STUDY THE BEHAVIOR OF STANDARD STEEL STRUCTURE THROUGH STATIC AND DYNAMIC ANALYSIS

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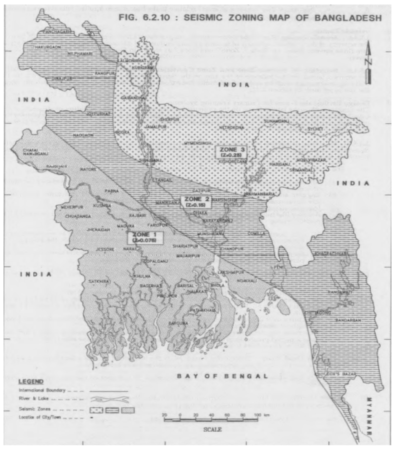
ABSTRACT

Steel structures are most popular form of structure used for office, garments and industrial usages. Many workers are working there specially women for earning their livelihood. So the importance of studying the vulnerability and its susceptibility to different natural hazard is essential. As standard steel structure this study includes the 9 story SAC model of Los Angeles under Pre-Northridge design condition as described in FEMA report 355C. For dynamic analysis this study includes the Response Spectrum analysis which is developed based on the soil types described in BNBC 2006 for Zone-2. RS1, RS2 & RS3 are the three response spectrum developed for soil type 1, 2 & 3 respectively of Zone-2. The model has been developed using SAP 2000 version 14.2.0 and the results are based on the software output. For dynamic analysis the response spectrum is developed as function and for static analysis this study has considered equivalent static method. For both the earthquake and wind load UBC 94 is considered as automatic lateral loading. The behavior is observed in case of joint displacement, story drift & base reaction. Maximum joint displacement for wind load is 0.39 in for earthquake load in X direction is 1.23 in and for earthquake load in Y-direction is 1.64 in. For wind load, maximum story drift at 2nd floor is 4.17E-04 in for earthquake in X-direction maximum drift is 1.06 E-03 in and for Y-direction is 1.57E-03 in. Story drift due EQ-X & EQ-Y are respectively 2.56 & 3.78 times greater than the story drift due to wind load. Story drift due to EQ-Y is 1.48 times greater than the story drift due to EQ-X. In case of base reaction RS3 is 28.24 times more than the base reaction generated by the EQ-X. The reaction for RS2 and RS1 are respectively 17.93 and 13.65 times than the EQ-X. In case of base moment, RS3 is 26.83 times more than the moment generated by EQ-X. And the moment generated by RS2 & RS1 are respectively 17.03 & 12.97 times than the EQ-X. Finally it can be concluded that the structural response due to RS3 is greater than the response produced by RS1 & RS2 i.e. for soil type 3 the structure will be more vulnerable compare to other two types of soil..

Keywords: *BNBC 2006, Dynamic analysis, FEMA, SAC, Static analysis.*

1. INTRODUCTION

According to a geologist, Bangladesh is located in the north-eastern part of the Indian sub-continent at the head of the Bay of Bengal. Tectonically, it lies on the north-eastern Indian plate near the edge of the Indian carton and at the junction of three tectonic plates - the Indian Plate, the Eurasian Plate and the Burmese micro plate. These form two long active tectonic structures where plates converge - the India-Eurasia plate boundary to the north forming the Himalaya Arc, and the India-Burma plate boundary to the east forming the Burma Arc. Moreover, it sits up on the world's largest river delta at close to sea level, facing both the risk posed by a quake and secondary risks of tsunamis and flooding in the quake's aftermath. After the massive quake that killed more than 3,000 people in Nepal, two tremors have hit Bangladesh. The country was jolted by a massive 7.5 quake causing panic among the people in the capital and parts of the country. When the weight of the building is reduced, the earthquake force affecting the building will be reduced. Building weight of steel buildings is 50% less than reinforced concrete buildings, so the earthquake force affecting the building will be reduced at the same ratio (BNBC: Bangladesh National Building Code, 2006). Steel is a ductile material. It is 18 times more ductile than reinforced concrete. As ductility ensures energy absorption when exposed to deformation beyond the flexibility behaviour, this feature gains importance under dynamic loads. Bangladesh is now constructing steel structure for industrial purpose as well as for official building. But we do not have any standard steel model to which we can apply the knowledge of seismic analysis. So, this study includes standard SAC model described in the report of FEMA 355C. 9 story SAC model (FEMA, 2000) of Los Angeles under Pre-Northridge design condition has been included for the purpose of analysis. This model has been developed for the office occupancy which includes two basements under it. Response spectrum analysis is a probabilistic dynamic analysis and a technique for performing an equivalent static lateral load analysis of structures for earthquake forces. It is useful in the evaluation of the reliability and safety of structures under earthquake forces. This method measures the contribution from each natural mode of vibration to indicate the likely maximum seismic response of an essentially elastic structure. It provides insight into dynamic behaviour by measuring pseudo-spectral acceleration, velocity, or displacement as a function of structural period for a given time history and level of damping. The response spectrums included in this study has been derived from the graph known as the normalized response spectrum for 5% damping provided in BNBC 2006 (BNBC: Bangladesh National Building Code, 2006)



