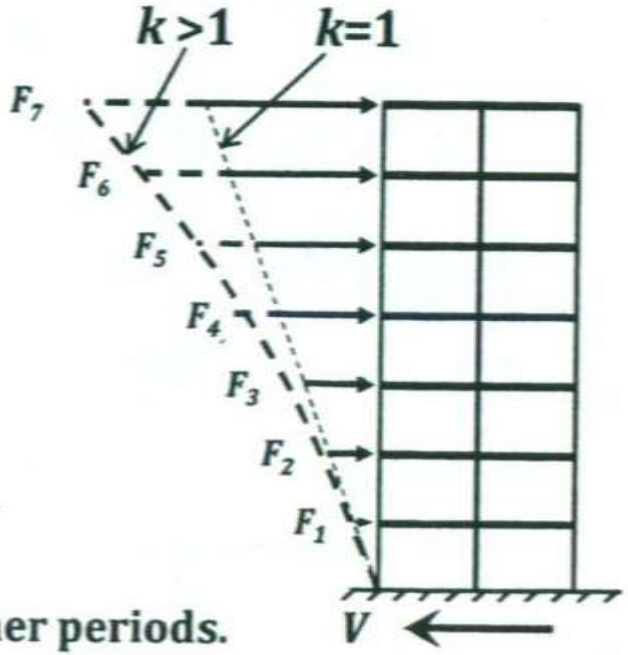
BNBC 2010 SEISMIC PROVISIONS
Equivalent Static Analysis

Spectral Acceleration $S_a = \frac{2}{3}\frac{ZI}{R}C_s$ (Eqn. 2.5.4)

Base shear $V = S_a W$ (Eqn. 2.5.7)



Vertical Distribution of base shear

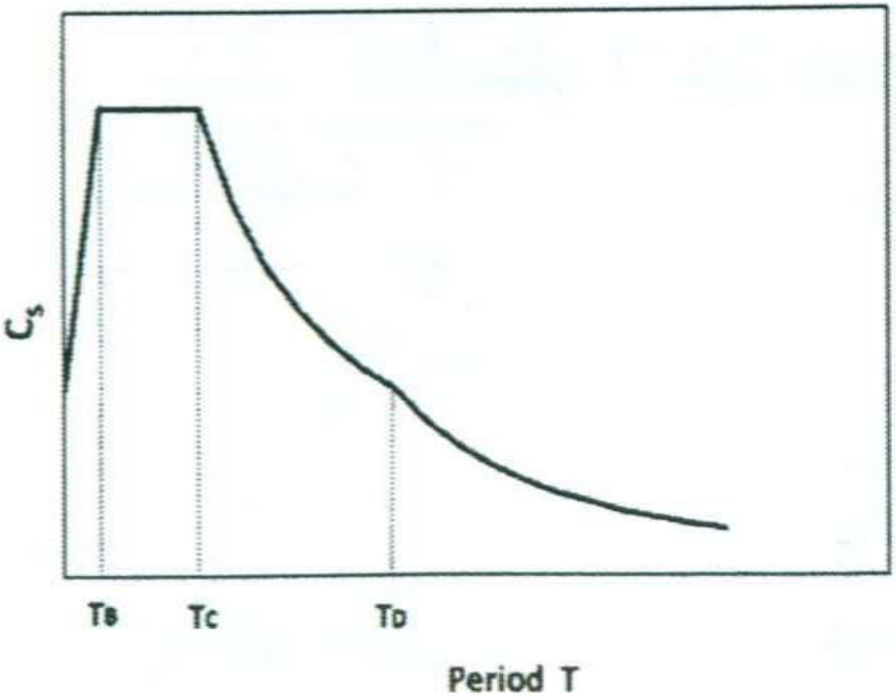
$$F_x = V\frac{w_x h_x^{\,k}}{\sum_{i=1}^{n} w_i h_i^{\,k}}$$

k = 1 for structure period ≤ 0.5
= 2 for structure period ≥ 2.5s
= linear interpolation between 1 and 2 for other periods.

BNBC 2010 SEISMIC PROVISIONS

Equivalent Static Analysis

Normalized acceleration response spectrum, C_s



Equations 2.5.5

$$C_s = S\left(1 + \frac{T}{T_B}(2.5\eta - 1)\right) \quad \text{for} \quad 0 \le T \le T_B$$

$$C_s = 2.5S\eta \quad \text{for} \quad T_B \le T \le T_C$$

$$C_s = 2.5S\eta\left(\frac{T_C}{T}\right) \quad \text{for} \quad T_C \le T \le T_D$$

$$C_s = 2.5S\eta\left(\frac{T_C T_D}{T^2}\right) \quad \text{for} \quad T_D \le T \le 4 \text{ sec}$$

$$\eta = \sqrt{10/(5+\xi)} \ge 0.55 \quad \textbf{Eqn 2.5.6}$$

Here ξ is structural damping expressed as a percentage of critical damping.

