Comparison of NBC (1985) seismic provisions with Japanese seismic regulations (1981)

Ishiyama, Y.

Publisher's version / Version de l'éditeur:

Paper (National Research Council of Canada. Division of Building Research); no. DBR-P-1297, 1985-07

National Research Council Canada
Conseil national de recherches Canada

Division of Building Research
Division des recherches en bâtiment

Comparison of NBC (1985) Seismic Provisions with Japanese Seismic Regulations (1981)

by Yuji Ishiyama

DBR Paper No. 1297

NRCC 24684

Price $3.00

DBR/DRB

Canada

COMPARISON OF NBC (1985) SEISMIC PROVISIONS WITH JAPANESE SEISMIC REGULATIONS (1981)

by Yuji Ishiyama
Noise and Vibration Section
Division of Building Research

DBR Paper No. 1297
July 1985
ISSN 0381-4319
NRCC 24684
Price $3.00

COMPARISON OF NBC (1985) SEISMIC PROVISIONS WITH JAPANESE SEISMIC REGULATIONS (1981)

by

Yuji Ishiyama*

ABSTRACT

The National Building Code of Canada 1985 has modified the seismic provisions relative to the 1980 Edition. In Japan, the new aseismic design method has been in force since 1981. This paper compares both codes considering the main factors involved in the seismic load calculation and points out some problems yet to be solved. Finally, research subjects are suggested.

1. INTRODUCTION

The National Building Code of Canada 1985[1] has substantially modified the seismic provisions, compared to those in the 1980 code.[2,3] In Japan, new seismic regulations for buildings[4] have been in force for all buildings since 1981. The regulations were made after a five-year national research project to develop new aseismic design methods and a three-year review.

Though the codes in Canada and Japan have introduced up-to-date knowledge of seismology, earthquake engineering, design and construction practices, etc., there seems to be room for improvement, not only through future developments of research and practice but also in the state of present knowledge, which is not adequately considered in the codes. This paper intends to compare the Canadian and Japanese seismic codes, to indicate the problems which should be solved, and to suggest research which should be carried out in order to improve the seismic codes.

The National Building Code of Canada provides technical requirements for ensuring public safety in buildings and is adopted and then used in municipal bylaws or provincial codes.

The Building Standard Law in Japan has been in force for all buildings since 1950 to safeguard the lives, health and property of the people and to increase the public welfare. The umbrella law was promulgated through the approval of the National Diet. The detailed regulations pertaining to aseismic design were made by Enforcement Order of the cabinet, notifications from the Ministry of Construction, etc. The new aseismic design method comprises the revised enforcement order, notifications and related regulations in force since 1981.

*Visiting Fellow at Noise and Vibration Section, Division of Building Research, National Research Council Canada. On leave from International Institute of Seismology and Earthquake Engineering, Building Research Institute, Ministry of Construction, Government of Japan.

Throughout this paper, "NBC" refers to the seismic provisions of the National of Building Code of Canada (1985) and "BSL" refers to the seismic regulations of the Building Standard Law of Japan and related Enforcement Order, notifications and regulations in force since 1981.

2. DESIGN PROCEDURE

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

The design procedure in BSL is to calculate the stresses on structural members caused by the load due to moderate earthquake motions and to design the members for stresses of load combinations of permanent load and seismic load using working stress design (Table 1). Furthermore, for buildings higher than 31 m it is required to calculate the ultimate lateral shear strength of each storey and to confirm it to be not less than the specified ultimate lateral shear for severe earthquake motions. This will be explained later in more detail. For buildings less than 31 m in height, special requirements are specified, i.e. a minimum wall/column ratio, prevention of brittle failure of structural members, etc. Flow charts of the various design requirements for concrete and steel structures are given in Appendices A and B, respectively.

TABLE 1

Load Combinations for Seismic Design

NBC			BSL
Working Stress Design	Limit States Design		Working Stress Design
	Concrete	Other Than Concrete	
D+Q	1.4D+1.8Q	1.25D+1.5Q	
	0.9D+1.4Q	0.85D+1.5Q	
0.75(D+L+Q)	1.4D+0.75(1.4L+1.8Q)	1.25D+0.7(1.5L+1.5Q)	D+L+Q*

D: Dead Load
L: Live Load
Q: Seismic Load

*The stresses by this load combination should be less than the allowable stresses for short-term load which are 1.5 to 2.0 times larger than the allowable stresses for long-term load.

3. SEISMIC LOAD

3.1 Method to Define Seismic Load

The NBC stipulates the base shear V by the following formula:

$$V = v \cdot S \cdot K \cdot I \cdot F \cdot W \quad (1)$$

where: v = zonal velocity ratio (see Section 3.3);
S = seismic response factor (see Section 3.4);
K = numerical coefficient for structural behaviour (see Section 3.6);
I = importance factor (see Section 3.7);
F = foundation factor (see Section 3.8);
and W = weight of the building (see Section 3.9).

The base shear is then distributed along the height of the building.

The BSL stipulates the lateral seismic shear coefficient C_i of the i-th storey by:

$$C_i = Z \cdot R_t \cdot A_i \cdot C_0 \quad (2)$$

where: Z = zoning coefficient (see Section 3.3);
R_t = design spectral coefficient (see Section 3.4);
A_i = lateral shear distribution factor (see Section 3.10);
and C_0 = standard shear coefficient (see Section 3.3).

The lateral seismic shear V_i of the i-th story is calculated by:

$$V_i = C_i \cdot W_i \quad (3)$$

where: W_i = weight of the building above the i-th storey.

BSL gives the shear which is produced at a certain level of the building and then the force at that level is calculated as the difference between the shears at and above this level. NBC gives the base shear, then the lateral force at each level is determined in proportion to the weight and storey height from the ground level. The shear distribution along the height of the building results from a summation of lateral forces. It should be noted that these two different methods of calculating the seismic load along the height of the building give similar shear distributions (see Section 3.10).

3.2 Base Shear Coefficient

The base shear coefficient C_B for NBC is:

$$C_B = v \cdot S \cdot K \cdot I \cdot F \quad (4)$$

Because A_i is always unity at the base, C_B for BSL is:

$$C_B = Z \cdot R_t \cdot C_0 \quad (5)$$

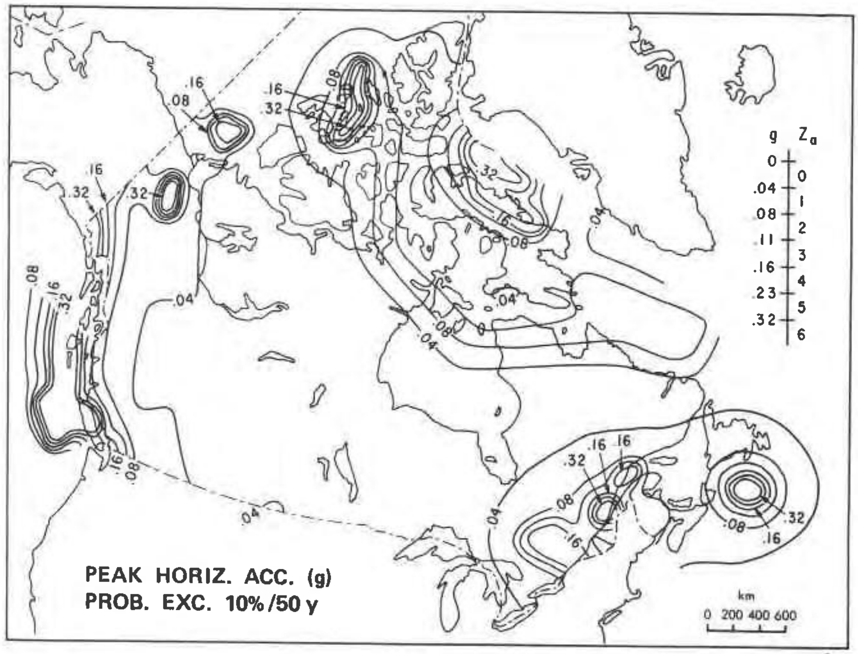


Figure 1a. Acceleration-related seismic zone Z_a (NBC) (after Heidebrecht, et al.[5])

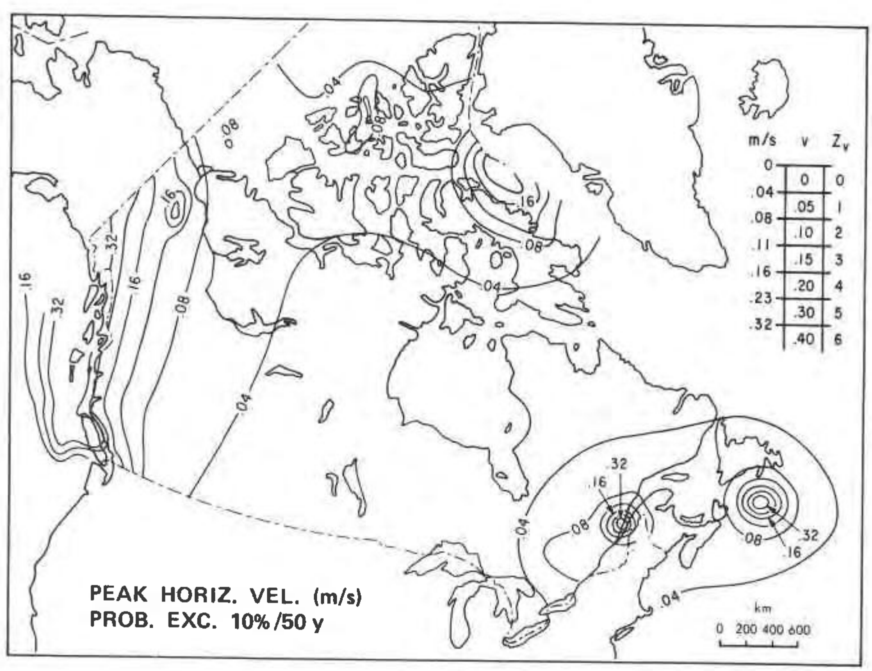


Figure 1b. Velocity-related seismic zone Z_v (NBC) (after Heidebrecht, et al.[5])

The factors in Equations (4) and (5) include the effects of: (a) seismic risk; (b) spectral content; (c) energy absorption capacity; (d) importance; and (e) soil/foundation as shown in Table 2.