(a)

Site Soil Characteristics		Coefficient, S
Type	Description	
S_1	A soil profile with either: a) A rock-like material characterized by a shear-wave velocity greater than 762 m/s or by other suitable means of classification, or b) Stiff or dense soil condition where the soil depth is less than 61 metres	1.0
S_2	A soil profile with dense or stiff soil conditions, where the soil depth exceeds 61 metres	1.2
S_3	A soil profile 21 metres or more in depth and containing more than 6 metres of soft to medium stiff clay but not more than 12 metres of soft clay	1.5
S_4	A soil profile containing more than 12 metres of soft clay characterized by a shear wave velocity less than 152 m/s	2.0
Note : (1)	The site coefficient shall be established from properly substantiated geotechnical data. In locations where the soil properties are not known in sufficient detail to determine the soil profile type, soil profile S_3 shall be used. Soil profile S_4 need not be assumed unless the building official determines that soil profile S_4 may be present at the site, or in the event that soil profile S_4 is established by geotechnical data.	

(b)

Figure 1: (a): Seismic zone map of Bangladesh; Source: BNBC fig 6.2.10, p-10630, (b): Soil types according to BNBC; Source: BNBC table 6.2.25, p-10633.

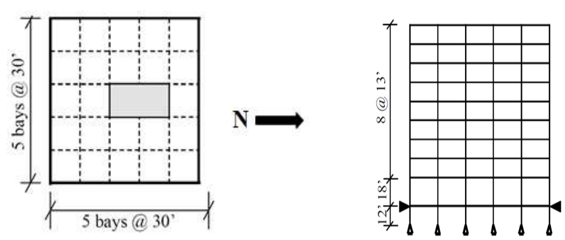
The soil S1, S2 & S3 described in BNBC 2006 is considered and the analysis has been done for Zone-2. Finally, the model has been developed by using SAP2000 version 14.2.0 (Structural Analysis Program, 2000) and analysed under BNBC response spectrum developed for Zone-2.

2. METHODOLOGY

It is already known that response spectrum is the most popular tool in the seismic analysis of structures. So, proper knowledge is required about the method of response spectrum analysis. This chapter will gradually discuss about the model development, load assignment, and other specification used to complete the study.

2.1 Development of the SAC model

Plan and the loading have been derived from the model used in the section FEMA 355C. Design conditions for Pre-Northridge model building of Los Angles have been followed. The chronological development of the model has been described by the snap taken from SAP 2000. The plan & elevation view of the model of 9 story LA building is shown below:



(a) (b)

Figure 2: (a) Plan view (b) Elevation view.

The materials used in this study including their properties are shown in the table below.

Table 1: Material Properties.

Name	Type	Modulus of Elasticity E lb/in²	Poison's ratio ν	Unit Weight lb/ft³	Design Strengths
4000Psi	Concrete	3122018.6	0.2	150	F_c=4000 lb/in²
A36	Steel	29000000	0.3	490	F_y=36000 lb/in²
Fy50	Steel	29000000	0.3	490	F_y=50000 lb/in²

The frame elements are defined as per FEMA 355C. The arrangement of the frame elements are shown in the figure below.