Structural Analysis & Design I

BNBC 2010
Site classification based on soil properties (Table 2.5.1)

Site Class	Description of soil profile up to 30 meters depth	Average Soil Properties in top 30 meters		
		Shear wave velocity $\bar{V}_s$ (m/s)	Standard Penetration Value, $\bar{N}$ (blows/30cm)	Undrained shear strength, $\bar{S}_u$ (kPa)
SA	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	> 800	--	--
SB	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth.	360 – 800	> 50	> 250
SC	Deep deposits of dense or medium dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.	180 – 360	15 - 50	70 - 250
SD	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180	< 15	< 70
SE	A soil profile consisting of a surface alluvium layer with V_s values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with V_s > 800 m/s.	--	--	--

BNBC 2010 SEISMIC PROVISIONS
Equivalent Static Analysis

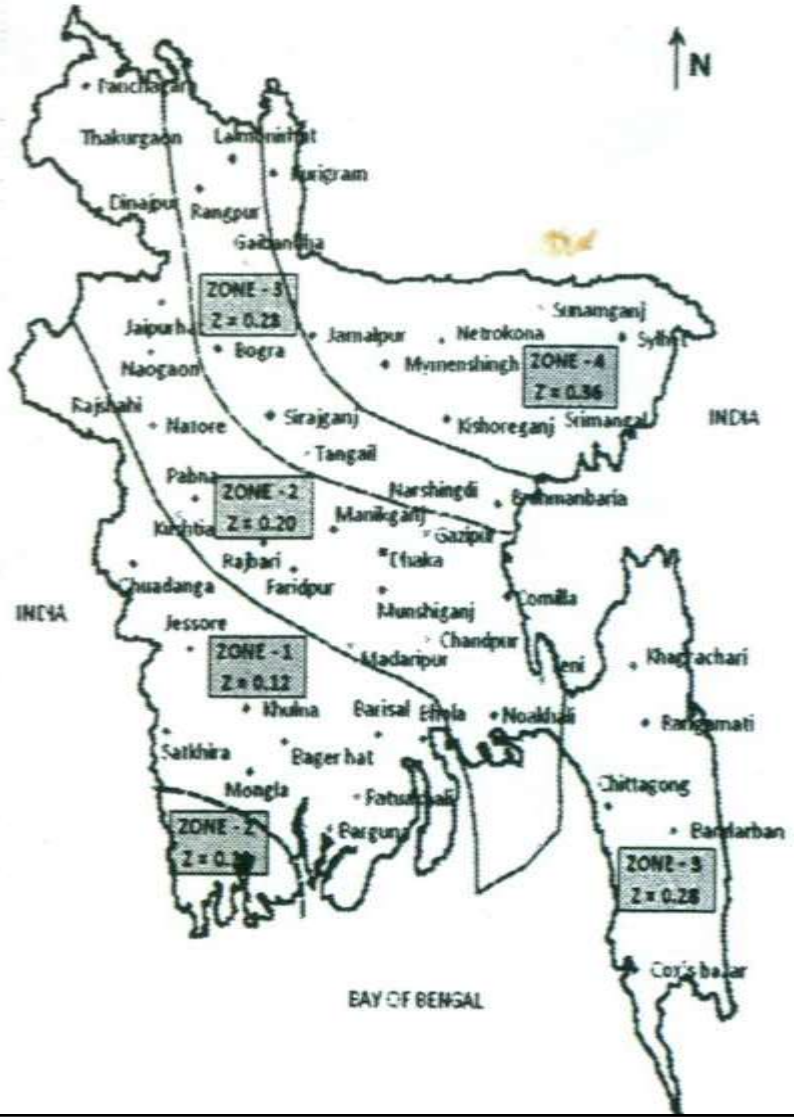
Site dependent soil factor (S) and other parameters defining elastic response spectrum (Table 2.5.4)

Soil type	S	T_B (s)	T_C (s)	T_D (s)
SA	1.0	0.15	0.40	2.0
SB	1.2	0.15	0.50	2.0
SC	1.15	0.20	0.60	2.0
SD	1.35	0.20	0.80	2.0
SE	1.4	0.15	0.50	2.0

