Rapid Load Evaluation for Steel Buildings and Bridges with NBCC/IBC/CHBDC

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1.0 Introduction

Load evaluation is a critical step in the structural design. The live loads and environmental loads on a structure are highly variable depending on the occupancy, geography and climate of the location of the structure. Thus, building and bridge codes provide guidelines for types and magnitudes of loads to be considered in structural design. However, as the codes cover a wide variety of structures and load cases, it is often a time consuming process to decipher the appropriate load cases for the problem at hand.

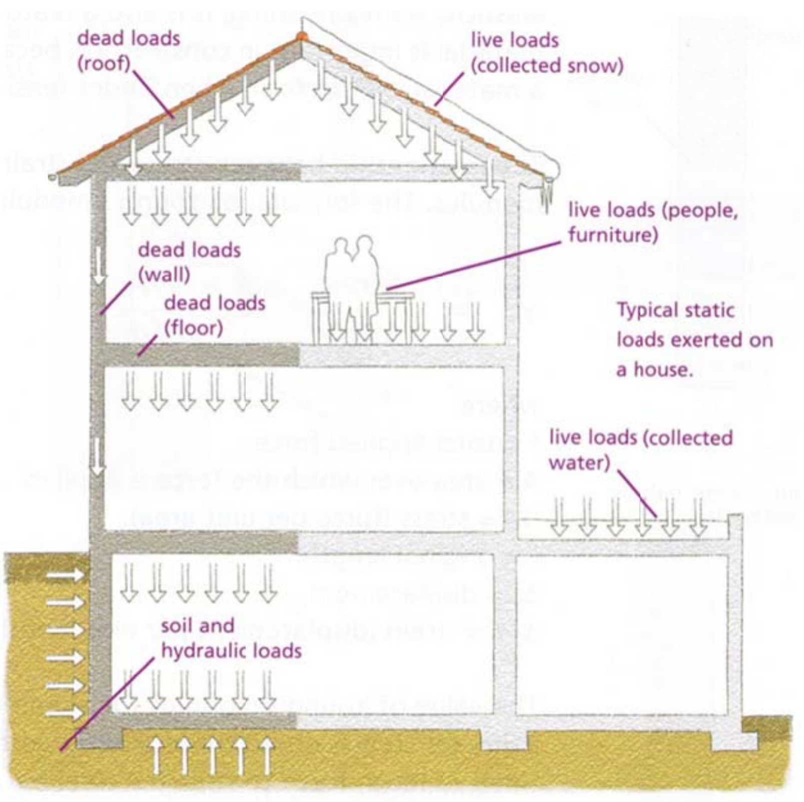


Figure 1: Types of loads on a typical building

In the present report, the load cases according to Canadian Highway Bridge Design Code (CHBDC) [1], National Building Code of Canada (NBCC) [2], and International Building Code (IBC) [3] are presented. At first, the load cases and combinations based on CHBDC (CAN/CSA S6.06) are presented. This is followed by the load cases and combinations for buildings as per the NBCC (NBCC 2005) and IBC (IBC 09). Finally, a numerical example for rapid load evaluation of a steel building is provided.

2.0 Canadian Highway Bridge Design Code

The Section 3 of CHBDC S6.06 primarily addresses the load cases relevant to steel bridges. The bridge code considers three types of loads; Permanent loads, transitory loads, and exceptional loads. It provides the load combinations for fatigue limit state (FLS), serviceability limit state (SLS) and the ultimate limit state (ULS). Tables 1 and 2 show the load combinations considered in the bridge code.

Table 1: CHBDC load combinations for FLS and SLS [S6.06, Table 3.1]

Loads	FLS	SLS-1	SLS-2
Permanent			
Dead load	1.0	1.0	0
Surcharge	1.0	1.0	0
Prestress	1.0	1.0	0
Transitory			
Live load	1.0	0.9	0.9
Effects of strains, deformations, displacements	0	0.8	0
Load due to differential settlement	0	1.0	0

Table 2: CHBDC load combination for ULS [S6.06, Table 3.1]

Loads	1	2	3	4	5	6	7	8	9
Permanent									
Dead load	α_D	α_D	α_D	α_D	α_D	α_D	α_D	α_D	1.35
Surcharge	α_E	α_E	α_E	α_E	α_E	α_E	α_E	α_E	α_E
Prestress	α_P	α_P	α_P	α_P	α_P	α_P	α_P	α_P	α_P
Transitory									
Live load	1.7	1.6	1.4	0	0	0	0	0	0
Effects of strains, deformations, displacements	0	1.15	1.0	1.25	0	0	0	0	0
Wind load on structure	0	0	0.5	1.65	0	0	0.9	0	0
Wind load on vehicles	0	0	0.5	0	0	0	0	0	0
Exceptional									
Earthquake	0	0	0	0	1.0	0	0	0	0
Stream loads, ice pressure	0	0	0	0	0	1.3	0	0	0
Ice acceleration	0	0	0	0	0	0	1.3	0	0
Collision	0	0	0	0	0	0	0	1.0	0

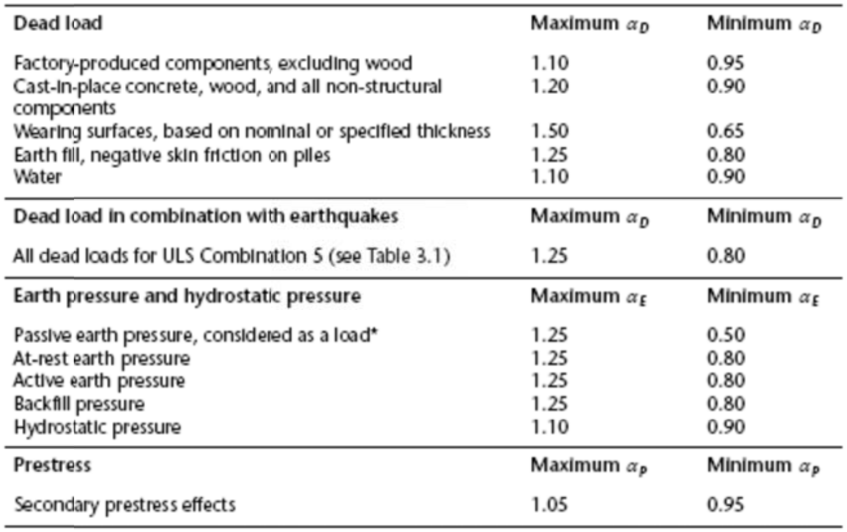
The description of load types and the load factors for the permanent loads are described in the following subsections.

2.1 Permanent Loads

Permanent loads are defined as those that are present always present on the bridge structure. These are dead loads from the self-weight of the structures, any permanent surcharge load due to earth pressure or hydrostatic pressure, and loads resulting from prestress.

Depending on the component type, such as factory-produced, or cast-in-place, the load factors for the dead loads vary. Similarly, depending on the type of earth pressure, such as active, or passive, the load factors vary. The load factors for the permanent loads are given in Table 3.

Table 3: Permanent loads – load factors for ULS [S6.06, Table 3.2]



Dead load	**Maximum α_D**	**Minimum α_D**
Factory-produced components, excluding wood	1.10	0.95
Cast-in-place concrete, wood, and all non-structural components	1.20	0.90
Wearing surfaces, based on nominal or specified thickness	1.50	0.65
Earth fill, negative skin friction on piles	1.25	0.80
Water	1.10	0.90
Dead load in combination with earthquakes	**Maximum α_D**	**Minimum α_D**
All dead loads for ULS Combination 5 (see Table 3.1)	1.25	0.80
Earth pressure and hydrostatic pressure	**Maximum α_E**	**Minimum α_E**
Passive earth pressure, considered as a load*	1.25	0.50
At-rest earth pressure	1.25	0.80
Active earth pressure	1.25	0.80
Backfill pressure	1.25	0.80
Hydrostatic pressure	1.10	0.90
Prestress	**Maximum α_P**	**Minimum α_P**
Secondary prestress effects	1.05	0.95

2.2 Transitory Loads

Transitory loads comprise of live loads, including dynamic allowance, wind loads on the structure and the vehicles, loads caused due to differential settlements, and the load effects caused by the strains, deformations and displacements due to temperature change and temperature differential, concrete shrinkage, differential shrinkage and creep. These are considered only when there is a possibility of their occurrence and if their inclusion increases the total factored load effect.