9-story Building

Story/Floor	COLUMNS		DOUBLER PLATES (in)	GIRDER
	Exterior	Interior		
-1/1	W14X370	W14X500	0,0	W36X160
1/2	W14X370	W14X500	0,0	W36X160
2/3	W14X370, W14X370	W14X500, W14X455	0,0	W36X160
3/4	W14X370	W14X455	0,0	W36X135
4/5	W14X370, W14X283	W14X455, W14X370	0,0	W36X135
5/6	W14X283	W14X370	0,0	W36X135
6/7	W14X283, W14X257	W14X370, W14X283	0,0	W36X135
7/8	W14X257	W14X283	0,0	W30X99
8/9	W14X257, W14X233	W14X283, W14X257	0,0	W27X84
9/Roof	W14X233	W14X257	0,0	W24X68

Figure 3: Arrangement of the frame elements.

Loads are distributed as gravity load & lateral load. Gravity loads are distributed over the floor and the roof. They are different for floor and roof. Gravity load distribution are given in the following tables.

Table 2: Gravity loads distributed over floor.

Load Name	Unit	Amount
Flooring	psf	3
Partitions	psf	10
Exterior wall	psf	25
Live load	psf	50
Mech. /Elect.	psf	7
Metal Deck	psf	122.5

Table 3: Gravity loads distributed over roof.

Load Name	Unit	Amount
Roofing	psf	7
Parapet	plf	175
Metal Deck	psf	122.5

Lateral loads include wind load and earthquake load. For both wind and earthquake load UBC 94 auto lateral load has been used. Wind load is considered in one direction but the earthquake load is considered in X & Y direction. For calculating lateral load, the joint constraint has been provided as rigid diaphragm. They were provided at each joint of each floor. It has particular significance in the calculation of lateral load specially wind load. For the simplicity of the calculation it will apply the lateral load to one point for each story rather than every point of the story. The area should be meshed for accurate & smooth calculation. Meshed areas increase the accuracy but also take more time to analyze the model. For this study auto meshed has been used. Mesh has been done by 5X5 area meshes. Mass source is another important parameter which has to be defined carefully. It is important for seismic analysis because it provide the mass which will be considered during earthquake load calculation. In this study, mass source has been defined as "From loads" where only the dead and super dead loads have been included.

UBC 94 ASD load combination has been used as per FEMA report. The load combination includes:

1. DL+LL
2. DL+LL+WL
3. DL+LL-WL
4. DL+LL+0.5WL
5. DL+LL-0.5WL
6. DL+LL+EQ-X
7. DL+LL- EQ-X
8. DL+LL- EQ-Y
9. DL+LL- EQ-Y
10. ENVELOPE

Here, DL= Dead Load; LL= Live Load; WL= Wind Load; EQ-X= Earthquake load in X direction; EQ-Y= Earthquake load in Y direction; ENVELOPE= Combination of all load combinations