3.3 Seismic Zoning

The seismic zoning maps in NBC 1985 (Figs. 1a and 1b)[5] differ from the maps in NBC 1980 in: (a) data analyses; (b) ground motion attenuation relations; (c) ground motion parameters (not only acceleration but also velocity); and (d) the probability of exceedance. In short, the seismic risk is expressed by two maps: one that gives zones derived from the peak ground acceleration (the parameter that is governed mainly 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.

Figure 1b gives the velocity-related seismic zone Z_v and the corresponding zonal velocity ratio v which governs mainly the longer period structures or higher buildings. Figure 1a gives the acceleration-related seismic zone Z_a which governs mainly the shorter period or lower buildings. The effects of Z_a and Z_v are combined into the seismic response factor S described in Section 3.4 (see also Fig. 3).

TABLE 2

Comparison of Factors

Effect	NBC	BSL
Seismic Risk	v	$Z \cdot C_0$
Spectral Content	S	R_t
Energy Absorption Capacity	K	D_s*
Importance	I	-
Soil/Foundation	F	R_t

*Structural coefficient which is used to calculate the specified ultimate lateral shear against severe earthquake motions (see Section 3.6).

The seismic zoning map in BSL (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 high seismicity zones to low seismicity zones. It is not explained whether these values are related to acceleration or to velocity. But considering that the seismic design coefficient has the unit of gravitational acceleration, the seismic zoning coefficient should be related to acceleration. The probability of exceedance is also not indicated. But comparing this map to the seismic contour lines drawn by Japanese researchers,[6,7] the map seems to be related not only to the statistical seismicity but also to the engineering experience that has been employed in Japan.

The standard shear coefficient C_0 reflects the absolute seismicity in Japan, and is 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

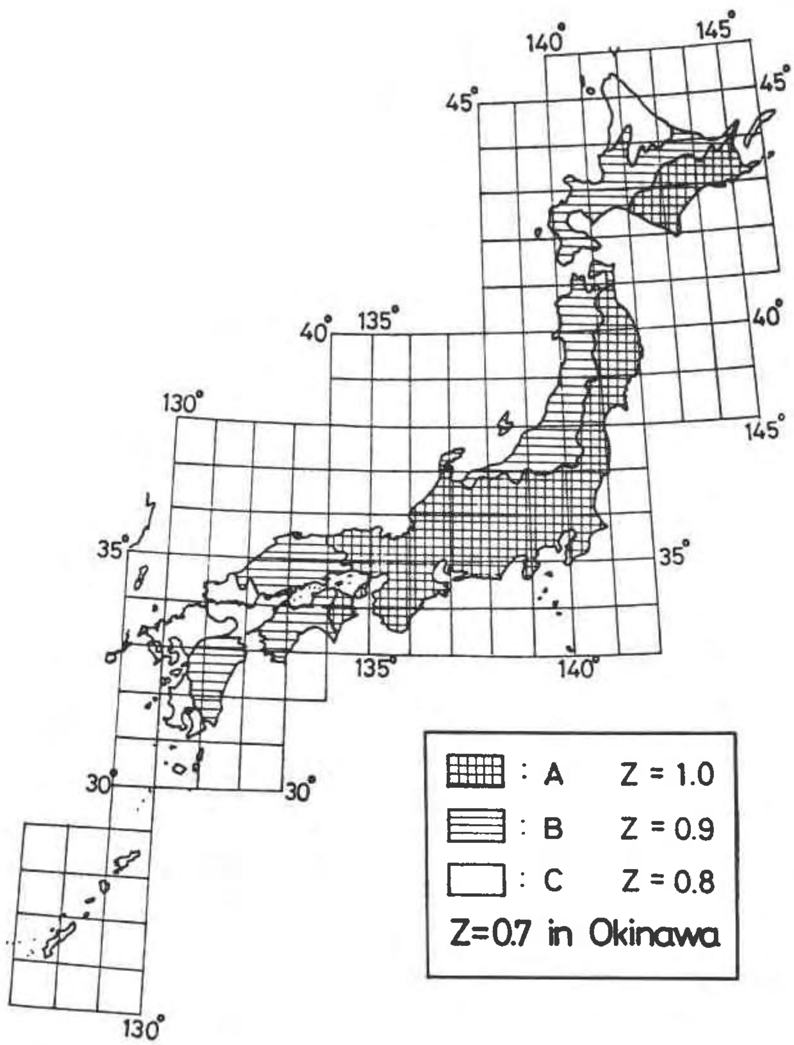


Figure 2. Seismic hazard zoning coefficient Z (BSL)

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 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 it can be reduced to 0.25 to 0.55, taking into account the energy-absorbing capacity, i.e., the ductility and the damping of structures (see D_s in Section 3.6).

Incidentally, the previous Japanese code contained only the seismic coefficient k = 0.2, which corresponds to the standard shear coefficient for moderate earthquake motions in the present code. It did not contain any provisions for severe earthquake motions and consequently it did not require the calculation of the ultimate lateral shear strength.

3.4 Spectral Content

The effect of the fundamental period T of the building is included in the seismic response factor S (Fig. 3) in NBC. The factor is constant for shorter periods or lower buildings ($T \leq 0.25$ s) and decreases inversely in proportion to the square root of the fundamental period for longer periods or higher buildings ($T \geq 0.5$ s). The curves for these two regions are connected by straight lines for $0.25 \text{ s} \leq T \leq 0.5$ s.

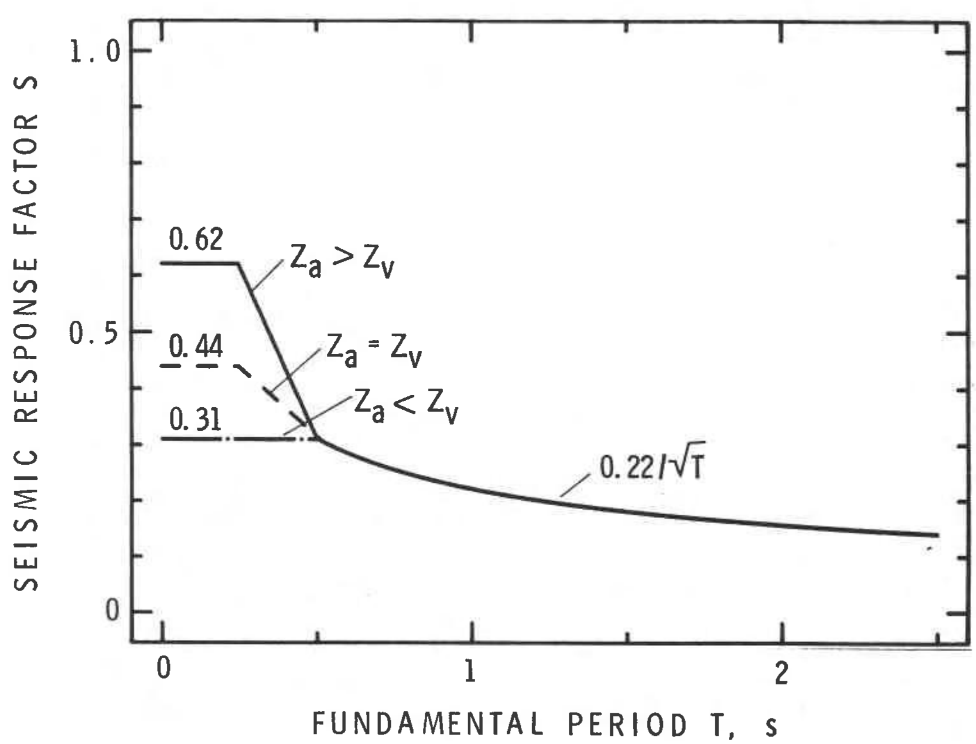


Figure 3. Seismic response factor S (NBC)

In BSL, the design spectral coefficient R_t (Fig. 4) is comparable to the seismic response factor S in NBC. The coefficient 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 according to $R_t = 1 - 0.2\ (T/T_c - 1)^2$. 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.