Structural Analysis & Design I

Description of Seismic Zones (Table 2.5.2)

Seismic Zone	Location	Seismic Intensity	Seismic Zone Coefficient, Z
1	Southwestern part including Barisal, Khulna, Jessore, Rajshahi	Low	0.12
2	Lower Central and Northwestern part including Noakhali, Dhaka, Pabna, Dinajpur, as well as Southwestern corner including Sundarbans	Moderate	0.20
3	Upper Central and Northwestern part including Brahmanbaria, Sirajganj, Rangpur	Severe	0.28
4	Northeastern part including Sylhet, Mymensingh, Kurigram	Very Severe	0.36



Structural Analysis & Design I

Table 2.5.7 Response reduction factor, deflection amplification factor for different Structural Systems and height limitations (m) for different seismic design categories

Seismic Force–Resisting System	Response Reduction Factor, R	Deflection Amplification Factor, C_d	Seis. Design Category B	Seis. Design Category C	Seis. Design Category D
			Height limit (m)		
A. BEARING WALL SYSTEMS (no frame)					
1. Special reinforced concrete shear walls	5	5	NL	NL	50
2. Ordinary reinforced concrete shear walls	4	4	NL	NL	NP
3. Ordinary reinforced masonry shear walls	2	1.75	NL	50	NP
4. Ordinary plain masonry shear walls	1.5	1.25	18	NP	NP
B. BUILDING FRAME SYSTEMS (with bracing or shear wall)					
1. Steel eccentrically braced frames, moment resisting connections at columns away from links	8	4	NL	NL	50
2. Steel eccentrically braced frames, non-moment-resisting, connections at columns away from links	7	4	NL	NL	50
3. Special steel concentrically braced frames	6	5	NL	NL	50
4. Ordinary steel concentrically braced frames	3.25	3.25	NL	NL	11
5. Special reinforced concrete shear walls	6	5	NL	50	50
6. Ordinary reinforced concrete shear walls	5	4.25	NL	NL	NP
7. Ordinary reinforced masonry shear walls	2	2	NL	50	NP
8. Ordinary plain masonry shear walls	1.5	1.25	18	NP	NP
C. MOMENT RESISTING FRAME SYSTEMS (no shear wall)					
1. Special steel moment frames	8	5.5	NL	NL	P
2. Intermediate steel moment frames	4.5	4	NL	NL	35
3. Ordinary steel moment frames	3.5	3	NL	NL	NP
4. Special reinforced concrete moment frames	8	5.5	NL	NL	NL
5. Intermediate reinforced concrete moment frames	5	4.5	NL	NL	NP
6. Ordinary reinforced concrete moment frames	3	2.5	NL	NP	NP

Structural Analysis & Design I

Table 2.5.3 Seismic Zone Coefficient Z for Some Important Towns of Bangladesh

Town	Z	Town	Z	Town	Z	Town	Z
Bagerhat	0.12	Dinajpur	0.20	Kushtia	0.20	Panchagarh	0.20
Bandarban	0.28	Faridpur	0.20	Lalmanirhat	0.28	Patuakhali	0.12
Barguna	0.12	Feni	0.20	Madaripur	0.20	Rajbari	0.20
Barisal	0.12	Gaibandha	0.28	Manikganj	0.20	Rajshahi	0.12
Bhola	0.12	Gazipur	0.20	Mongla	0.12	Rangamati	0.28
Bogra	0.28	Habiganj	0.36	Munshiganj	0.20	Rangpur	0.28
Brahmanbaria	0.28	Jaipurhat	0.20	Mymensingh	0.36	Satkhira	0.12
Chandpur	0.20	Jamalpur	0.36	Narsingdi	0.28	Sirajganj	0.28
Chittagong	0.28	Jessore	0.12	Natore	0.20	Srimangal	0.36
Chuadanga	0.12	Khagrachari	0.28	Naogaon	0.20	Sunamganj	0.36
Comilla	0.20	Khulna	0.12	Netrakona	0.36	Sylhet	0.36
Cox's Bazar	0.28	Kishoreganj	0.36	Noakhali	0.20	Tangail	0.28
Dhaka	0.20	Kurigram	0.36	Pabna	0.20	Thakurgaon	0.20

Structural Analysis & Design I

Occupancy Category of Buildings and Other Structures (Table 1.2.1)