The live loads are evaluated based on the number of design lanes and the specified CL-W Truck, the idealized five-axle truck, loading as shown in Figure 2. (S6.06, C3.8)

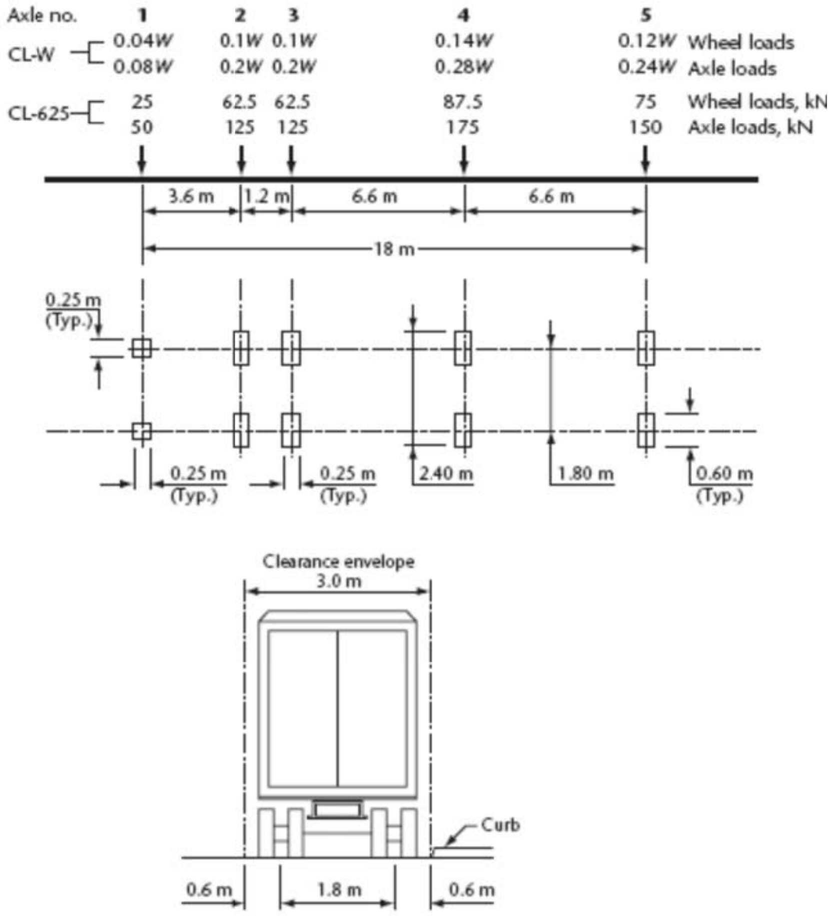


Figure 2: CL-W Truck load distribution [S6.06, Figure 3.2]

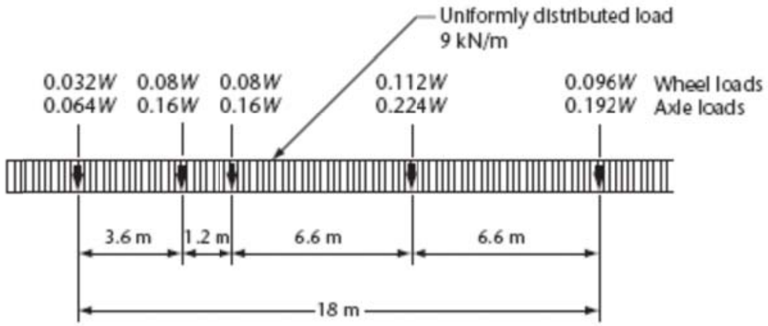


Figure 3: CL-W lane load [S6.06, Figure 3.3]

Figure 3 shows the design lane load, which has the CL-W Truck axle loads reduced by 20% and has a superimposed uniformly distributed load of 9kN/m. For FLS and SLS-2, only the truck load in Figure 2 is considered. For all the other load combinations, either the lane load in Figure 3 or the truck load in Figure 2 with dynamic load allowance, whichever produces a higher load effect is considered.

The load effects due to temperature change and temperature differential have greater influence on the steel bridges with concrete deck than those with steel deck (S6.06, C3.9.3, C3.9.4). The wind loads have greater effect on the superstructures of long-span bridges (S6.06, C3.10).

2.3 Exceptional Loads

The exceptional loads are considered only for the ULS combinations. These are; earthquake loads, loads to stream pressure and ice pressure or debris torrents, loads due to ice acceleration, and loads caused by the collision of vessels, or highway vehicles to the bridge (S6.06, C3.11-3.15). These are specific to the bridge type and the location of the bridge.

3.0 National Building Code

The structural loads and combinations are addressed in Part 4 of NBCC05. This code provides load cases and load combinations only for the load and resistance factor design (LRFD). There are five main load categories, which are, dead loads (D), live loads (L), snow and rain loads (S), wind loads (W) and earthquake loads (E). Additionally, NBCC also considers permanent loads due to lateral earth pressure including ground water (H), permanent effects due to prestress (P), and the load effects due to the strains, deformations and displacements due to changes in temperature, moisture content and so on (T). These loads are considered when they specifically affect the structural safety. For the ultimate limit states of typical buildings, the load combinations provided in Table 4 are generally considered.

Table 4: ULS load combinations [NBCC05, Table 4.1.3.2]

Case	Principal loads	Companion loads
1	1.4D	-
2	1.25D+1.5L	0.5S or 0.4W
3	1.25D+1.5S	0.5L or 0.4W
4	1.25D+1.4W	0.5L or 0.5S
5	1.4W or 1.5L or 1.5S	-
6	1.0D+1.0E	0.5L+0.25S
7	1.0E	-

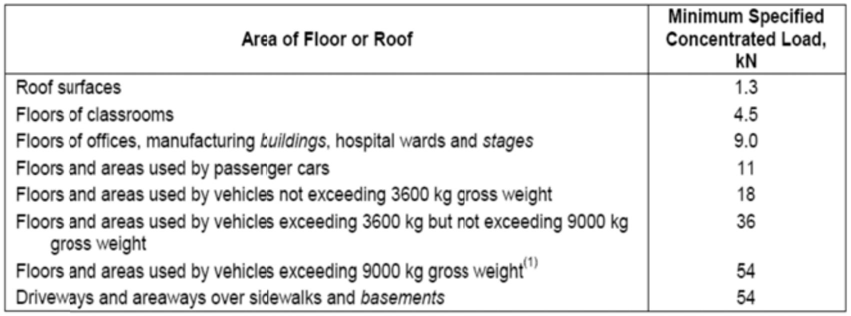
3.1 Dead Loads

In NBCC05, the dead loads include the self-weight of the structural member, and all the permanent loads supported by the member including those of partitions, materials, vertical load of soil, plants and trees. However, when the partition dead loads and the vertical loads due to soil, superimposed earth, plant and trees are counteractive, they must not be included for estimating the design load (NBCC05, C4.1.4).

3.2 Live Loads

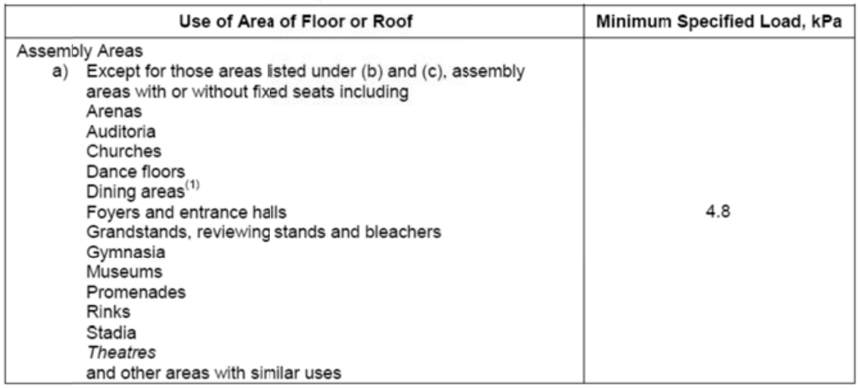
The live loads are evaluated based on the intended occupancy of the buildings. The NBCC05 provides the minimum uniformly distributed loads and concentrated loads based on the intended use and the occupancy of the buildings. A list of building uses and the corresponding minimum specified live loads are shown in Tables 5 and 6.

Table 5: Concentrated live load [NBCC05, Table 4.1.5.10]