3.5 Estimation of Fundamental Period

The fundamental period T (s) in NBC is:

$$T = 0.09\ h/\sqrt{D_s} \tag{6a}$$

where: h = height (m) above the base;
and D_s = dimension (m) of the lateral force resisting system in the direction of the applied forces;

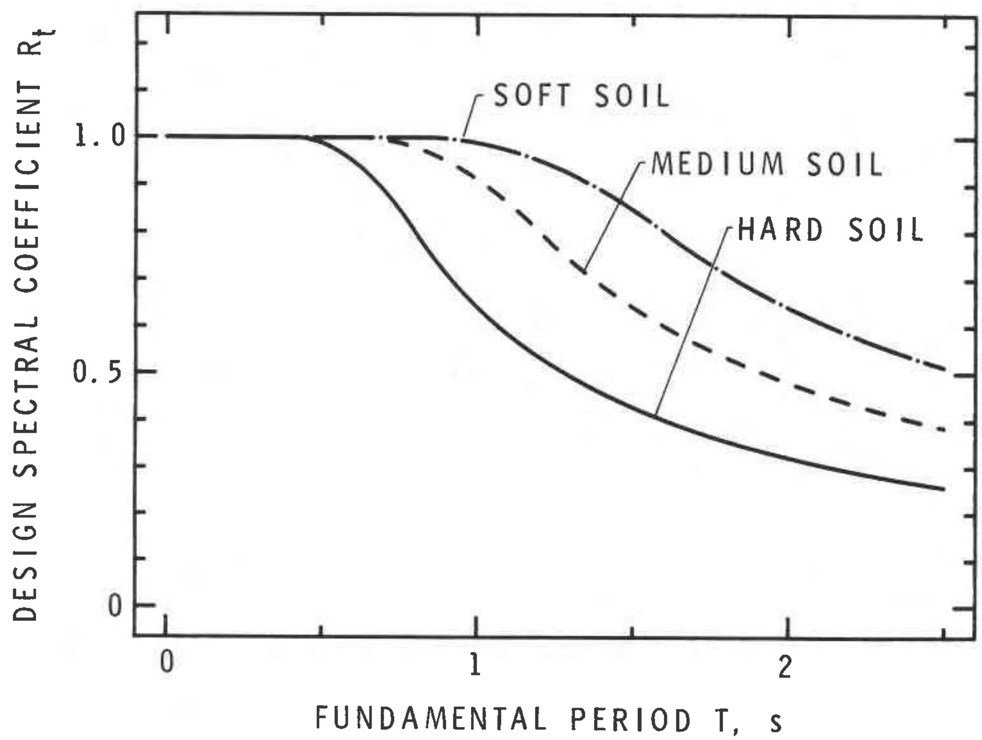


Figure 4. Design spectral coefficient R_t (BSL)

except that for moment resisting frames,

$$T = 0.1 \cdot N \tag{6b}$$

where: N = total number of stories above exterior grade.

T can be obtained by other established methods but it cannot be more than 1.2 times the value given by either of the above formulae, [Equations (6a) and (6b)].

T in BSL is given by:

$$T = h(0.02 + 0.01\ \alpha) \tag{7}$$

where: α = the ratio of the height of steel construction (built on top of concrete construction) to the total height of the building.

Thus, for a building entirely of concrete,

$$T = 0.02\ h \tag{7a}$$

for one entirely of steel,

$$T = 0.03\ h \tag{7b}$$

T can be calculated by other established methods than the above formulae, [Equations (7), (7a) and (7b)] but the base shear must not be less than 0.75 of the base shear obtained with this formula. However, the distribution of the forces along the height of the building has to be modified by the calculated T as per Fig. 7, which results in larger forces being applied to the upper stories for longer period buildings.

Figure 5 shows the comparison of fundamental periods calculated by the aforementioned formulae. All formulae indicate the fact that the higher the building, the longer the fundamental period. However, the large divergence in Figure 5 may also indicate that precise estimation of the fundamental period is impossible by using a simple formula with only a few parameters in it. From the viewpoint of practical design, the formula which gives smaller values will be preferable for achieving a more conservative design since it results in larger design base shear. It should be noted that in BSL the longer period means not only a reduction in the design base shear but also an increase of the forces applied to upper stories. This controls designers' temptation to seek a longer period for reasons of economy.

3.6 Energy-Absorbing Capacity

The numerical coefficient K in NBC reduces the seismic load depending on the material and type of construction, damping, ductility, and/or energy-absorptive capacity as given in Table 3.

In BSL, the buildings 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 $C_0 = 0.2$.

In the case of severe earthquake motions, the building cannot remain in the elastic range and will sustain the inelastic response when subjected to ground motion. Therefore, BSL requires design against severe earthquake motions, by confirming that the ultimate lateral shear strength of each storey is not less than the specified ultimate lateral shear Q_{un} which is given by:

$$Q_{un} = D_s \cdot F_{es} \cdot Q_{ud} \tag{8}$$

where: D_s = the structural coefficient;
F_{es} = the shape factor = $F_e \cdot F_s$;
and Q_{ud} = the lateral seismic shear for severe earthquake motions.

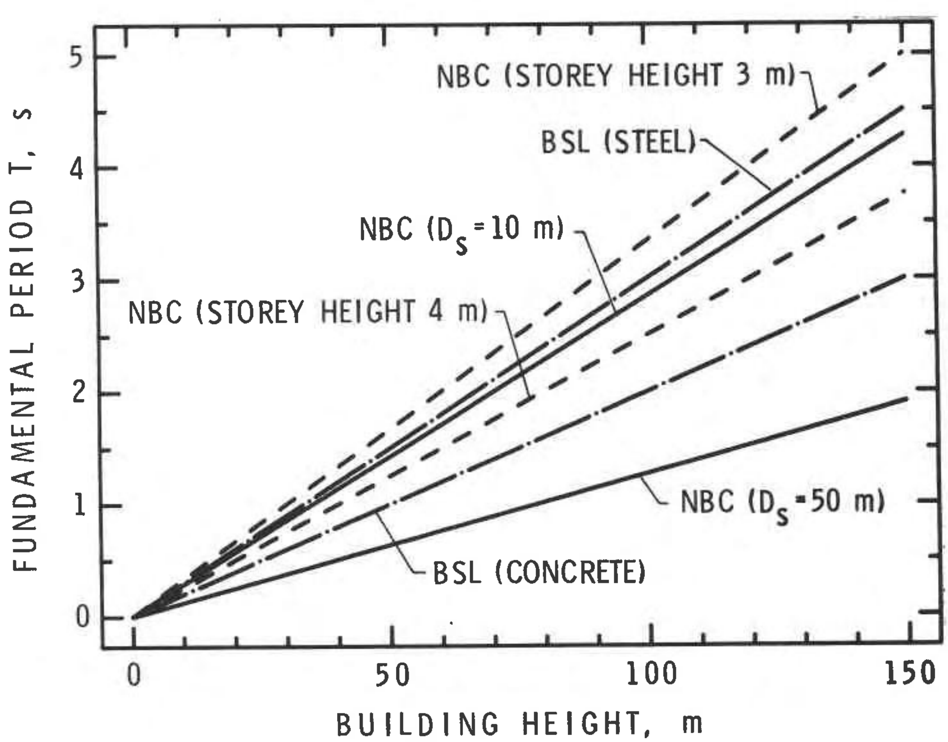


Figure 5. Fundamental periods by NBC and BSL

The structural coefficient D_s (see Tables 4a and 4b) can be interpreted as the reduction factor of the elastic response force that reaches 1 g during severe earthquake motions, and takes into account the energy-absorbing capacity of the building. The shape factor F_{es} is the product of the shape factor due to eccentricity F_e (see Section 4.1) and the shape factor due to variation of stiffness F_s (see Section 4.2).

It should be noted that the ratio of the most ductile structure (K = 0.7) to the usual structure (K = 1.3) in NBC is approximately 0.5 and the ratio of D_s = 0.25 to D_s = 0.55 in BSL is almost the same.

The classification of structures becomes frequently controversial when Table 3 or Tables 4a and 4b are used. Therefore, the precise description of structures is very important. Appendices C and D are taken from the BSL manual[8] that provides guidance in the application of Tables 4a and 4b to reinforced concrete buildings and steel buildings, respectively.

TABLE 3

Coefficient K (NBC)
(With abbreviated description from Table 4.1.9.A of NBC 1985)

	Structural Type of Buildings	K
1	Ductile moment resisting space frame.	0.7
2	Ductile moment resisting space frame with ductile flexural walls (frame must carry at least 25% of total shear).	0.7
3	Ductile moment resisting space frame with shear walls or steel braces (walls or braces to carry total shear and frame to carry at least 25% of total shear).	0.8
4	Buildings with ductile flexural walls or with ductile framing systems other than 1, 2, 3 or 5.	1.0
5	Ductile moment resisting space frame with walls having masonry infilling (wall with infilling to carry total shear, frame at least 25% of total shear).	1.3
6	Reinforced concrete, structural steel or reinforced masonry shear walls.	1.3
7*	Unreinforced masonry and other than the above.	2.0
8	Elevated cross-braced tanks.	3.0

*Not allowed for $Z_v \geq 2$ for buildings more than 3 stories.

TABLE 4a

Structural Coefficient D_s for Buildings of Steel Construction (BSL)

Behaviour of Members	Type of Frame (1) Ductile Moment Frame	(2) Frame Other Than (1) and (3)	(3) Frame With Compression Braces
A. Members of excellent ductility	0.25	0.3	0.35
B. Members of good ductility	0.3	0.35	0.4
C. Members of fair ductility	0.35	0.4	0.45
D. Members of poor ductility	0.4	0.45	0.5

TABLE 4b

Structural Coefficient D_s for Buildings of Reinforced Concrete or Steel-Encased-by-Reinforced-Concrete Construction (BSL)*

Behaviour of Members	Type of Frame (1) Ductile Moment Frame	(2) Frame Other Than (1) and (3)	(3) Frame With Shear Walls or Braces
A. Members of excellent ductility	0.3	0.35	0.4
B. Members of good ductility	0.35	0.4	0.45
C. Members of fair ductility	0.4	0.45	0.5
D. Members of poor ductility	0.45	0.5	0.55

*Values are decreased by 0.05 for steel-encased-by-reinforced-concrete construction.

3.7 Importance Factor

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

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

Before introducing the importance factor into the code, the concept of importance of the building should be clarified. The limitation of storey drift* or other requirements might be more appropriate than the increase of design load by the importance factor. The requirements for the building performance should be specified, depending on the function that is required for the building during and after earthquakes.