Nature of Occupancy	Occupancy Category
Buildings and other structures that represent a low hazard to human life in the event of failure	I
All buildings and other structures except those listed in Occupancy Categories I, III, and IV	II
Buildings and other structures that represent a substantial hazard to human life in the event of failure, including, but not limited to: • W here more than 300 people congregate in one area • Daycare facilities with a capacity greater than 150 • S chool facilities with a capacity greater than 250 • C olleges or adult education facilities having more than 500 students. • Health care facilities with a capacity of 50 or more resident patients but nor surgery facility. • Jails and detention facilities	III
Buildings and other structures designated as essential facilities, including, but not limited to: • Hospitals and other health care facilities having surgery or emergency treatment facilities • Fire, rescue, ambulance, and police stations and emergency vehicle garages • Designated earthquake, hurricane, or other emergency shelters • Designated emergency preparedness, communication, and operation centers and other facilities required for emergency response • Power generating stations and other public utility facilities required in an emergency • Ancillary structures (including, but not limited to, communication towers, fuel storage tanks, cooling towers, electrical substation structures, fire water storage tanks or other structures housing or supporting water, or other fire-suppression material or equipment) required for operation of Occupancy Category IV structures during an emergency	IV

Importance Factors for Buildings and Structures for Earthquake design (Table 2.5.5)

Occupancy Category	Importance factor *I*
I or II	1.0
III	1.25
IV	1.5

BNBC 2010 SEISMIC PROVISIONS
Equivalent Static Analysis

Natural Period $T = C_t (h_n)^m$ (Eqn. 2.5.8)

h_n = Height of building in *meters* from foundation or from top of rigid basement. This excludes the basement storeys, where basement walls are connected with the ground floor deck or fitted between the building columns. But it includes the basement storeys, when they are not so connected.

C_t and m are obtained from Table 2.5.8

Structure type	C_t	m
Concrete moment-resisting frames	0.0466	0.9
Steel moment-resisting frames	0.0724	0.8
Eccentrically braced steel frame	0.0731	0.75
All other structural systems	0.0488	0.75

NOTE:
Consider moment resisting frames as frames which resist 100% of seismic force and are not enclosed or adjoined by components that are more rigid and will prevent the frames from deflecting under seismic forces.

BNBC 2010: Equivalent Static Analysis

Calculation Steps

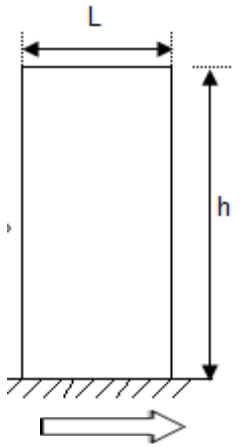
a. Select site class (SA or SB etc.) from Table 2.5.1.
b. Determine building height h in meter.
c. Determine C_t and m from Table 2.5.8 based on framing type.
d. Calculate natural period T from eqn. 2.5.8.
e. Determine zone co-efficient Z (Table 2.5.3 or Fig. 2.5.1).
f. Determine Occupancy category (Table 1.2.1), Importance factor I (Table 2.5.5), Response Reduction Factor R (Table 2.5.7) and Seismi Design Category (Table 2.5.6).
g. Based on site class (SA or SB etc.) determine soil factor (S) and other parameters (T_A, T_B etc.) from Table 2.5.4.
h. Select a percent structural damping ξ (normally ξ=5) and calculate from eqn. 2.5.6.
i. Now calculate C_s using the appropriate one of eqns. 2.5.5 using the values of η, T, T_A etc.
j. Now calculate S_a using eqn. 2.5.4 and the V using eqn. 2.5.7.
k. Now use eqn. 2.5.11 to vertically distribute the base shear.

Structural Analysis & Design I

Problem: Calculate the distribution of EQ force on the 20 storied office building shown in figure. **Location-** Dhaka. A **soil profile consisting of a surface alluvial layer.** DL including partition= 13.25 kN/sq-m. structural type IMRF.

Consider 5% structural damping.