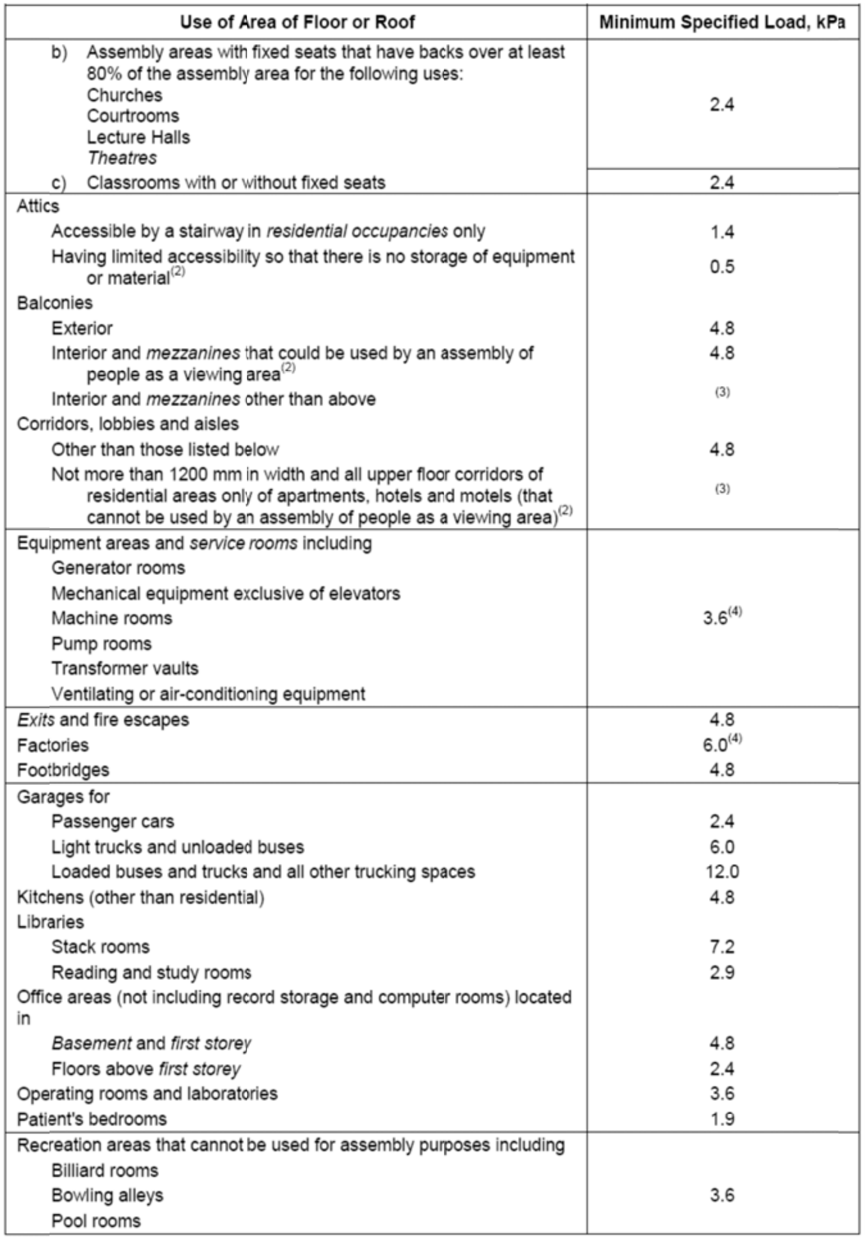


Area of Floor or Roof	Minimum Specified Concentrated Load, kN
Roof surfaces	1.3
Floors of classrooms	4.5
Floors of offices, manufacturing *buildings*, hospital wards and *stages*	9.0
Floors and areas used by passenger cars	11
Floors and areas used by vehicles not exceeding 3600 kg gross weight	18
Floors and areas used by vehicles exceeding 3600 kg but not exceeding 9000 kg gross weight	36
Floors and areas used by vehicles exceeding 9000 kg gross weight(1)	54
Driveways and areaways over sidewalks and *basements*	54

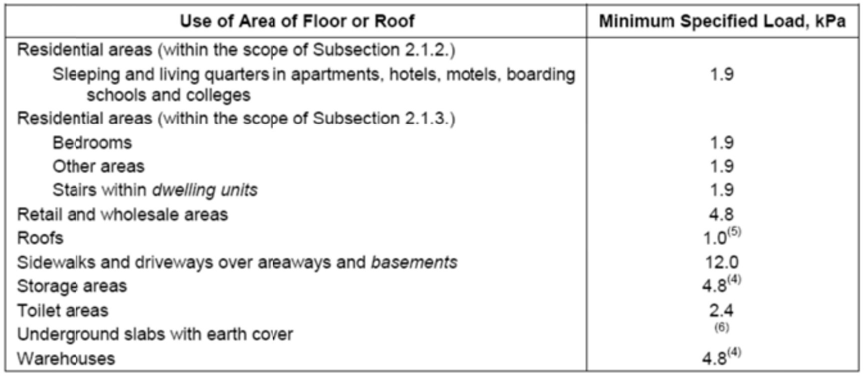
Table 6: Minimum uniformly distributed live load [NBCC05, Table 4.1.5.3]



Use of Area of Floor or Roof	Minimum Specified Load, kPa
Assembly Areas a) Except for those areas listed under (b) and (c), assembly areas with or without fixed seats including Arenas Auditoria Churches Dance floors Dining areas(1) Foyers and entrance halls Grandstands, reviewing stands and bleachers Gymnasia Museums Promenades Rinks Stadia *Theatres* and other areas with similar uses	4.8



Use of Area of Floor or Roof	Minimum Specified Load, kPa
b) Assembly areas with fixed seats that have backs over at least 80% of the assembly area for the following uses: Churches Courtrooms Lecture Halls *Theatres*	2.4
c) Classrooms with or without fixed seats	2.4
Attics	
Accessible by a stairway in *residential occupancies* only	1.4
Having limited accessibility so that there is no storage of equipment or material(2)	0.5
Balconies	
Exterior	4.8
Interior and *mezzanines* that could be used by an assembly of people as a viewing area(2)	4.8
Interior and *mezzanines* other than above	(3)
Corridors, lobbies and aisles	
Other than those listed below	4.8
Not more than 1200 mm in width and all upper floor corridors of residential areas only of apartments, hotels and motels (that cannot be used by an assembly of people as a viewing area)(2)	(3)
Equipment areas and *service rooms* including Generator rooms Mechanical equipment exclusive of elevators Machine rooms Pump rooms Transformer vaults Ventilating or air-conditioning equipment	3.6(4)
Exits and fire escapes	4.8
Factories	6.0(4)
Footbridges	4.8
Garages for	
Passenger cars	2.4
Light trucks and unloaded buses	6.0
Loaded buses and trucks and all other trucking spaces	12.0
Kitchens (other than residential)	4.8
Libraries	
Stack rooms	7.2
Reading and study rooms	2.9
Office areas (not including record storage and computer rooms) located in	
Basement and *first storey*	4.8
Floors above *first storey*	2.4
Operating rooms and laboratories	3.6
Patient's bedrooms	1.9
Recreation areas that cannot be used for assembly purposes including Billiard rooms Bowling alleys Pool rooms	3.6



Use of Area of Floor or Roof	Minimum Specified Load, kPa
Residential areas (within the scope of Subsection 2.1.2.)	
Sleeping and living quarters in apartments, hotels, motels, boarding schools and colleges	1.9
Residential areas (within the scope of Subsection 2.1.3.)	
Bedrooms	1.9
Other areas	1.9
Stairs within *dwelling units*	1.9
Retail and wholesale areas	4.8
Roofs	1.0(5)
Sidewalks and driveways over areaways and *basements*	12.0
Storage areas	4.8(4)
Toilet areas	2.4
Underground slabs with earth cover	(6)
Warehouses	4.8(4)

3.3 Snow Loads

The NBCC05 considers snow loads and the associated due to rain accumulation together. The specified snow loading is computed as, (NBCC05, C4.1.6.2)

$$S = I_s(S_s \cdot C_b \cdot C_w \cdot C_s \cdot C_a + S_r) \tag{1}$$

where,

I_s = the importance factor depending on the category of the building as listed in Table 7,

S_s = 1-in-50 years ground snow load in kPa

C_b = the basic roof snow load factor = 0.8, except for large roofs

C_w = the wind exposure factor = 1.0, except for buildings with more exposure

C_s = the slope factor = 1.0 for roof slope, $\alpha < 30^o$

= $(70^o - \alpha)/40^o$ for $30^o < \alpha < 70^o$

= 0 for $\alpha > 70^o$, except for slippery roofs

C_a = the shape factor = 1.0, except for roofs with non-uniform snow loads

S_r = 1-in-50 years associated rain load in kPa

However, S_r must not be greater than $S_s(C_bC_wC_sC_a)$.

Table 7: Importance factor for snow load [NBCC05, Table 4.1.6.2]

Importance Category	Importance factor , I_s	
	ULS	SLS
Low	0.8	0.9
Normal	1.0	0.9
High	1.15	0.9
Post Disaster	1.25	0.9

3.4 Wind Loads

The wind loads are computed as the pressure acting normal to the surface of the building under consideration. The external pressure is computed as,(NBCC05, C4.1.7.1)

$$p = I_w \cdot q \cdot C_e \cdot C_g \cdot C_p \tag{2}$$

Where,
I_w = Importance factor of the wind loads as shown in Table 8
q = the reference velocity pressure with the probability of exceeding in any one year of 1 in 50.
C_e = the exposure factor = $(h/10)^{0.2} > 0.9$ for open terrain
= $0.7(h/12)^{0.3} > 0.7$ for rough terrain, where h is the height of the surface above grade
= an intermediate value for other terrains or a dynamic approach
C_g = the gust effect factor = 2.0 for structural members
= 2.5 for small elements, including cladding
C_p = the external pressure coefficient

The values of C_p are dependent on the height of the building, roof shape, and roof slope. Figure 4 shows the flowchart to assess C_p and the wind pressures, based on the height of the building, roof dimensions, and design element. The internal pressures are computed similar to Eq.(2) with internal gust effect factor, C_{gi}, and the internal pressure coefficient, C_{pi}.