3.8 Effect of Soil Profile and Foundation

The foundation factor F for NBC is 1.0 for very dense, stiff and hard soils, 1.3 for medium soils, and 1.5 for loose and soft soils, except $F \cdot S \leqslant 0.44$ where $Z_a \leqslant Z_v$, and $F \cdot S \leqslant 0.62$ where $Z_a > Z_v$ (Figs. 6a to 6c).

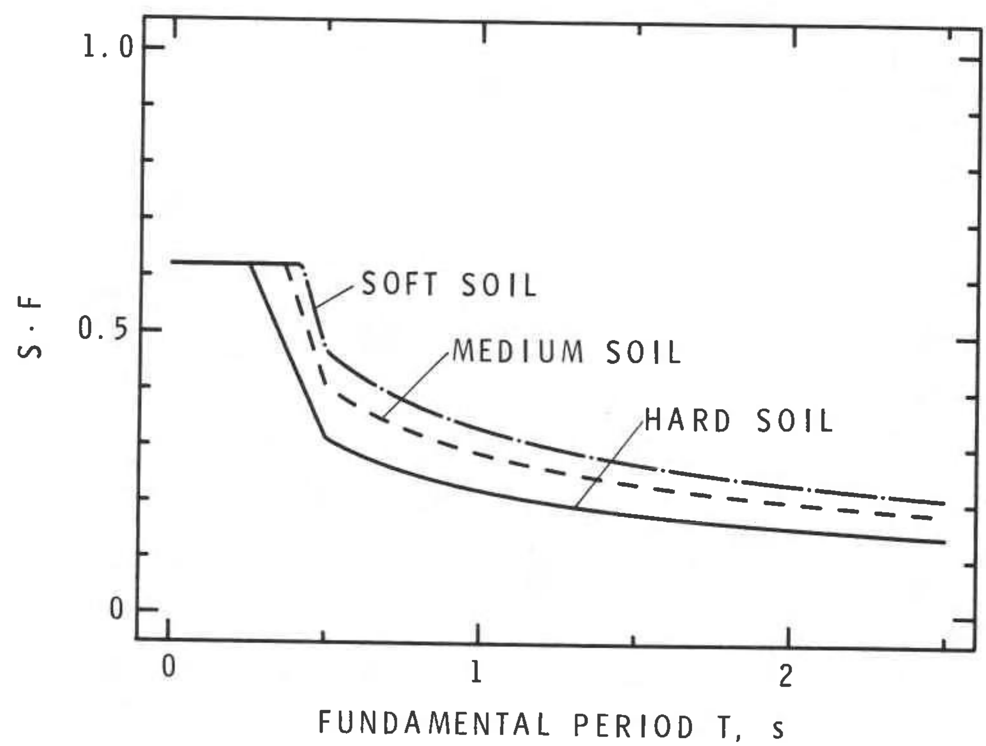


Figure 6a. Seismic response factor times foundation factor, S •F, for $Z_a > Z_v$ (NBC)

*The difference of the horizontal deflections at the top and bottom of the storey under consideration

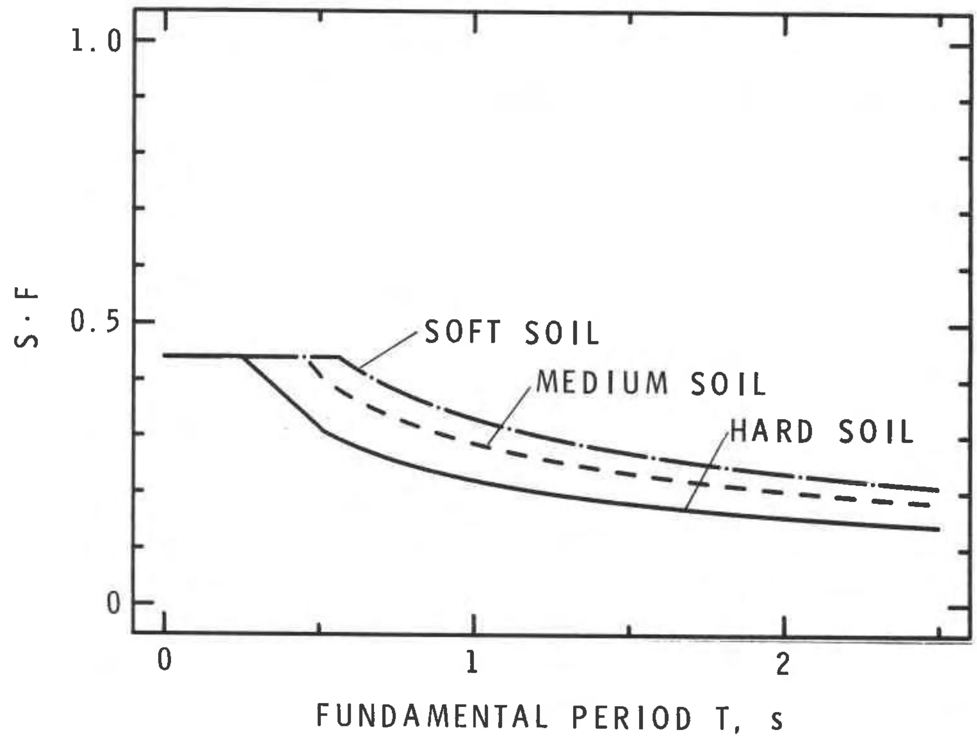


Figure 6b. Seismic response factor times foundation factor, S • F, for $Z_a = Z_v$ (NBC)

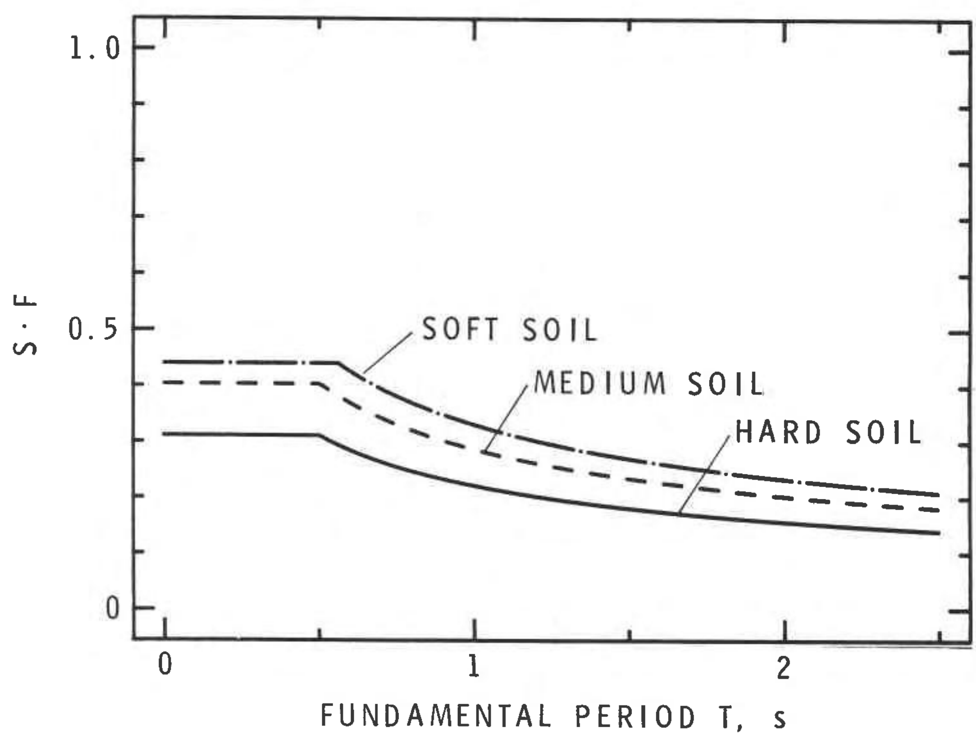


Figure 6c. Seismic response factor times foundation factor, S • F, for $Z_a < Z_v$ (NBC)

BSL does not explicitly stipulate soil or foundation factors, but the design response spectrum (Fig. 4) indicates the factor can be calibrated as 1.0 for hard soils, 1.5 for medium soils and 2.0 for soft soils.

Tables E1 and E2 in Appendix E indicate the soil classification in NBC and BSL, respectively.

3.9 Weight of the Building

NBC 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.

BSL stipulates that the weight of the building includes dead load plus applicable portions of live load and snow load (in the case of heavy snow districts). The applicable portion is about one-third of the design live load for floor slabs (e.g., 0.6 kN/m^2 for residential rooms and 0.8 kN/m^2 for offices).

The inclusion of the live load in BSL is practically the only difference between the calculation of the weight of the building in NBC and BSL. The applicable contribution of the live load to the total weight of the building may be from 5 to 10% of the total weight.

3.10 Distribution of Seismic Load

In NBC, 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:

$$F_t = 0.004\, V\left(\frac{h_n}{D_s}\right)^2 \leq 0.15\, V \tag{9a}$$

$$F_t = 0 \text{ for } \frac{h_n}{D_s} \leq 3 \tag{9b}$$

The remainder is distributed by:

$$F_x = (V - F_t)\,\frac{W_x h_x}{\sum_{i=1}^{n} W_i h_i} \tag{10}$$

In BSL, the lateral seismic shear coefficient is given for each storey and the distribution of the coefficient depends only on the lateral shear distribution factor A_i which is given by (Fig. 7):

$$A_i = 1 + \left(\frac{1}{\sqrt{\alpha_i}} - \alpha_i\right) \frac{2T}{1 + 3T} \qquad (11)$$

where α_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.