2.2 Development of BNBC response spectrum

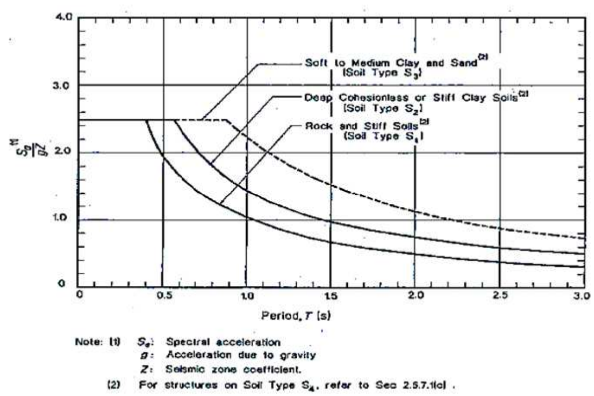


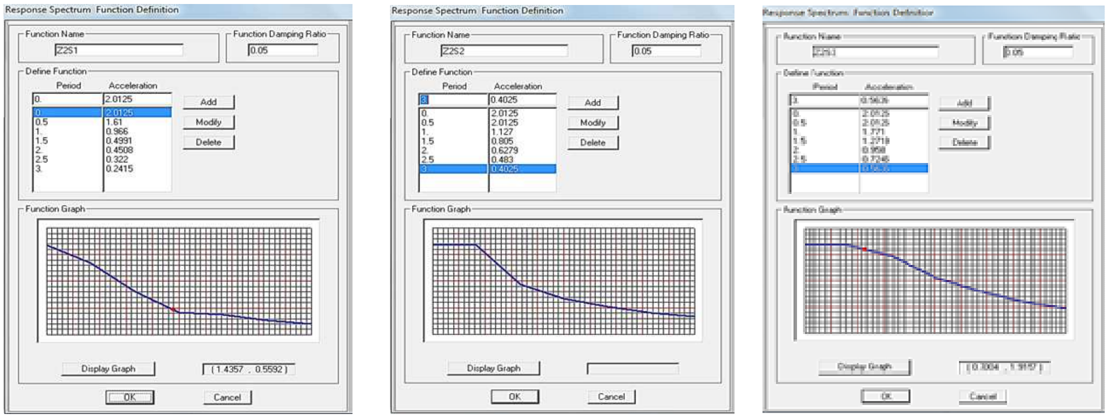
Figure 4: BNBC normalized response spectrum for 5% damping ratio; Source: BNBC fig 6.2.11, p- 10637.

From Figure 4 we seen that, Y axis represents the values of S_a/gZ, where S_a = spectral acceleration, g = acceleration due to gravity, Z = Seismic zone coefficient. The values of S_a has obtained by multiplying the values of Y axis by gZ, where g = 32.2 ft/sec^2 & Z = 0.15 for Zone 2. Than for ordinary moment resisting frame the values of S_a has been divided by the value of R = 6 (Shafi et al., 2015). Finally the following table can be prepared.

Table 4: BNBC response spectrum data of ordinary moment resisting frame for Zone-2.

Time period	**Soil type 1**	**Soil type 2**	**Soil type 3**
0	2.0125	2.0125	2.0125
0.5	1.61	2.0125	2.0125
1	0.966	1.127	1.771
1.5	0.4991	0.805	1.2719
2	0.4508	0.6279	0.95795
2.5	0.322	0.483	0.7245
3	0.2415	0.4025	0.5635

The response spectrum data obtained from Table 4 is used to define the response spectrum functions. In this study the functiones are named as Z2S1, Z2S2 & Z2S3 respectively. The shape of the graphs are shown in Figure 5. For all the cases damping ratio of 5% is being considered. The Figure 5 (a) is developed by using 1st & 2nd column of table 4. The Figure 5 (b) & (c) are developed by using column 1 & 3 and column 1 & 4 of Table 4 respectively. After defining the function, load cases are defined as RS1, RS2 & RS3 respectively. In modal load case maximum of 12 modes have been considered. Types of modes are taken as Eigen vectors. As for combination CQC is considered as modal combination and SRSS is considered as directional combination.



(a) (b) (c)

Figure 5: Response spectrum functions for zone-2 (a) soil type 1 (b) soil type 2 and (c) soil type 3. Source: Snap from SAP 2000.