R=8



20 @ 3m=60m

Soln



24 m

24 m

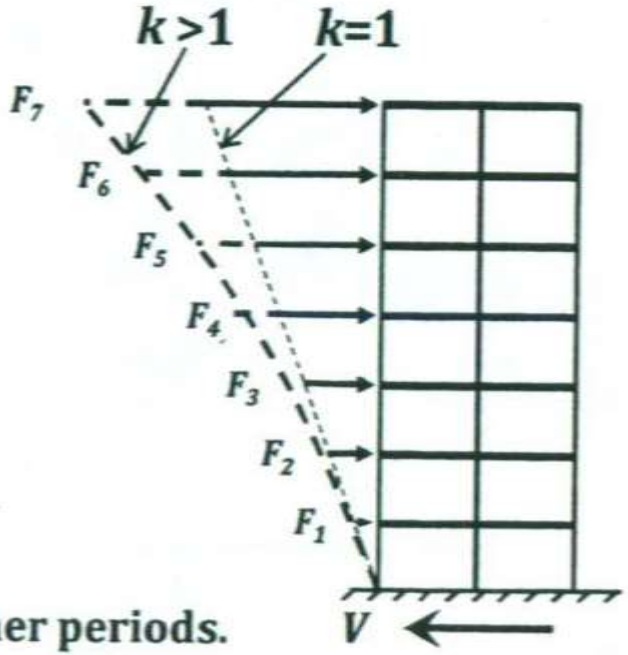
Structural Analysis & Design I

Time Period			
Enter Ct	0.04666		(Table 2.5.8)
Enter hn	60		
Enter m	0.9		
Time Period (T)	1.859006292	Sec	(Eq. 2.5.8)
Enter S	1.4		(Table 2.5.4)
Calculation of Cs	0.942		(Eq. 2.5.5)
Enter TB	0.15		(Table 2.5.4)
Enter Tc	0.5		(Table 2.5.4)
Enter Damping	1.0		(Eq. 2.5.6)
Enter I	1		(Table 2.5.5)
Enter R	8		(Table 2.5.7)
Sa	0.0157		
Enter W	15640 kN		
V(Base Shear)	3052.066377	KN	

BNBC 2010 SEISMIC PROVISIONS
Equivalent Static Analysis

Spectral Acceleration $S_a = \frac{2}{3}\frac{ZI}{R}C_s$ (Eqn. 2.5.4)

Base shear $V = S_a W$ (Eqn. 2.5.7)



Vertical Distribution of base shear

$$F_x = V\frac{w_x h_x^{\,k}}{\sum_{i=1}^{n} w_i h_i^{\,k}}$$

k = 1 for structure period ≤ 0.5
= 2 for structure period ≥ 2.5s
= linear interpolation between 1 and 2 for other periods.

Structural Analysis & Design I

Floor	Ht (m)	k	h^k	Fx
20	60	1.68	971	383
19	57	1.68	891	351.4
18	54	1.68	814	320.9
17	51	1.68	739	291.5
16	48	1.68	668	263.3
15	45	1.68	599	236.2
14	42	1.68	533	210.4
13	39	1.68	471	185.7
12	36	1.68	412	162.4
11	33	1.68	356	140.3
10	30	1.68	303	119.5
9	27	1.68	254	100.1
8	24	1.68	208	82.16
7	21	1.68	166	65.65
6	18	1.68	128	50.67
5	15	1.68	94.6	37.3
4	12	1.68	65	25.64
3	9	1.68	40.1	15.81
2	6	1.68	20.3	8.002
1	3	1.68	6.33	2.497
			7740	3052

Structural Analysis & Design I

Floor	ht	W	h^k	w*h^k	Base Shear(V)
20	60	7632	971.167	7411949.68	382.955
19	57	7632	890.984	6799987.58	351.337
18	54	7632	813.62	6209546.42	320.83
17	51	7632	739.125	5641002.05	291.455
16	48	7632	667.552	5094758.95	263.232
15	45	7632	598.959	4571254.33	236.184
14	42	7632	533.407	4070963.13	210.336
13	39	7632	470.965	3594404.1	185.713
12	36	7632	411.707	3142147.46	162.346
11	33	7632	355.716	2714824.63	140.268
10	30	7632	303.084	2313140.8	119.514
9	27	7632	253.917	1937891.62	100.126
8	24	7632	208.331	1589985.81	82.1503
7	21	7632	166.467	1270476.91	65.6421
6	18	7632	128.487	980609.667	50.6654
5	15	7632	94.5874	721891.082	37.2982
4	12	7632	65.0166	496206.964	25.6377
3	9	7632	40.0984	306031.251	15.8118
2	6	7632	20.2906	154857.578	8.00107
1	3	7632	6.33233	48328.3613	2.497
		152640	7739.81	59070258.4	3052
				Sum (wihi^k)	

Structural Analysis & Design I

Assignment –(1)

20 storied (each floor 25 m x 25 m) RC office building at Dhaka/Chittagong/Sylhet. Soil condition soft to medium stiff clay (SC). Dead load including partition wall/floor = 12 kn/m^2 add 25% of live load (LL) of building where LL=4 kN/m^2, (BNBC, 2020), Damping 5% and R=8.

Date of Submission : Before Next CL