Figure 8 shows NBC and BSL shear distributions normalized by the base shear as a function of normalized weight α_i. If the mass is distributed uniformly along the height of the building, the normalized weight is almost equivalent to 1.0 minus the normalized height. It should be noted that $\alpha_i = 1/N \neq 0$ at the top storey of a uniform N-storey building. Then we may say that the NBC distribution with concentrated force at the top $F_t = 0.15$ V is almost equivalent to BSL distribution for T = 2.0. However, the fixed concentrated force at the top is not practical where the plan of the top storey is significantly smaller than the lower storeys (see Fig. 9). This anomaly can be avoided by the adoption of shear coefficients instead of a concentrated force. A big difference, however, can be observed between the NBC distribution without a concentrated top force and the BSL distribution for T = 0.2 pertaining to low-rise buildings or stubby buildings.

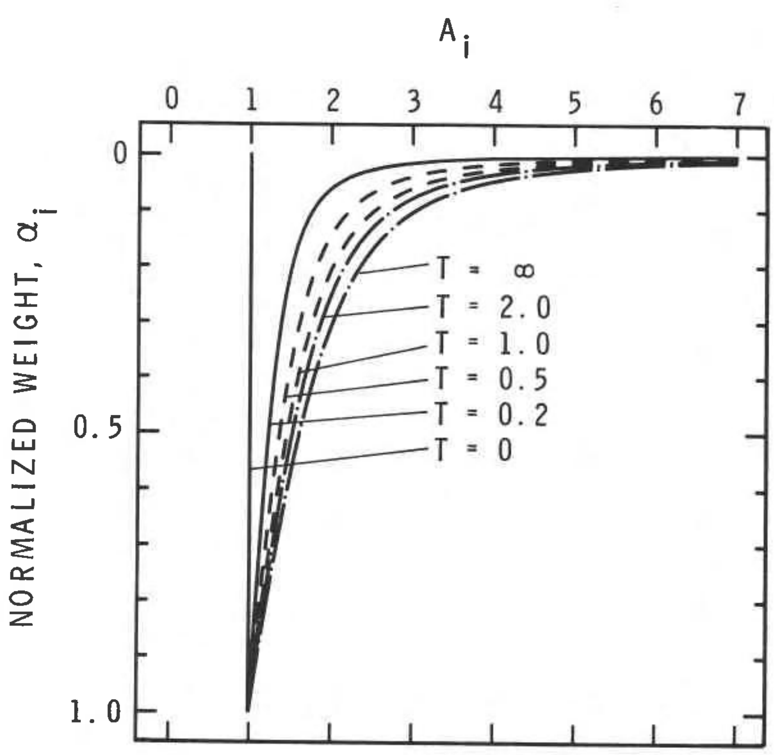


Figure 7. Lateral shear distribution factor A_i (BSL)

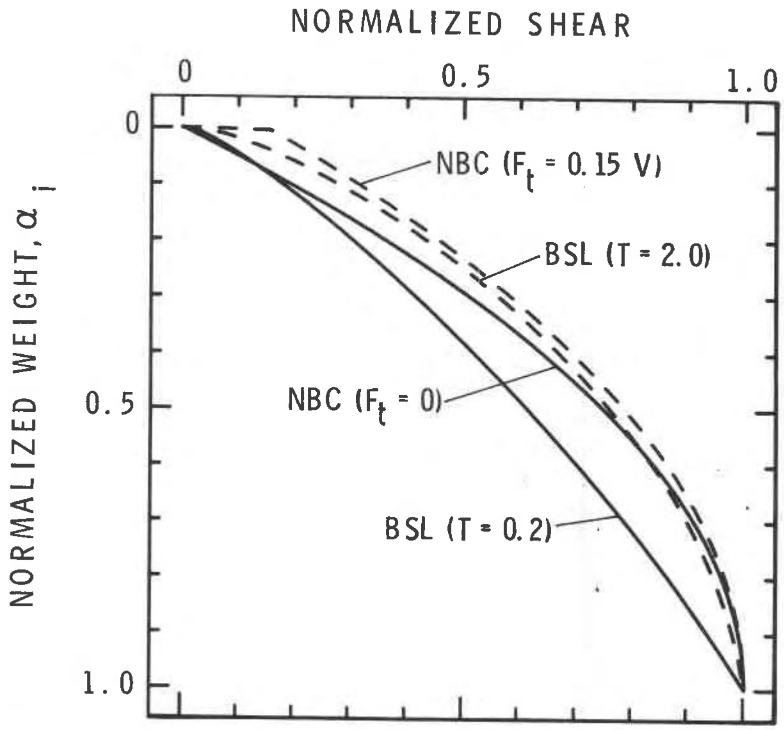


Figure 8. Shear distribution by NBC and BSL

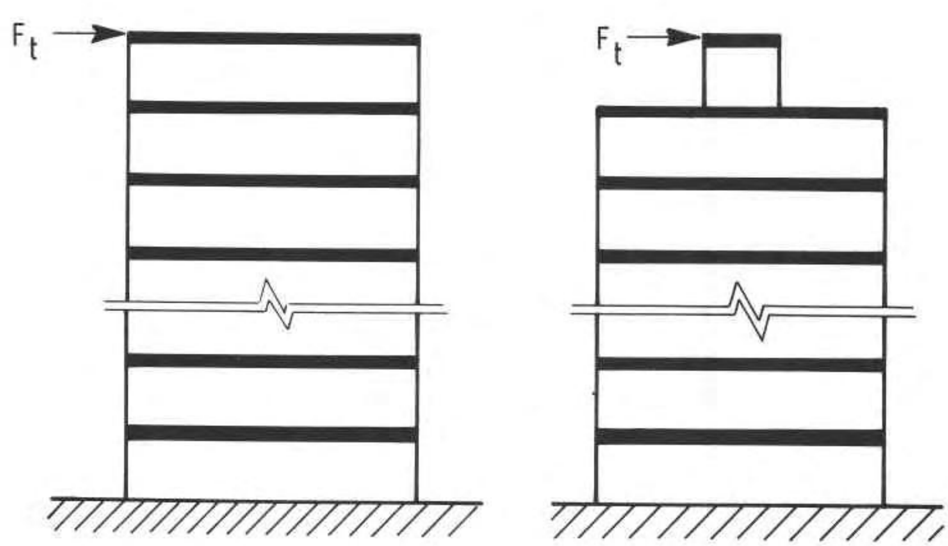


Figure 9. Anomaly of concentrated top force (NBC)

4. OTHER CONSIDERATIONS

4.1 Torsion

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

$$M_{tx} = (F_t + \sum_{i=x}^{n} F_i)e_x \qquad (12)$$

where: e_x = the design eccentricity at level x and is computed by one of the following, whichever provides the greater stresses:

$$e_x = 1.5\ e + 0.10\ D_n \qquad (13a)$$

$$e_x = 0.5\ e - 0.10\ D_n \qquad (13b)$$

where: e = the distance between the location of the resultant of all forces at and above the level and the centre of stiffness at the level,

and D_n = 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 BSL, 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:

$$R_e = \frac{e}{r_e} < 0.15 \qquad (14)$$

where: r_e = the 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 lateral shear as increased by the factor of F_e, taking into account the value of R_e (see Equation (8) and Table 5). 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.

4.2 Mass and Stiffness Distribution

NBC qualitatively takes into account the discontinuity of mass and stiffness distribution by stating that "the building design shall take full account of the possible effect of setbacks". It is also stated that "for buildings in $Z_v \geq 2$ in which discontinuities in columns or shear walls occur, special design provisions shall be made to ensure that failure at the point of discontinuity will not occur before the capacity of the remaining portion of the structure has been realized."

BSL specifies the following variation of lateral stiffness R_s of each storey:

$$R_s = \frac{r}{\bar{r}} \geq 0.6 \qquad (15)$$

where: r = the lateral stiffness which is defined as the storey height divided by the storey drift;
and $\bar{r}$ = the mean lateral stiffness which is defined as the arithmetic mean of the lateral stiffness above ground level.

In case R_s becomes less than 0.6, the ultimate lateral shear strength must be calculated and be more than the specified ultimate lateral shear as increased by the factor of F_s (see Equation (8) and Table 6).

4.3 Storey Drift Limitation

NBC gives no absolute value of storey drift limitation. However, it says "storey drift shall be considered in accordance with accepted practice," and the commentary recommends storey drift limitation to be 1/200 times the storey height. Furthermore, the drift obtained from elastic analysis is multiplied by 3 to give realistic values of anticipated deflection. To prevent collision of buildings, adjacent structures are separated by twice their individual deflections if they are not connected to each other.

TABLE 5

Shape Factor F_e Corresponding to Eccentricity of Stiffness R_e (BSL)

R_e	F_e
less than 0.15	1.0
$0.15 \leq R_e \leq 0.3$	linear interpolation
greater than 0.3	1.5

TABLE 6

Shape Factor F_s Corresponding to Eccentricity of Lateral Stiffness R_s (BSL)

R_s	F_s
greater than 0.6	1.0
$0.3 \leq R_s \leq 0.6$	linear interpolation
less than 0.3	1.5

BSL restricts the storey drift caused by moderate earthquake motions not to exceed 1/200 of the storey height. This can be increased to 1/120 if the non-structural members will sustain no severe damage. It is not required to calculate the storey drift caused by severe earthquake motions.

4.4 Overturning Moment Reduction Coefficient

NBC allows a reduction of the overturning moment at the base by a reduction coefficient J as shown in Fig. 10. The overturning moment at level x is also reduced by multiplying by J_x where:

$$J_x = J + (1 - J)(h_x/h_n)^3 \qquad (16)$$

BSL does not allow a reduction of the overturning moment at any level; however, it is not required to calculate the overturning moment under the ground level for severe earthquake motions.

4.5 Seismic Load for Appendages, etc.

In NBC, the parts of buildings are designed for the following lateral force V_p:

$$V_p = v \cdot S_p \cdot W_p \qquad (17)$$

where: v = zonal velocity ratio (Figs. 1a and 1b);
S_p = horizontal force factor in Table 7;
W_p = weight of the part.