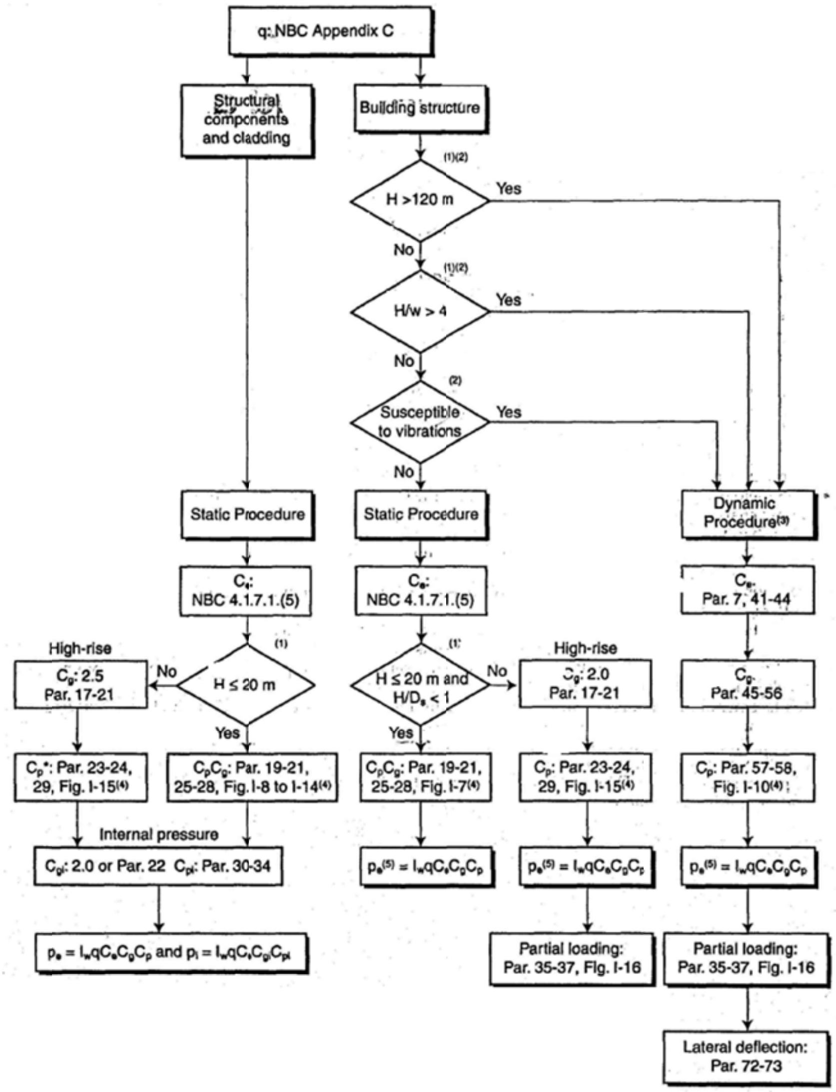
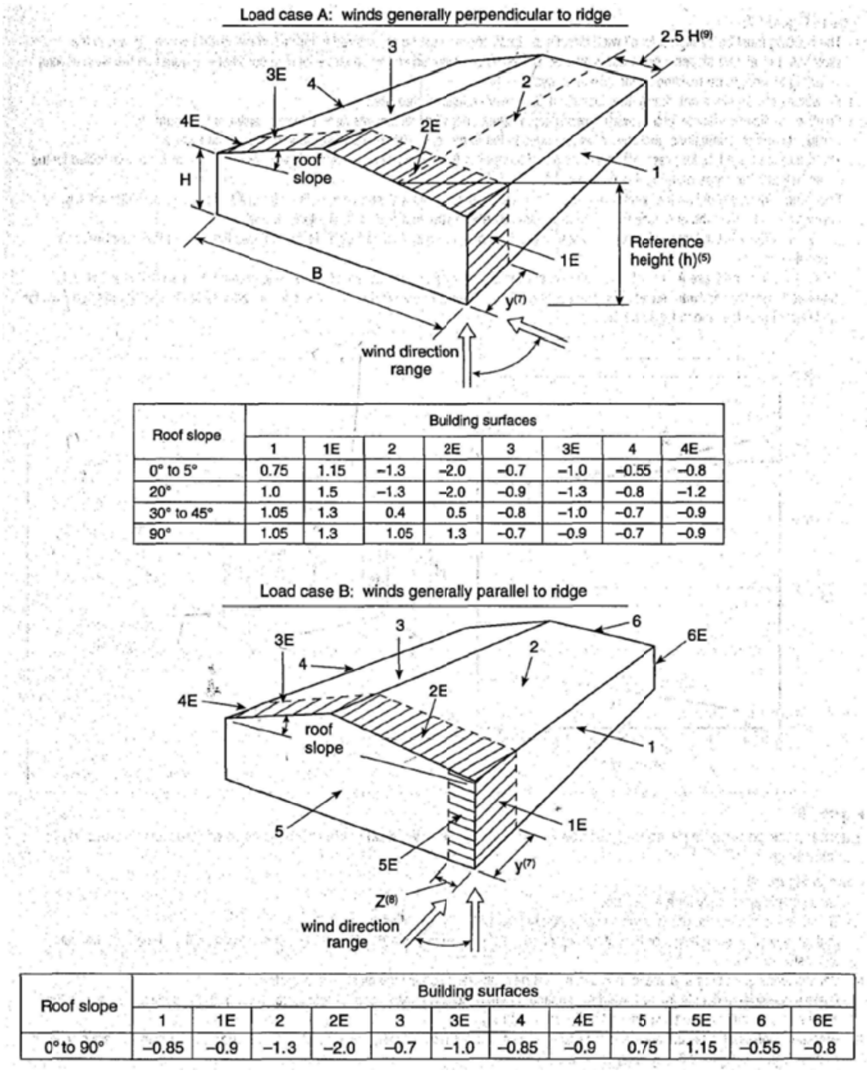


Figure 4: Flowchart to evaluate wind loading on buildings [2]



Roof slope	Building surfaces							
	1	1E	2	2E	3	3E	4	4E
0° to 5°	0.75	1.15	−1.3	−2.0	−0.7	−1.0	−0.55	−0.8
20°	1.0	1.5	−1.3	−2.0	−0.9	−1.3	−0.8	−1.2
30° to 45°	1.05	1.3	0.4	0.5	−0.8	−1.0	−0.7	−0.9
90°	1.05	1.3	1.05	1.3	−0.7	−0.9	−0.7	−0.9

Roof slope	Building surfaces											
	1	1E	2	2E	3	3E	4	4E	5	5E	6	6E
0° to 90°	−0.85	−0.9	−1.3	−2.0	−0.7	−1.0	−0.85	−0.9	0.75	1.15	−0.55	−0.8

Figure 5: Assessment of C_pC_g for low-rise buildings with height <20m [2]

Figures 5 and 6 provide the values of C_p for the primary structural system depending on the building type under consideration.

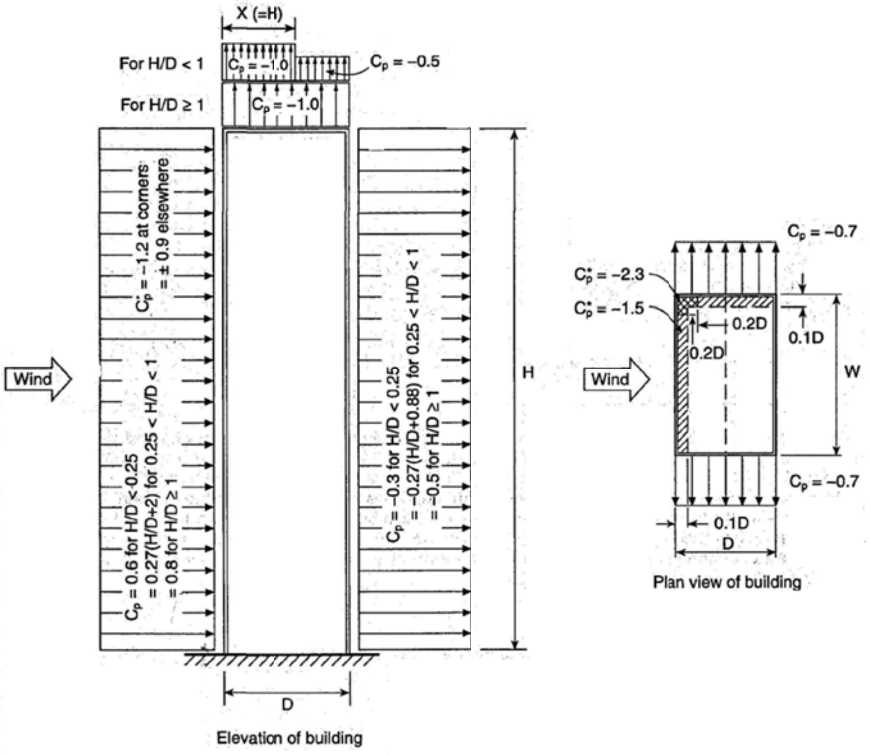


Figure 6: Assessment of C_p for buildings with height > 20m [2]

Table 8: Importance factor for wind load [NBCC05, Table 4.1.7.1]

Importance Category	Importance factor , I_w	
	ULS	SLS
Low	0.8	0.75
Normal	1.0	0.75
High	1.15	0.75
Post Disaster	1.25	0.75

The net wind pressure on a surface is the difference between the internal and external wind pressure. The net wind load (W) on a building is the difference between the wind pressures on the windward surface and the leeward surface of the building.

3.5 Earthquake Loads

The NBCC05 recommends dynamic analysis procedures for the buildings that are

- irregular of types 1-5,7, according to Table 9, and have the height greater than 20m and fundamental period greater than 0.5s.
- of height greater than 60m and fundamental period greater than 2s
- for cases where $I_E F_a S_a(0.2)>0.35$, where I_E is the importance factor for earthquake load as per Table 10, F_a is the acceleration-based site coefficient, $S_a(0.2)$ is the 5% damped spectral acceleration at period 0.2s, expressed in units of g (acceleration due to gravity).