3. DATA COLLECTION

3.1 Joint Displacement

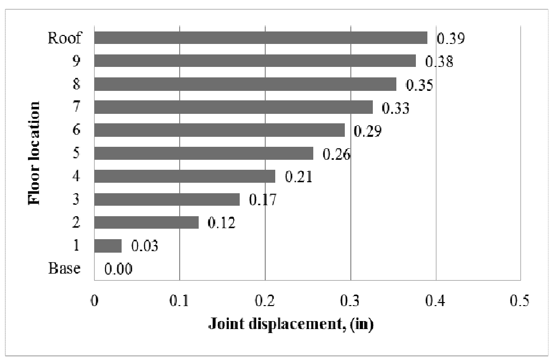
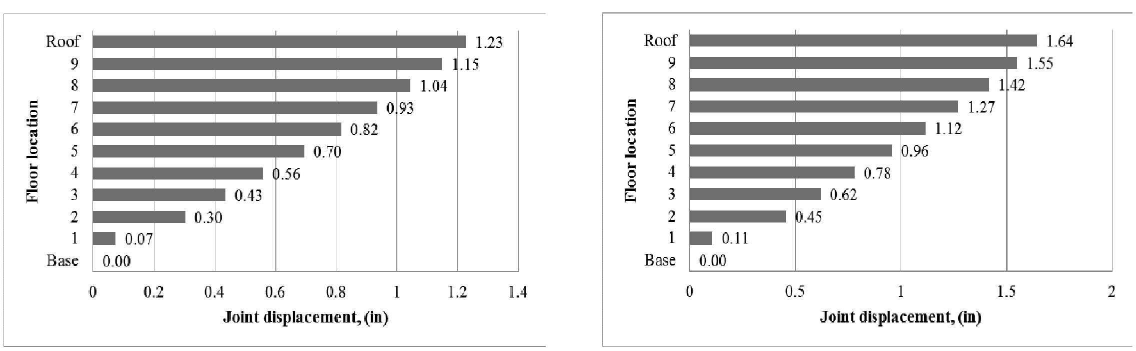


Figure 6: Joint displacement for wind load.

The joint displacement obtained for different floor level due to wind load is shown in Figure 6. Horizontal axis represents joint displacement in inches & vertical axis represents the floor location from base to roof. Joint displacement values varied from zero to 0.39″. The maximum joint displacement is occurred at the roof and the value is 0.39″. It is also observed that the joint displacements are increasing from base to roof.



(a) (b)

Figure 7: (a): Joint displacement for earthquake load in X direction (b): Joint displacement for earthquake load in Y direction.

The joint displacement due to earthquake loading in X-direction & Y-direction is shown in Figure 7 (a) & (b) respectively. Displacement is being increased from the base to roof and the values vary from zero to 1.23″ for earthquake load in X direction and zero to 1.64″ for earthquake load in Y direction. In both cases, maximum joint displacement is obtained at roof level and the value is 1.23″ for earthquake load in X direction and 1.64″ for earthquake load in Y direction.

3.2 Story Drift

According to FEMA 355C, the limit for the story drift is taken as h/400 where "h" is the story height. So the limit for story 1 is (12X12)/400=0.36″, for story 2 is (18*12)/400=0.54″ and for the other stories are (13X12)/400=0.39″. In case of wind load, the variation of story drift with respect to floor location is shown in Figure 8.

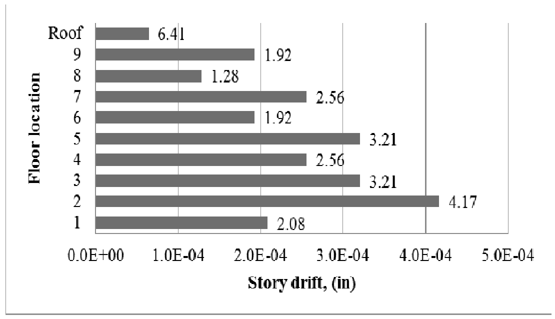
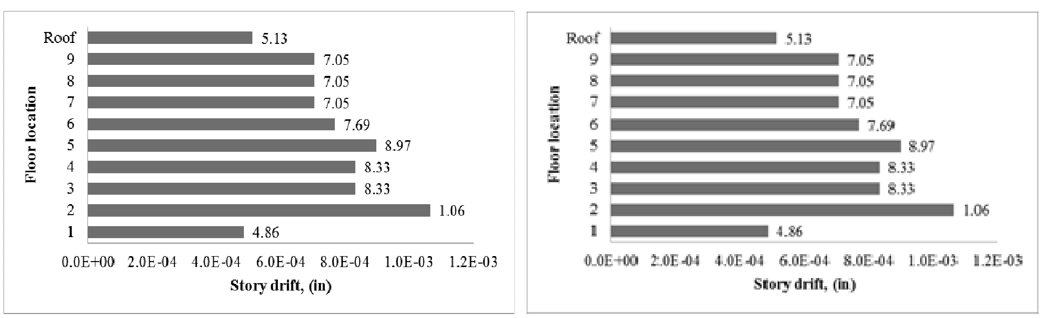


Figure 8: Story drifts due to wind loading.