In BSL, the lateral seismic shear V_p for appendages is:

$$V_p = k \cdot W_p \qquad (18)$$

where: k = the seismic design coefficient and is 1.0.

It can be reduced to 0.5 in case no harm to human lives will occur.

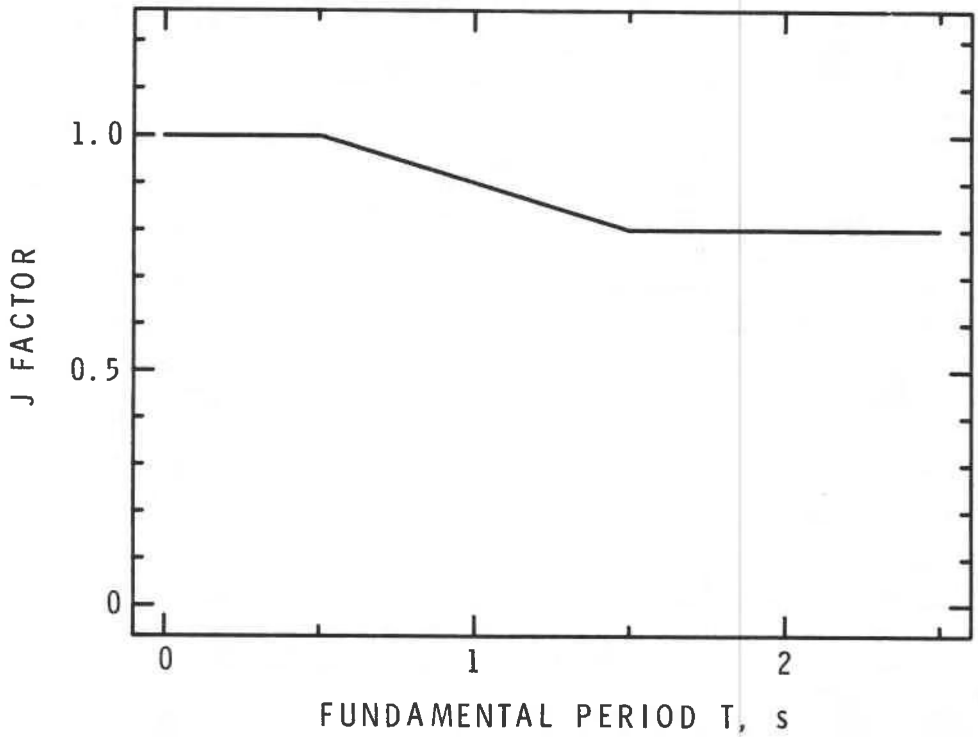


Figure 10. Overturning moment reduction coefficient J (NBC)

BSL gives the lateral seismic shear of the basement V_B as:

$$V_B = V_E + k \cdot W_B$$

where: V_E = the portion of the base shear that will extend to the basement;
W_B = the weight of the basement;

and:

$$k = 0.1(1 - \frac{H}{40})\ Z \qquad (19)$$

where: H = depth of the basement in metres and equals 20 for $H > 20$;
Z = zoning coefficient in Fig. 2.

4.6 Dynamic Analysis

In NBC, a dynamic analysis is required in some cases when the irregular torsional behaviour is expected, as explained in Section 4.1. 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.

TABLE 7

Horizontal Force Factor S_p (NBC)
(With abbreviated description from Table 4.1.9.C of NBC 1985)

	Part	S_p
1	Walls except in 2 and 3	0.9
2	Cantilever walls	4.4
3	Ornamentations and appendages	4.4
4	Rigidly connected equipment, etc.	0.9
	Other than above	4.4
5	Towers, etc. connected to a building	1.3
6	Tanks on the ground floor	0.9
7	Diaphragms	0.45
8	Connections	11.0

In BSL, the fundamental period of the building can also be calculated by using an accepted method of dynamics. Then the design spectral coefficient R_t (Fig. 4) can be obtained from Fig. 4 provided R_t is not less than 0.75 times the original R_t using T from Equation (7). The shear distribution factor A_i (Fig. 6) is then calculated by using T obtained from the dynamic analysis. The shear distribution can also be determined by SRSS using R_t (Fig. 4) as an acceleration response spectrum or by other dynamic analyses including linear and non-linear time history analyses.

Because BSL 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.

4.7 Soil-Structure Interaction

Both NBC and BSL have no provision to consider the effect of soil-structure interaction in practical design. However, damage caused by earthquakes shows that the interaction plays an important role in the behaviour of buildings. Therefore, it should be taken into account in design. Tentative provisions in the United States, known as ATC-3,[9] suggest a method for considering this effect.

5. RESEARCH NEEDED FOR FUTURE CODIFICATION

Though all items discussed in the previous sections should be studied further, the author would like to suggest that the following subjects be investigated for future codification.

5.1 Estimation of Seismic Risk

Estimation of seismic risk is one of the most influential factors on seismic load. Theoretical analysis proposed so far, mainly performed in a stochastic manner, does not always give an acceptable design basis, mainly because of the infrequent occurrence of major earthquakes. Inclusion of two different seismic zoning maps in NBC may suggest the way to solve this problem. The basis for design against various levels of earthquake shaking should be investigated further.

5.2 Basis for Earthquake Resistant Design

Though most codes in the world admit some damage to buildings subjected to severe earthquake motions, the damage should be restrained from exceeding an acceptable level. There seem to be two ways to achieve this: 1) elastic design in which the non-linear behaviour of buildings is considered by some factors like K in NBC, and 2) ultimate strength design in which the non-linear analysis is performed like the estimation of ultimate lateral shear strength of BSL. The choice and the preferable method of the above two procedures should be studied, and perhaps other design procedures should also be considered.

5.3 Torsional Effects

Since the three-dimensional analysis is not practical for usual design, an appropriate procedure to take into account the effect of torsion is required. The procedure should be applicable to multi-storey buildings with varying eccentricity from storey to storey. Also, two translational and rotational movements of the ground motions must be studied.

5.4 Structural Discontinuities

Discontinuities in structures frequently cause severe damage during earthquakes. Methods to estimate this effect should be studied. The distribution of design shear and the stiffness ratio in BSL are current provisions that consider this effect. However, both should be improved.

5.5 Dynamic Analysis

A standard method for dynamic analysis should be proposed as a guideline for designers. It should include how to model the structures (one to three dimensional, estimation of sway/rocking, etc.), choice of input ground motions or spectral content/intensity, stochastic or deterministic analysis, etc.

5.6 Soil-Structure Interaction

Since NBC and BSL do not have any provisions for soil-structure interaction, a practical procedure for consideration of the interaction should be proposed. The effect of lengthened period is not the only factor. The effects of embedded basement, pile foundation, etc. should also be studied. Furthermore, effects which are not included in the factor, such as liquifaction, land slides, and faults, cannot be neglected.

6. SUMMARY AND CONCLUSIONS

The Canadian code (NBC) is mainly based on limit state design whereas the Japanese code (BSL) is based on working stress design and ultimate design.

Both codes include the effects of seismic risk, spectral contents, energy absorption capacity and soil/foundation for seismic load. The importance of a building is included in NBC but not in BSL.

The other effects included are torsion, mass and stiffness distribution, storey drift limitation, overturning moment reduction (only in NBC), seismic load for appendages, and dynamic analysis. The details of the provisions are fairly different in the NBC and BSL. Therefore, a numerical comparison is difficult and has little importance without taking account of specific details. However, for limited sets of parameters, a comparison of base shear coefficients is shown in Appendix F. Soil-structure interaction is not included in either code.

Future research for codification should be carried out in the areas of seismic risk, design for severe earthquakes, torsion, discontinuity, dynamic analysis and soil-structure interaction.

7. ACKNOWLEDGEMENTS

This report was prepared while the author was at the Noise and Vibration Section, Division of Building Research, National Research Council Canada, as a visiting fellow of the Natural Sciences and Engineering Research Council of Canada. The author wishes to express deepest appreciation to NRC and NSERC for their support, to Dr. J.H. Rainer for his advice and reviewing, and to Miss L. Ernst for typing the manuscript.

REFERENCES

(1) "National Building Code of Canada, 1985." Associate Committee on the National Building Code, National Research Council Canada, Ottawa, NRCC 23174, pp. 165-172.

(2) "National Building Code of Canada, 1980." Associate Committee on the National Building Code, National Research Council Canada, Ottawa, NRCC 17303, pp. 147-154.

(3) "Supplement to the National Building Code of Canada, 1980." Associate Committee on the National Building Code, National Research Council Canada, Ottawa, NRCC 17724, pp. 209-240.

(4) "Earthquake Resistant Regulations: A World List - 1984." International Association for Earthquake Engineering, July 1984, pp. 534-546.

(5) A.C. Heidebrecht, et al. "Engineering Applications of New Probabilistic Seismic Ground-Motion Maps of Canada." Canadian Journal of Civil Engineering, Vol. 10, No. 4, 1983, pp. 670-680.