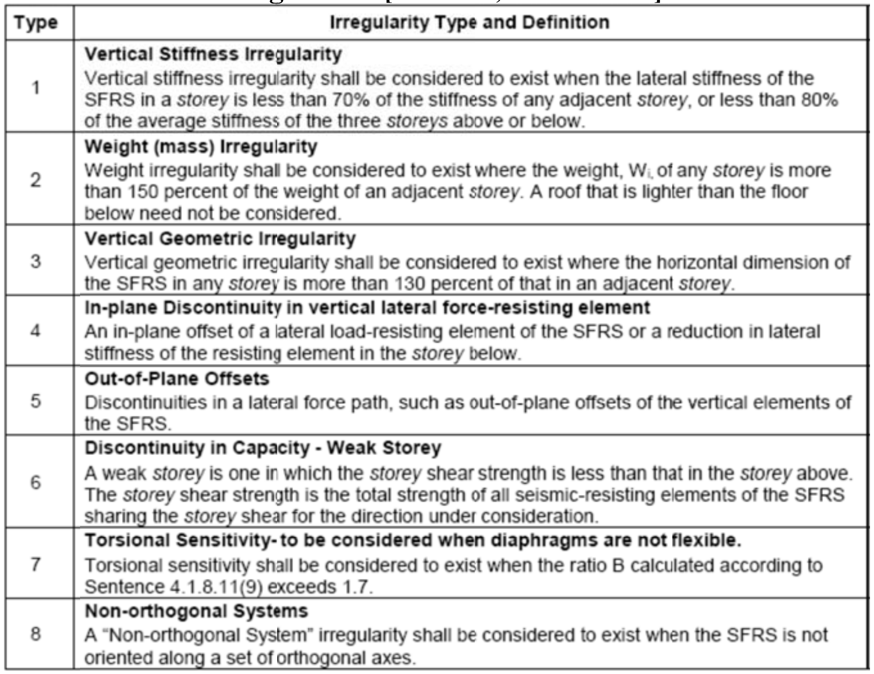
For the buildings that are outside the above criteria, the lateral earthquake load to be applied for a static analysis procedure is specified as, (NBCC05, C4.1.8.11)

$$V = S(T_a) \cdot M_v \cdot I_E \cdot W/(R_d \cdot R_o) \qquad (3)$$

$$V > S(2.0) \cdot M_v \cdot I_E \cdot W/(R_d \cdot R_o) \qquad (4)$$

Where V is the base shear, $S(T_a)$ is the design spectral acceleration at fundamental period of the structure T_a, M_v is the factor accounting for the higher mode effects on the base shear, W is the weight of the building, R_d is the ductility factor which allows for force reduction due to the inelastic behavior of the structure, and R_o is the overstrength factor that allows for force reduction due to the dependable reserve strength of the structure.

Table 9: Structural irregularities [NBCC05, Table 4.1.8.6]



Type	Irregularity Type and Definition
1	**Vertical Stiffness Irregularity** Vertical stiffness irregularity shall be considered to exist when the lateral stiffness of the SFRS in a *storey* is less than 70% of the stiffness of any adjacent *storey*, or less than 80% of the average stiffness of the three *storeys* above or below.
2	**Weight (mass) Irregularity** Weight irregularity shall be considered to exist where the weight, W_L of any *storey* is more than 150 percent of the weight of an adjacent *storey*. A roof that is lighter than the floor below need not be considered.
3	**Vertical Geometric Irregularity** Vertical geometric irregularity shall be considered to exist where the horizontal dimension of the SFRS in any *storey* is more than 130 percent of that in an adjacent *storey*.
4	**In-plane Discontinuity in vertical lateral force-resisting element** An in-plane offset of a lateral load-resisting element of the SFRS or a reduction in lateral stiffness of the resisting element in the *storey* below.
5	**Out-of-Plane Offsets** Discontinuities in a lateral force path, such as out-of-plane offsets of the vertical elements of the SFRS.
6	**Discontinuity in Capacity - Weak Storey** A weak *storey* is one in which the *storey* shear strength is less than that in the *storey* above. The *storey* shear strength is the total strength of all seismic-resisting elements of the SFRS sharing the *storey* shear for the direction under consideration.
7	**Torsional Sensitivity- to be considered when diaphragms are not flexible.** Torsional sensitivity shall be considered to exist when the ratio B calculated according to Sentence 4.1.8.11(9) exceeds 1.7.
8	**Non-orthogonal Systems** A "Non-orthogonal System" irregularity shall be considered to exist when the SFRS is not oriented along a set of orthogonal axes.

For a seismic force resisting system (SFRS) with R_d greater than or equal to 1.5, the base shear is,

$$V \leq \tfrac{2}{3} S(2.0) \cdot I_E \cdot W/(R_d \cdot R_o) \qquad (5)$$

Table 10: Importance factor for earthquake load [NBCC05, Table 4.1.8.5]

Importance Category	Importance factor , I_E
	ULS
Low	0.8
Normal	1.0
High	1.3
Post Disaster	1.5

The design spectral acceleration is computed as (NBCC05, C4.1.8.4.6),

$$S(T) = F_a S_a(0.2) \text{ for } T \leq 0.2s$$
$$= F_v S_a(0.5) \text{ or } F_a S_a(0.2) \text{ whichever is smaller for } T = 0.5s$$
$$= F_v S_a(1.0) \text{ for } T = 1.0s$$
$$= F_v S_a(2.0) \text{ for } T = 2.0s$$
$$= F_v S_a(2.0)/2.0 \text{ for } T \geq 2.0s \qquad (6)$$

where F_a, the acceleration-based site coefficient computed based on Table 11 and F_v is the velocity-based site coefficient computed based on Table 12. The $S(T)$ values for the intermediate values of fundamental period, T are computed based on linear interpolation.

Table 11: Values of F_a for various site classes [NBCC05, Table 4.1.8.4B]

Site Class	Values of F_a for $S_a(0.2)$				
	≤0.25	=0.50	=0.75	=1.00	=1.25
A	0.7	0.7	0.8	0.8	0.8
B	0.8	0.8	0.9	1.0	1.0
C	1.0	1.0	1.0	1.0	1.0
D	1.3	1.2	1.1	1.1	1.0
E	2.1	1.4	1.1	0.9	0.9

Table 12: Values of F_v for various site classes [NBCC05, Table 4.1.8.4C]

Site Class	Values of F_v for $S_a(1.0)$				
	≤0.1	=0.2	=0.3	=0.4	≥0.5
A	0.5	0.5	0.5	0.6	0.6
B	0.6	0.4	0.7	0.8	0.8
C	1.0	1.0	1.0	1.0	1.0
D	1.4	1.3	1.2	1.1	1.1
E	2.1	2.0	1.9	1.7	1.7

For soil site class, other than those listed in Tables 11 and 12, the site coefficient must be determined by site-specific geotechnical investigations. The factor accounting for higher mode effects is determined based on Table 13, while the values not listed are computed based on the linear interpolation. The R_d, R_o factors are determined based on the SFRS type and the value of $I_E F_a S_a(0.2)$.

Table 13: Values of M_v for various SFRS types [NBCC05, Table 4.1.8.11]

$S_a(0.2)/S_a(2.0)$	SFRS type	$T_a \leq 1.0$	$T_a \geq 2.0$
<0.8	Moment resisting frames or “coupled walls”	1.0	1.0
	Braced frames	1.0	1.0
	Walls, wall-frame systems, other systems	1.0	1.2
≥0.8	Moment resisting frames or “coupled walls”	1.0	1.2
	Braced frames	1.0	1.5
	Walls, wall-frame systems, other systems	1.0	2.5

4.0 International Building Code

The structural loads and combinations are addressed in Section 16 of IBC09. In contrast to the NBCC05, IBC09 provides load combinations for allowable stress design or “working stress design”, in addition to LRFD method. Furthermore, this code considers loads due to fluid pressure (F), roof live load (L_r) as separate from live load (L), and rain load (R) separately from the snow load (S). Other loads, such as, dead loads (D), wind loads (W), earthquake loads (E), permanent loads due to lateral earth pressure including ground water (H), and the load effects due to the strains, deformations and displacements due to changes in temperature, moisture content and so on (T), are similar to

NBCC05. The load combinations for the ULS of LFRD are as shown in Table 14.

Table 14: Load combinations for ULS of LRFD [3]

Equation No.	Load combination
16-1	1.4(D+F)
16-2	1.2(D+F+T) +1.6(L+H)+0.5(L_r or S or R)
16-3	1.2D+1.6(L_r or S or R) + (f_1L or 0.8W)
16-4	1.2D+1.6W+f_1L+0.5(L_r or S or R)
16-5	1.2D+1.0E+f_1L+f_2S
16-6	0.9D+1.6W+1.6H
16-7	0.9D+1.0E+1.6H

f_1 = 1 for floors in public assembly places or L > 100psf (4.79 kN/m^2), or for parking garage live load
= 0.5 for other live loads
f_2 = 0.7 for roof configurations that do not allow sliding of snow off the structure
= 0.2 for others

4.1 Dead Loads

Similar to the NBCC05, in IBC09 the dead loads include the self-weight of the structural member, and all the permanent loads supported by the member including those of partitions, and all materials of construction.

4.2 Live Loads

The live loads are evaluated based on the intended occupancy of the buildings. IBC09 provides the minimum uniformly distributed loads and concentrated loads based on the intended use and the occupancy of the buildings. A selected list of building occupancy and use, and the corresponding minimum specified live loads are shown in Table 15. Furthermore, IBC09 provides detailed live load assessments for impact loads, parking garages, vehicle barrier systems, and crane loads (IBC09, Section 1607).

