seismic risk, design for severe earthquakes considering acceptable damage levels, torsion, structural discontinuity, dynamic analysis and soil-structure interaction.

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