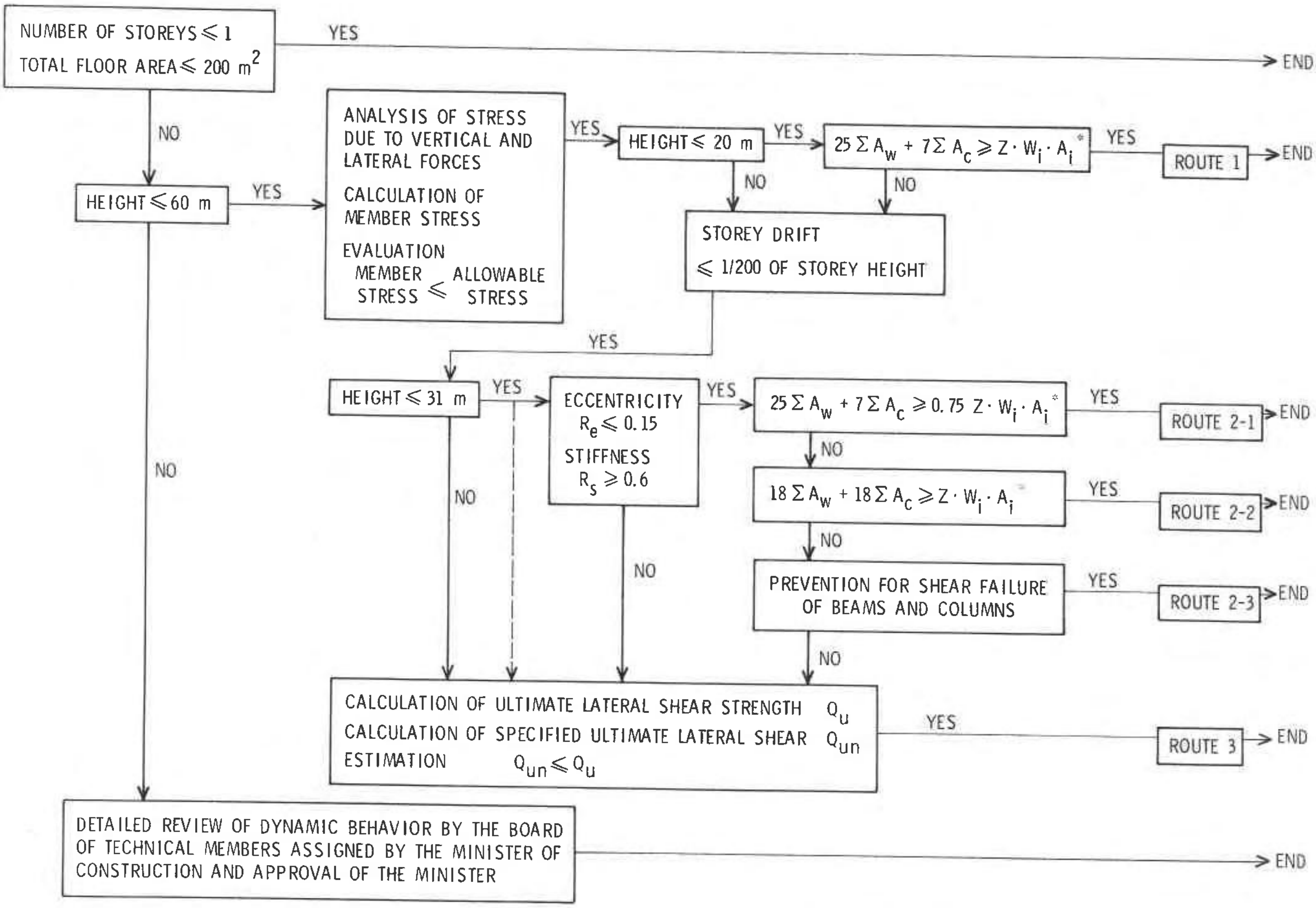
(6) S. Hattori. "Regional Distribution of Presumable Maximum Earthquake Motions at the Base Rock in the Whole Vicinity of Japan." Bulletin of the International Institute of Seismology and Earthquake Engineering, Vol. 14, 1976, pp. 47-86.

(7) S. Hattori. "Regional Peculiarities on the Maximum Amplitudes of Earthquake Motion in Japan." Bulletin of the International Institute of Seismology and Earthquake Engineering, Vol. 15, 1977, pp. 1-21.

(8) "Guideline and Commentary for Structural Calculations Based on the New Aseismic Design Method of Revised Building Standard Law Enforcement Order." (In Japanese.) Building Instruction Department, Housing Bureau and Building Research Institute, Ministry of Construction, Building Centre of Japan, Tokyo, 1981.

(9) "Tentative Provisions for the Development of Seismic Regulations for Buildings." Applied Technology Council, National Bureau of Standards Special Publication 510, Washington, DC, 1978; second revised printing 1984.

APPENDIX A: Design Procedures for Reinforced Concrete Buildings (BSL)



* NOTE: ΣA_w = TOTAL AREA OF SHEAR WALLS (cm^2)

ΣA_c = TOTAL AREA OF COLUMNS (cm^2)

W_i = WEIGHT OF THE BUILDING ABOVE THE i-th STOREY (kg)

25 = AVERAGE ULTIMATE SHEAR STRENGTH OF SHEAR WALLS (kg/cm^2)

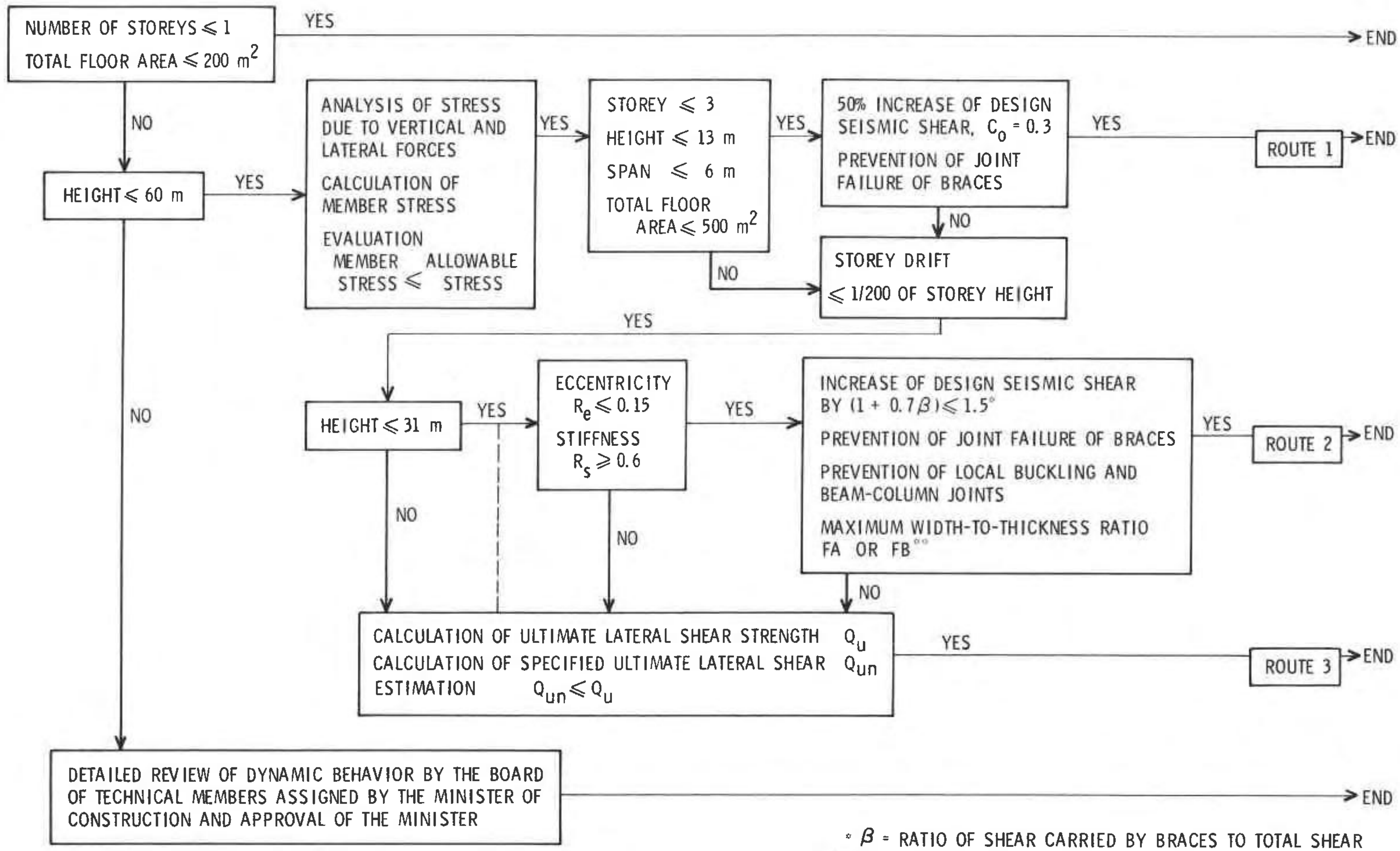
7 = AVERAGE ULTIMATE SHEAR STRENGTH OF COLUMNS (kg/cm^2)

18 = AVERAGE ULTIMATE SHEAR STRENGTH OF SHEAR WALLS AND COLUMNS (kg/cm^2)

THE ABOVE ARE GIVEN IN JAPANESE CONVENTIONAL UNITS.
THE CONVERSION IS:

1 kg = 9.8 N

1 kg/cm^2 = 98 kPa



* β = RATIO OF SHEAR CARRIED BY BRACES TO TOTAL SHEAR

** SEE TABLE D3

APPENDIX C: STRUCTURAL COEFFICIENT FOR REINFORCED CONCRETE BUILDINGS (BSL)

TABLE C1

Structural Coefficient D_s

Type of Frame**	TYPE OF SHEAR WALL*					
	WA			WB		
	$\beta_u<0.3$	$0.3<\beta_u<0.7$	$\beta_u>0.7$	$\beta_u<0.3$	$0.3<\beta_u<0.7$	$\beta_u>0.7$
FA	0.3	0.35	0.4	0.35	0.4	0.45
FB	0.35	0.4	0.45	0.35	0.4	0.45
FC	0.4	0.45	0.45	0.4	0.45	0.5
FD	0.45	0.5	0.55	0.45	0.5	0.55

Type of Frame**	TYPE OF SHEAR WALL*					
	WC			WD		
	$\beta_u<0.3$	$0.3<\beta_u<0.7$	$\beta_u>0.7$	$\beta_u<0.3$	$0.3<\beta_u<0.7$	$\beta_u>0.7$
FA	0.35	0.4	0.5	0.4	0.45	0.55
FB	0.35	0.45	0.5	0.4	0.5	0.55
FC	0.4	0.45	0.5	0.45	0.5	0.55
FD	0.45	0.5	0.55	0.45	0.5	0.55

*For classification of shear walls WA, WB, WC and WD, see Table C2.
**For classification of frames FA, FB, FC and FD, see Table C3.
β_u: Ratio of ultimate shear carried by shear walls to total ultimate shear.