Table 15: Minimum live loads for selected uses [IBC09, Table 1607.1]

Occupancy or Use	Uniform (psf)	Concentrated (lbs)
Access floor systems		
Office use	50	2000
Computer use	100	2000
Armories and drill rooms	150	-
Assembly areas and theaters		-
Fixed seats	60	
Follow spot, projections and control rooms	50	
Lobbies	100	
Movable seats	100	
Stages and platforms	125	
Other assembly areas	100	
Bowling alleys	75	-
Catwalks	40	300
Cornices	60	-
Corridors	100	-
Dance halls and ball rooms	100	-
Dining halls and restaurants	100	-
Elevator machine room grating (on area of 4in^2)	-	300
Finish light floor plate construction (on area of 1in^2)	-	200
Fire escapes	100	-
On single-family dwellings	40	
Gymnasiums, main floors and balconies	100	-
Hospitals		

Corridors above first floor	80	1000
Operating rooms, Laboratories	60	1000
Patient rooms	40	1000
Libraries		
Corridors above first floor	80	1000
Reading rooms	60	1000
Stack rooms	150	1000
Manufacturing		
Heavy	250	3000
Light	125	2000
Marquees	75	-
Office buildings		
Corridors above first floor	80	2000
Lobbies and first-floor corridors	100	2000
Offices	50	2000
Penal institutions		-
Cell blocks	40	
Corridors	100	
Residential		-
One-and two-family dwellings		
Uninhabitable attics without storage	10	
Uninhabitable attics with limited storage	20	
Habitable attics and sleeping areas	30	
All other areas	40	
Hotels and multifamily dwellings		
Private rooms and corridors	40	
Public rooms and corridors	100	
Schools		
Classrooms	40	1000
Corridors above first floor	80	1000
First floor corridors	100	1000
Skating rinks	100	-
Storage warehouses		-
Heavy	250	
Light	125	
Stores		
Retail		
First floor	100	1000
Upper floors	75	1000
Wholesale, all floors	125	1000
Walkways and elevated platforms	60	-
Yards and terraces, pedestrians	100	-

4.3 Snow Loads

The IBC09 refers to ASCE 7 [4] for the determination of the snow loads. In contrast to the NBCC05, the rain loads are not included in the snow load computations as per IBC09 or ASCE7. The snow loads on flat roofs, with roof slope $\alpha < 5^{\circ}$, are determined such as,

$$p_f = 0.7 \cdot C_e \cdot C_t \cdot I_s \cdot p_g \tag{7}$$

where, C_e is the secondary exposure factor based on Table 16, C_t is the thermal factor = 1.0 except for unheated structures or structures kept continuously heated, I_s is the snow load importance factor as show in Table 17, and p_g is the ground snow load.

Table 16: Exposure factor of snow loads [ASCE7, Table 7.2]

Terrain Category	Roof exposure type		
	Fully exposed	Partially exposed	Sheltered
A	N/A	1.1	1.3
B	0.9	1.0	1.2
C	0.9	1.0	1.1
D	0.8	0.9	1.0

Table 17: Importance factor for snow load [4]

Importance Category	ULS
Low	0.8
Normal	1.0
High	1.1
Post Disaster	1.2

The snow loads on inclined roofs are evaluated such that,

$$p_s = C_s \cdot p_f \qquad (8)$$

where C_s is the roof slope factor determined using Figure 7, which is based on the ability of the roof to shed the snow and the angle of roof slope.

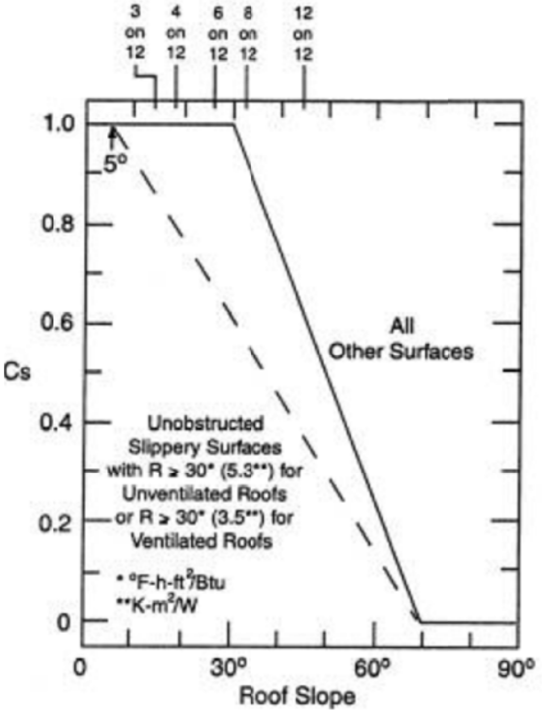


Figure 7: Roof slope factor for warm roofs, $C_t \leq 1.0$

Additional evaluation of the snow load distribution must be performed for the roofs with unusual shapes, such as gable, curved roofs and so on. For sheltered roofs, the possible snow load increase due to drifts must also be evaluated.

4.4 Wind Loads

Similar to the snow loads, IBC09 refers to ASCE7 for the evaluation of the wind loads. However, for regular structures which are not sensitive to dynamic effects, with height less than 75ft (22.86 m), and with height-to-least width ratio ≤ 4.0, the "alternate all-heights" method in IBC09 is applicable (IBC09, Section 1609.6). According to this method, the net wind pressure on a building is evaluated as (IBC 09, Eq. 16-34),

$$P_{net} = q_s \cdot K_z \cdot C_{net} \cdot [I_w K_{zt}] \qquad (9)$$

Where q_s = wind stagnation pressure in psf = $0.002565V^2$,
where V = basic wind speed in mph,
K_z = velocity pressure exposure coefficient = $2.01(z/z_g)^{(2/a)}$,where z = height of the structure, and Table 18 provides the values for z_g and a depending on the exposure category.
K_{zt} = topographic factor = 1.0 for z < 15ft for exposure C and D, and for z < 60ft for exposure B, and
I_w = importance factor as shown in Table 19.
C_{net} = net-pressure coefficient based on the gust factor and the directionality coefficient evaluated based Table 20.

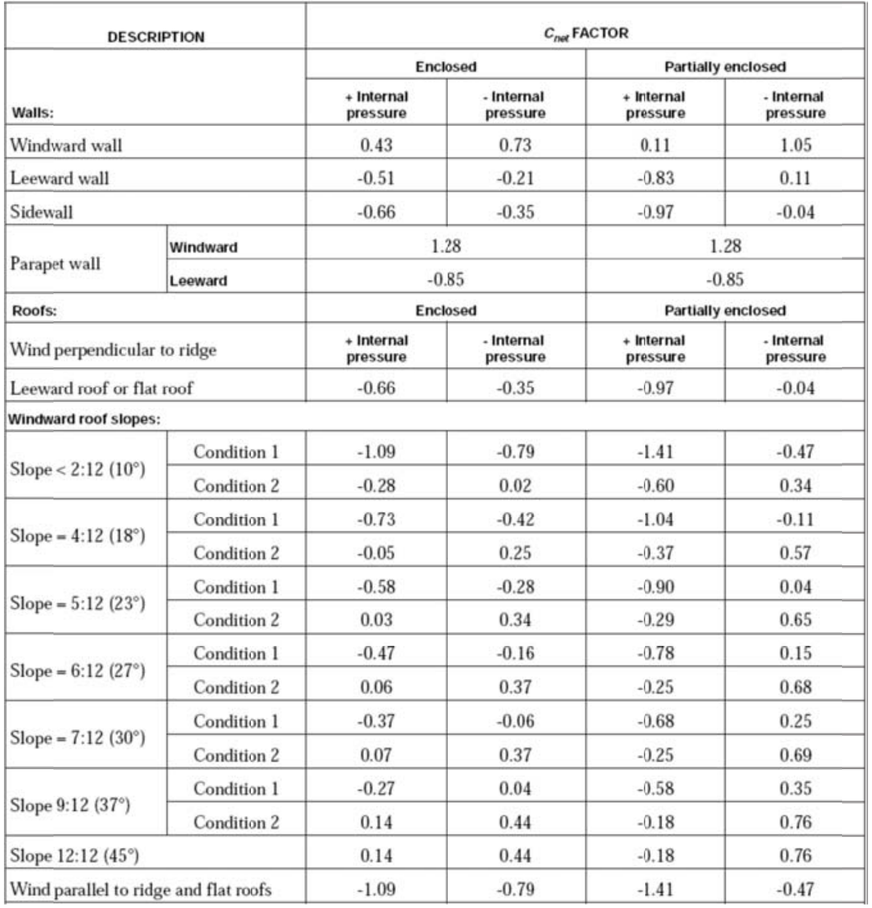
Table 18: K_z factor for wind load [ASCE7-05 Table 6.2]

Exposure category	z_g (ft)	a
B	1200	7
C	900	9.5
D	700	11.5

Table 19: Importance factor for wind load [4]

Importance Category	ULS
Low	0.87
Normal	1.0
High	1.15
Post Disaster	1.15

Table 20: C_{net} factor for main wind resisting systems of buildings [IBC09, Table 1609.6.2(2)]