It is observed that, story drift values for wind load vary from 6.41E-05″ to 4.17E-04″. The maximum story drift is observed at 2nd floor and the value is 4.17E-04″ which is less than the limit value i.e. 54″. Story drift due to earthquake load in X direction is shown in Figure 9 (a). The values are varied from 4.86 E-4″ to 1.06 E-3″. The maximum value is obtained in 2nd floor and the value is 1.06 E-3″.

Figure 9 (b) represents story drift due to earthquake load in Y direction. It is seen that, the values are varied from 4.86 E-4″ to 1.06 E-3″. Here maximum value is obtained as 1.06E-05″.



(a) (b)

Figure 9: (a) Story drift due to earthquake load in X direction (b) Story drift due to earthquake load in Y direction.

3.3 Base Reaction

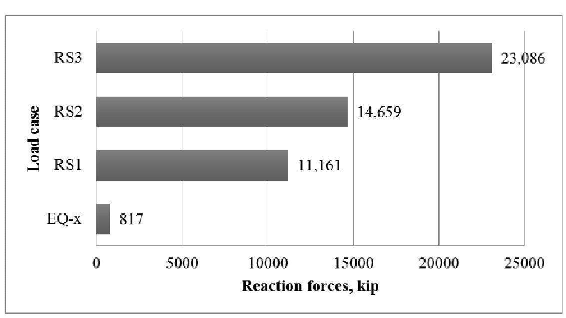


Figure 10: Base reaction force (kip)

Figure 10, illustrated the variation in base reaction force F_X (kip) in the global-X direction of the structure due to earthquake load in X-direction and the three response spectrums. It is seen that the base reaction is much higher in case of dynamic analysis than the static analysis. For RS3 we have the maximum reaction force of 23086 kip.

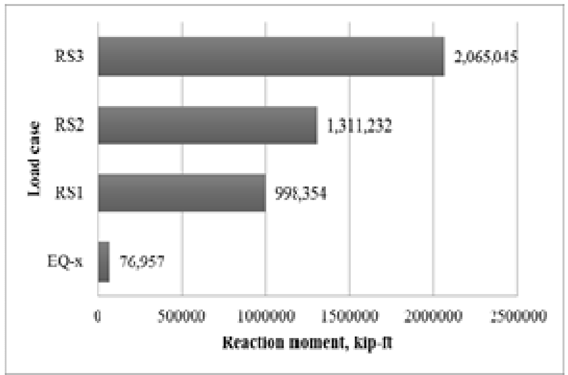


Figure 11: Base reaction moment (kip-ft)

Figure 11, has described the variation in base reaction moment M_Y (kip-ft) in the global-Y direction of the structure due to earthquake in X-direction and the three response spectrums. Dynamic analysis values are greater than the static analysis. Maximum reaction moment is obtained for RS3 and the value is 2065045 kip-ft.

4. CONCLUSIONS

For wind load, maximum story drift at 2nd floor is 4.17E-04 inch. For earthquake loading, maximum drift occurs at 2nd floor for both the directions. For earthquake load in X direction maximum drift is 1.06E-03 inch and for Y direction is 1.57E-03 inch. According to FEMA 355C all the story drifts are within limit. Story drift due earthquake load in X direction & earthquake load in Y direction are respectively 2.56 & 3.78 times greater than the story drift due to wind load. Story drift due to earthquake load in Y direction is 1.48 times greater than the story drift due to earthquake load in X direction. In case of base reaction, RS3 has maximum base reaction force in global X direction. It is 28.24 times more than the base reaction generated by the static earthquake loading in X direction. The reaction for RS2 and RS1 are respectively 17.93 and 13.65 times than the earthquake loading in X direction. Maximum reaction moment is generated for RS3 which is 26.83 times more than the moment generated by earthquake loading in X direction. And the moment generated by RS2 & RS1 are respectively 17.03 & 12.97 times than the earthquake loading in X direction.

Since base reaction is an important parameter to understand the structural behaviour; we can conclude that, soil type 3 will produce more response to the earthquake than the other two types of soil. Structure will be more vulnerable if constructed over soil type 3.

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