TABLE C2

Classification of Shear Walls

Type of shear wall:	WA	WB	WC	WD
Shear failure:	not allowed			other than WA, WB or WC
Upper limit of τ_u/F_c:	0.2	0.25	no limit	

τ_u: Average shear stress (kg/cm^2) at the time of failure mechanism.
F_c: Standard strength of concrete (kg/cm^2).
Note: 1 kg/cm^2 = 98 kPa.

TABLE C3

Classification of Frames

Type of Frame:		FA	FB	FC	FD
Failure Mode:		Bending Failure			other than WA, WB or WC
Columns	h_0/D	≥ 2.5	≥ 2.0	no limit	
	$\sigma \leq F_c$	≤ 0.35	≤ 0.45	≤ 0.55	
	p_t	$\leq 0.8\%$	$\leq 1.0\%$	no limit	
	$\tau_u \leq F_c$	≤ 0.1	≤ 0.125	≤ 0.15	
Beams	$\tau_u \leq F_c$	≤ 0.15	≤ 0.2	no limit	

h_0: Clear height of columns (cm).
D: Depth of columns (cm)
σ: Normal stress (kg/cm^2) at the time of failure mechanism.
F_c: Standard strength of concrete (kg/cm^2).
p_t: Ratio of tensile reinforcement.
τ_u: Average shear stress at the time of failure mechanism.
Note: 1 kg/cm^2 = 98 kPa.

APPENDIX D: STRUCTURAL COEFFICIENT FOR STEEL BUILDINGS (BSL)

TABLE D1

Structural Coefficients D_s

Type of Moment Resisting Portion of Braced Frames**	TYPE OF BRACES OF BRACED FRAMES*			
	BA or $\beta_u=0$	BB $\beta_u<0.3$	BB $0.3<\beta_u<0.7$	BB $\beta_u>0.7$
FA***	0.25	0.25	0.3	0.35
FB***	0.3	0.3	0.3	0.35
FC***	0.35	0.35	0.35	0.4
FD	0.4	0.4	0.45	0.5

Type of Moment Resisting Portion of Braced Frames**	TYPE OF BRACES OF BRACED FRAMES* BC		
	$\beta<0.3$	$0.3<\beta_u<0.5$	$\beta_u>0.5$
FA***	0.3	0.35	0.4
FB***	0.3	0.35	0.4
FC***	0.35	0.4	0.45
FD	0.4	0.45	0.5

*For classification of braces BA, BB and BC, see Table D2.

**For classificaton of moment resisting portion of braced frames, see Table D3.

***The following are required for FA, FB and FC frames:

- joints of braces will not break before the braces yield;
- yield hinges will not occur at beam-column joints;
- transverse supports for beams will be required to prevent out-of-plane buckling.

β_u: Ratio of ultimate shear carried by braces to total ultimate shear.

TABLE D2

Classification of Bracing

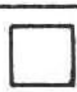
BA	BB	BC
$\lambda \leq 50/\sqrt{F}$	$50/\sqrt{F} < \lambda \leq 90\sqrt{F}$	$90/\sqrt{F} < \lambda < 200/\sqrt{F}$

OR: $\lambda > 200/\sqrt{F}$

λ: Effective slenderness ratio of braces.
F: Standard strength of braces (t/cm^2) (see the footnote to Table D3).
Note: 1 t/cm^2 = 98 MPa.

TABLE D3

Classification of Columns and Beams

	Type of Frame:			FA	FB	FC	FD
Members	Section	Portion	Steel	Maximum Width-to-Thickness Ratio			
Columns		Flange	SS41*	9.5	12	15.5	greater width-to-thickness ratio than those of FC
			SM50**	8	10	13.2	
		Web	SS41	43	45	48	
			SM50	37	39	41	
			SS41	33	37	48	
			SM50	27	32	41	
			SS41	50	70	100	
			SM50	36	50	73	
Beams		Flange	SS41	9	11	15.5	
			SM50	7.5	9.5	13.2	
		Web	SS41	60	65	71	
			SM50	51	55	61	

*Steel conforming to SS41, SM41, SMA41, STK41 and STKR41 in Japan Industrial Standard (JIS). (standard strength F = 2.4 t/cm^2.)
**Steel conforming to SM50, SMA50, SM50Y, STK50 and STKR50 in JIS. (standard strength F = 3.3 t/cm^2.)
Note: 1 t/cm^2 = 98 MPa.

APPENDIX E: CLASSIFICATION OF SOILS

TABLE E1
Soil Description and Foundation Factor F (NBC)

Soil Type	Type and Depth of Soil Measured From the Foundation or Pile Cap Level	F
Hard Soil	Rock, dense and very dense coarse-grained soils, very stiff and hard fine-grained soils; compact coarse-grained soils and firm and stiff fine-grained soils from 0 to 15 m deep.	1.0
Medium Soil	Compact coarse-grained soils, firm and stiff fine-grained soils with a depth greater than 15 m; very loose and loose coarse-grained soils and very soft and soft fine-grained soils from 0 to 15 m deep.	1.3
Soft Soil	Very loose and loose coarse-grained soils, and very soft and soft fine-grained soils with depths greater than 15 m (see Appendix A in NBC 1985).	1.5

TABLE E2
Soil Description and Critical Period T_c (BSL)

Soil Type	Ground Characteristics	T_c*
TYPE 1 (Hard Soil)	Ground consisting of rock, hard sandy gravel, etc. classified as Tertiary or older. Or ground whose ground period, estimated by calculation or by other investigation, is equivalent to that of the above.	0.4
TYPE 2 (Medium Soil)	Other than Type 1 or 2.	0.6
TYPE 3 (Soft Soil)	Alluvium consisting of soft delta deposits, topsoil, mud, or the like (including fills, if any), whose depth is 30 m or more, land obtained by reclamation of a marsh, muddy sea bottom, etc., where the depth of the reclaimed ground is 3 m or more and where 30 years have not yet elapsed since the time of reclamation. Or ground whose ground period, estimated by calculation or by other investigation, is equivalent to that of the above.	0.8

*Critical period (see Section 3.4).

APPENDIX F: COMPARISON OF BASE SHEAR COEFFICIENTS

1. NBC: $C_B = v \cdot S \cdot K \cdot I \cdot F$ (see Equation (4), Section 3.2).

   where K = 1.0, I = 1.0, and F = 1.0

Victoria	$Z_a = 5$, $Z_v = 5$, $v = 0.30$
Vancouver	$Z_a = 4$, $Z_v = 4$, $v = 0.20$
Ottawa Montreal	$Z_a = 4$, $Z_v = 2$, $v = 0.10$
Toronto	$Z_a = 1$, $Z_v = 0$, $v = 0.05$

2. BSL: $C_B = Z \cdot R_t \cdot C_0$ (see Equation (5), Section 3.2).

   where $C_0 = 0.2$ and R_t for hard soil

Tokyo	Z = 1.0
Okinawa	Z = 0.7

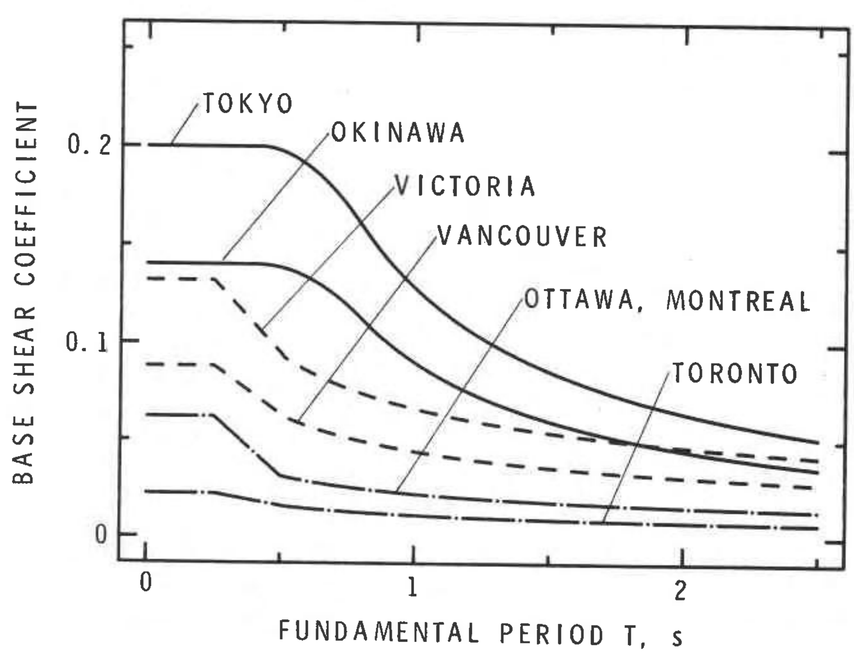


Figure F1. Comparison of base shear coefficients