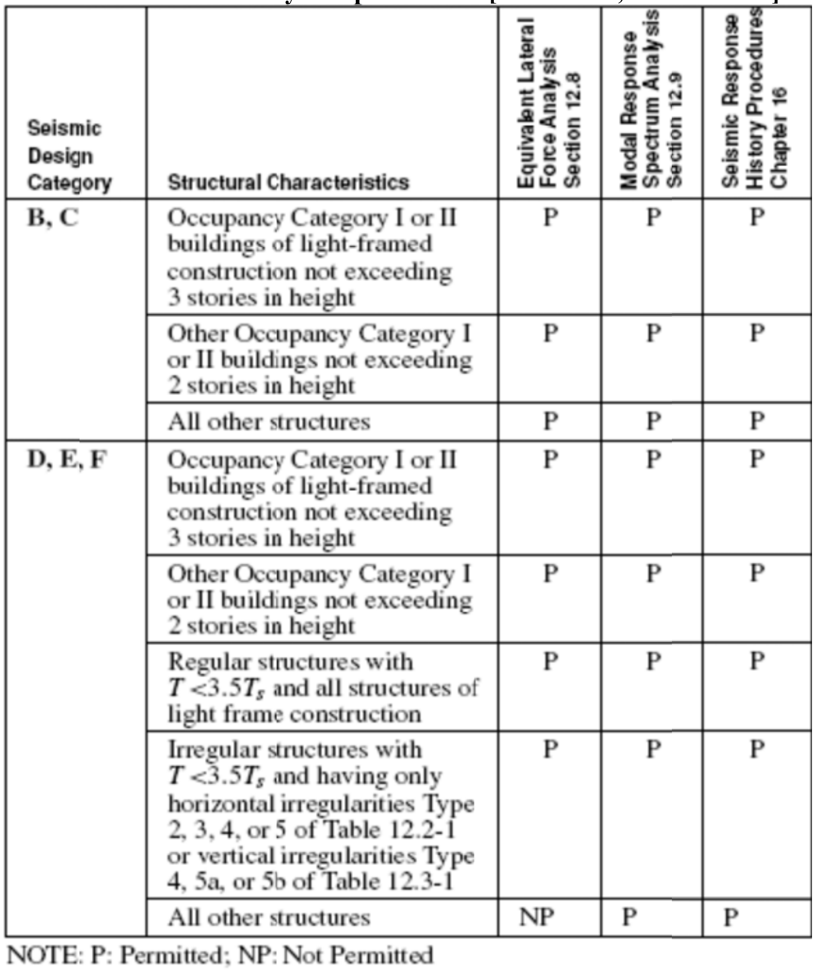


DESCRIPTION		C_{net} FACTOR			
		Enclosed		Partially enclosed	
Walls:		+ Internal pressure	- Internal pressure	+ Internal pressure	- Internal pressure
Windward wall		0.43	0.73	0.11	1.05
Leeward wall		-0.51	-0.21	-0.83	0.11
Sidewall		-0.66	-0.35	-0.97	-0.04
Parapet wall	Windward	1.28		1.28	
	Leeward	-0.85		-0.85	
Roofs:		Enclosed		Partially enclosed	
Wind perpendicular to ridge		+ Internal pressure	- Internal pressure	+ Internal pressure	- Internal pressure
Leeward roof or flat roof		-0.66	-0.35	-0.97	-0.04
Windward roof slopes:					
Slope < 2:12 (10°)	Condition 1	-1.09	-0.79	-1.41	-0.47
	Condition 2	-0.28	0.02	-0.60	0.34
Slope = 4:12 (18°)	Condition 1	-0.73	-0.42	-1.04	-0.11
	Condition 2	-0.05	0.25	-0.37	0.57
Slope = 5:12 (23°)	Condition 1	-0.58	-0.28	-0.90	0.04
	Condition 2	0.03	0.34	-0.29	0.65
Slope = 6:12 (27°)	Condition 1	-0.47	-0.16	-0.78	0.15
	Condition 2	0.06	0.37	-0.25	0.68
Slope = 7:12 (30°)	Condition 1	-0.37	-0.06	-0.68	0.25
	Condition 2	0.07	0.37	-0.25	0.69
Slope 9:12 (37°)	Condition 1	-0.27	0.04	-0.58	0.35
	Condition 2	0.14	0.44	-0.18	0.76
Slope 12:12 (45°)		0.14	0.44	-0.18	0.76
Wind parallel to ridge and flat roofs		-1.09	-0.79	-1.41	-0.47

4.5 Earthquake Loads

IBC09 refers to ASCE7-05 for the evaluation of the earthquake loads. Similar to NBCC05, the equivalent static procedures for the earthquake load evaluation is restricted to buildings meeting the criteria set in Table 21.

Table 21: Permitted analytical procedures [ASCE7-05, Table 12.6-1]

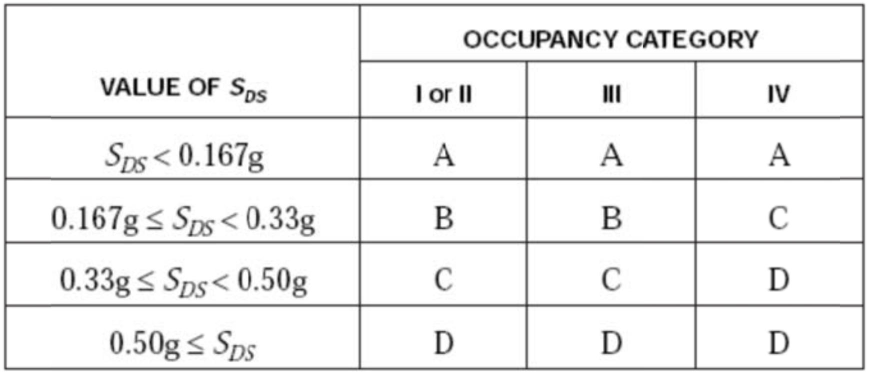


Seismic Design Category	Structural Characteristics	Equivalent Lateral Force Analysis Section 12.8	Modal Response Spectrum Analysis Section 12.9	Seismic Response History Procedures Chapter 16
B, C	Occupancy Category I or II buildings of light-framed construction not exceeding 3 stories in height	P	P	P
	Other Occupancy Category I or II buildings not exceeding 2 stories in height	P	P	P
	All other structures	P	P	P
D, E, F	Occupancy Category I or II buildings of light-framed construction not exceeding 3 stories in height	P	P	P
	Other Occupancy Category I or II buildings not exceeding 2 stories in height	P	P	P
	Regular structures with $T < 3.5T_s$ and all structures of light frame construction	P	P	P
	Irregular structures with $T < 3.5T_s$ and having only horizontal irregularities Type 2, 3, 4, or 5 of Table 12.2-1 or vertical irregularities Type 4, 5a, or 5b of Table 12.3-1	P	P	P
	All other structures	NP	P	P

NOTE: P: Permitted; NP: Not Permitted

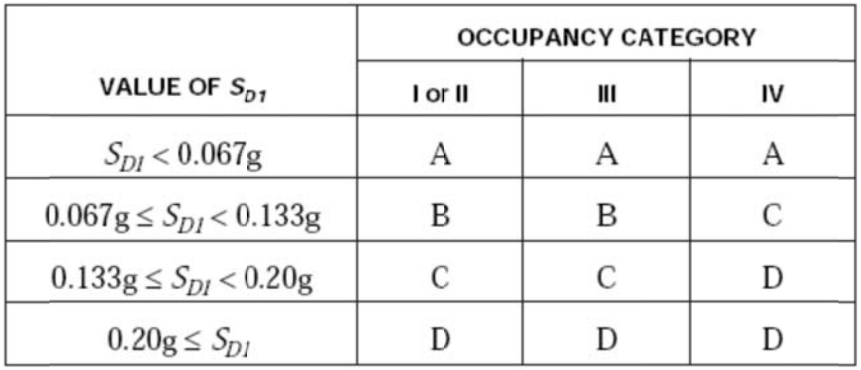
The seismic design categories are assessed based on the importance category of the buildings, and the design spectral accelerations at short periods (0.2s),S_{DS} and at the period 1.0s, S_{D1}. Tables 22 and 23 show the classification criteria.

Table 22: Seismic design category based on short period response acceleration [IBC09, Table 1613.5.6(1)]



VALUE OF S_{DS}	OCCUPANCY CATEGORY		
	I or II	III	IV
$S_{DS} < 0.167g$	A	A	A
$0.167g \le S_{DS} < 0.33g$	B	B	C
$0.33g \le S_{DS} < 0.50g$	C	C	D
$0.50g \le S_{DS}$	D	D	D

Table 23: Seismic design category based on 1.0s period response acceleration [IBC09, Table 1613.5.6(2)]



VALUE OF S_{D1}	OCCUPANCY CATEGORY		
	I or II	III	IV
$S_{D1} < 0.067g$	A	A	A
$0.067g \le S_{D1} < 0.133g$	B	B	C
$0.133g \le S_{D1} < 0.20g$	C	C	D
$0.20g \le S_{D1}$	D	D	D

The design spectral accelerations are evaluated as (IBC09, Section 1613.5.4),

$$S_{DS} = \frac{2}{3} S_{MS} \tag{7}$$

$$S_{D1} = \frac{2}{3} S_{M1} \tag{8}$$

Where S_{MS} is the spectral acceleration of maximum considered earthquake expressed in g (acceleration due to gravity) for short period (0.2s), and S_{M1} is the spectral acceleration at period 1.0s. These are evaluated as (IBC09, Section 1613.5.3),

$$S_{MS} = S_S \cdot F_a \tag{9}$$

$$S_{M1} = S_1 \cdot F_v \tag{10}$$

Where F_a = site coefficient determined based on Table 24, S_S = the mapped spectral acceleration for short period (0.2s) with 5% critical damping (IBC09, Figure 1613.5(1-7,10-11)), F_v = site coefficient determined based on Table 25, S_1 = the mapped spectral acceleration for 1.0s period with 5% critical damping (IBC09, Figure 1613.5(8-10,12).

Table 24: F_a values [IBC09, Table 1613.5.3(1)]

Site Class	$S_S \le 0.25$	$S_S = 0.50$	$S_S = 0.75$	$S_S = 1.00$	$S_S \ge 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9

Table 25: F_v values [IBC09, Table 1613.5.3(2)]

Site Class	$S_1 \le 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \ge 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4

The base shear for the equivalent static analysis is computed as,

$$V = C_s \cdot W \tag{11}$$

Where, C_s = seismic response coefficient and W = seismic weight. The seismic response coefficient is computed as,

$$C_s = S_{DS} \cdot I/R \tag{12}$$

where R = response modification factor based on the SFRS, and I is the importance factor based on Table 26. The value of C_s must not be less than,

$$\begin{aligned} &C_s \geq 0.044 \cdot S_{DS} \cdot I \text{ or } 0.01 \text{ whichever is greater for } S_1 < 0.6 \\ &\geq 0.5 \cdot S_1 \cdot \frac{I}{R} \text{ for } S_1 \geq 0.6 \end{aligned} \tag{13}$$

and the value of C_s need not be greater than,

$$\begin{aligned} C_s &\leq S_{D1} \cdot \frac{I}{T \cdot R} \text{ for } T < T_L \\ &\leq S_{D1} \cdot I \cdot \frac{T_L}{T^2 \cdot R} \text{ for } T \geq T_L \end{aligned} \tag{14}$$

where T_L is the long period transition value based on ASCE7-05, Figure 22-15 to 22-17, and T is the fundamental period of the structure.

Table 26: Importance factor for earthquake load [ASCE7-05, Table 11.5-1]

Importance Category	ULS
Low	1.0
Normal	1.0
High	1.25
Post Disaster	1.5

5.0 Numerical Example

A single storey, single bay building with steel moment frame as lateral load resisting system, is considered to illustrate the load evaluation based on NBCC05 and IBC09. The building is considered to be 4m high with a foot print of 12mx12m. The roof of the building is considered as flat and accessible for maintenance. Two moment frames are designed to resist the lateral loads in North-South (N-S) direction, while the lateral loads in East-West (E-W) direction are resisted by concentric braces. The bay-width of the moment frame is 12m, and the height is 4m. The building is considered to be located in Vancouver, Canada, on a stiff soil in a rough terrain with partially open exposure, and of normal occupancy. In the following, the computation of loads on each moment frame according to NBCC05 and IBC09 is demonstrated. This is followed by the computations for design load of the beam element of the frame.

5.1 NBCC (2005)

Dead loads:
Roofing = 0.35 kN/m^2
Insulation = 0.10 kN/m^2
Steel deck = 0.10 kN/m^2
Ceiling = 0.05 kN/m^2
Duct work and fixtures = 0.25 kN/m^2
Open web steel joists = 0.10kN/m^2

Total dead load = 0.95 kN/m^2
Self-weight of the girder = 2.0 kN/m
Uniformly distributed vertical load on each moment frame = 0.95x12/2 +2.0 = <u>7.70 kN/m</u>

Live loads:
From Table 6, Live load = 1.0 kPa

Uniformly distributed vertical load on each moment frame = 1.0x12/2 = 6.0kN/m

Snow loads:
S_s = 1.8 kPa
I_s = 1.0
C_b = 0.8
C_w = 1.0
C_s = 1.0
C_a = 1.0
S_r = 0.2 kPa
S = 1.64 kPa

Uniformly distributed vertical load due to snow on each moment frame = 1.64 x 12/2 = 9.84kN/m

Wind loads:
Terrain = rough
q = 0.48kPa
I_w = 1.0
C_e = 0.7
$C_g C_p$ = 1.15 for $h<20$m
$C_{gi} C_{pi}$ = -0.8 for $h<20$m
p = 0.3864 kPa
p_i = -0.2688 kPa

Net wind pressure on the building wall = 0.6552kPa
Uniformly distributed lateral load due to wind on each moment frame = 0.6552 x 12/2 = 3.93kN/m

Earthquake loads:
Soil site class = C
$S_a(0.2) = 0.94g$
$S_a(0.5) = 0.64g$
$S_a(1.0) = 0.33g$
$S_a(2.0) = 0.17g$
Fundamental period, $T = 0.085(4)^{(3/4)} = 0.24$s
$S(T = 0.24) = 0.88g$
I_E = 1.0
M_v = 1.0
R_d = 1.5 (normal construction)
R_o = 1.3
W = 0.95x12x12+2x2.0x12 = 184.80 kN
V = 83.50kN

Lateral earthquake load on each moment frame = 41.75kN

The uniformly distributed vertical loads from the dead load, live load and snow load are applied to each moment frame as shown in Figure 8. Figures 9 and 10 show the application of wind load and earthquake load respectively.

Figure 8: Applied dead load, live load and snow load on moment frame

Figure 9: Applied wind load on the moment frame

Figure 10: Applied earthquake load on the moment frame

5.2 IBC (2009)

Dead loads:
Similar to NBCC05,

Uniformly distributed vertical load on each moment frame = 0.95x12/2 +2.0 = <u>7.70 kN/m</u>

Live loads:
From IBC09,Table 1607.1, Live load = 20psf = 0.96 kPa
Uniformly distributed vertical load on each moment frame = 0.96x12/2 = <u>5.75kN/m</u>

Snow loads:
p_g = 20psf = 0.96 kPa, (Closest to Vancouver, at Bellingham)
Exposure: Partial
Terrain: B
$I_s = 1.0$
$C_e = 1.0$
$C_t = 1.0$
$P_f = 14$ psf $< 20I_s \Rightarrow P_f = 20$ psf = 0.96 kPa

Uniformly distributed vertical load due to snow on each moment frame = 0.96 x 12/2 = <u>5.75kN/m</u>

Wind loads:
V = 90mph
q_s = 20.74psf = 0.99kPa
$I_w = 1.0$
Exposure: B
$K_z = 0.57$ for z = 4m = 13ft < 15ft,
$K_{zt} = 1.0$ for h<60ft = 18.2m
$C_{net} = 1.05$ (highest value for windward wall, partially enclosed)
P_{net} = 0.60 kPa

Net wind pressure on the building wall = 0.60kPa
Uniformly distributed lateral load due to wind on each moment frame = 0.60 x 12/2 = <u>3.60kN/m</u>

Earthquake loads:
Soil site class = C
$S_s = 0.94g$
$S_1 = 0.33g$
Fundamental period, $T = 0.085(4)^{(3/4)} = 0.24$s
$T_L = 16$s
$S_{DS} = 1.0g$
$S_{D1} = 0.29g$
$I = 1.0$
$R = 3.5$ (ordinary construction)
$C_s = 0.29$
$W = 0.95 \mathrm{x} 12 \mathrm{x} 12 + 2 \mathrm{x} 2.0 \mathrm{x} 12 = 184.80$ kN
$V = 52.80$kN

Lateral earthquake load on each moment frame = 26.40kN

The dead load, live load and snow load are distributed on the moment frame as shown in Figure 8, similar to NBCC05 loads. The wind load and earthquake loads are applied on the frame as shown in Figures 9 and 10, respectively.

Table 27: Load effects on the beam elements for NBCC05 loads

Load type	Maximum positive moment (kN/m)	Maximum negative moment (kN/m)	Maximum shear force (kN)	Maximum axial force (kN)
Dead	198.00	79.20	59.40	29.70
Live	154.29	61.71	46.29	23.14
Snow	253.03	101.21	75.91	37.95
Wind	1.25	0.50	0.15	9.98
Earthquake	55.67	55.67	9.28	41.75

Table 28: Load effects on the beam elements for IBC09 loads

Load type	Maximum positive moment (kN/m)	Maximum negative moment (kN/m)	Maximum shear force (kN)	Maximum axial force (kN)
Dead	198.00	79.20	59.40	29.70
Live	147.86	59.14	44.36	22.18
Snow	147.86	59.14	44.36	22.18
Wind	1.14	0.46	0.13	9.14
Earthquake	35.19	35.19	5.86	26.40

Table 29: Design load values and corresponding load combinations for the beam element of the moment frame

Load effect	NBCC05		IBC09	
	Load	Combination	Load	Combination
Maximum positive moment (kN/m)	704.19	1.25D+1.5S+0.5L	548.10	1.2D+1.6L+ 0.5S
Maximum negative moment (kN/m)	281.67	1.25D+1.5S+0.5L	219.24	1.2D+1.6L+ 0.5S
Maximum shear force (kN)	211.26	1.25D+1.5S+0.5L	164.43	1.2D+1.6L+ 0.5S
Maximum axial force (kN)	105.63	1.25D+1.5S+0.5L	88.65	1.2D+1.0E+ f1L+f2S

Tables 27 and 28 show the maximum positive moment, maximum negative moment, axial load and shear force on the beam element of the moment frame due to the loads evaluated from NBCC05, and IBC09 respectively. Based on these load effects, the design loads are evaluated from the load combinations in Tables 4 and 14. The final design values and the corresponding load combinations are given in Table 29.

6.0 Conclusion

In the present report, load evaluation methods for steel bridges and buildings according to CHBDC (S6.06), NBCC05, and IBC09 are demonstrated. NBCC09 has conservative load factors compared to IBC09 for the environmental loads. An Excel spreadsheet is developed for rapid evaluation of loads on steel buildings, according to NBCC05 and IBC09. The Excel spreadsheet for load evaluation for steel bridges is modified to reflect the update CHBDC.

7.0 References

1. *Canadian Highway Bridge Design Code*, CAN/CSA S6.06
2. *National Building Code of Canada*, 2005, and *User's Guide – Structural Commentaries*, NRC
3. *International Building Code*, 2009
4. SEI/ASCE7, 2005, *Minimum design loads for buildings and other structures*. ASCE

Appendix

BuildingCodes_NBCC_IBC.xls