INELASTIC SEISMIC RESPONSE FOR SYMMETRICAL & ASYMMETRICAL RCC BUILDINGS

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Abstract - *In the structure when center of rigidity and center of mass do not coincide then structure produce translation & coupled translation responses to earthquake ground motion. Then torsional motions may occur even in nominally symmetric structures due to accidental eccentricity and rotational component of ground motions. In present dissertation work, the inelastic seismic behaviour of symmetric & asymmetric plan RCC structures is studied using the Base Shear and Torque surfaces. We have analysed 20 number (1 no of symmetric in plan, 6 no of uniaxial asymmetric in plan, 12 no of biaxial asymmetric in plan and 1 no with vertical asymmetry) of G+3 floor RCC structures have been analysed using Base Shear and Torque surfaces. Base Shear and Torque surface provides sufficiently general framework to explain the inelastic torsional behavior of RCC structures. We also have analysed 7 number (1 symmetric in plan and 6 asymmetric in plan) of G+3 floor RCC structures have been analysed by Static Pushover Analysis. The Performance points for all RCC structures are plotted. From the graph at performance point for all RCC structures, it is observed that as the asymmetry increases base shear increases and displacement decreases. Due to Asymmetry Ductility of RCC structure is lost and failure of RCC structure is likely to be brittle. Ultimately, analysis using Base Shear and Torque surface decides symmetry or asymmetry of RCC structure.*

Key Words: **Base shear and torque surface, Inelastic Analysis, Static Push Over Analysis, SAP 2000, Symmetric & Asymmetric building.**

1. INTRODUCTION

1.1 GENRAL

RCC Structures are especially vulnerable during seismic tremor due to asymmetrical scattering of stiffness & strength in plan. RCC structures subjected to ground shaking undergo lateral as well as torsional motions simultaneously. Such motions are due to natural torsion in the RCC structure with asymmetric in the plan; and accidental torsion in all RCC structures, even in those with symmetric in plan.

The coupling between torsional and lateral motions in the RCC structures with plan asymmetry inevitably leads to non-uniform distortion demand on the lateral resisting planes of the system. In view of this, the study of asymmetric RCC structures is done using Base Shear and Torque surface and Pushover analysis.

1.2 SCOPE

The dissertation work includes comparison of asymmetrical & symmetrical RCC structures using Base Shear and Torque surface and Static pushover analysis.

2 types of RCC structures viz. 20 number (1 no of symmetric in plan, 6 no of uniaxial asymmetric in plan, 12 no of biaxial asymmetric in plan and 1 no with vertical asymmetry) of G+3 floor RCC structures have been analysed using Base Shear and Torque surfaces and 7 number (6 asymmetric in plan and 1 symmetric in plan) of G+3 floor RCC structures have been analysed by Static Pushover Analysis. The asymmetry has been presented by changing the measures of columns sections. BST analysis is carried out for 2 cases namely biaxial asymmetry in plan and uniaxial asymmetry in plan. Pushover analysis is carried out using SAP2000 software.

2. GUIDELINES

2.1 AIM

1. The reaction of structures deforming into their inelastic Range during serious ground shaking is of prime significance in earthquake engineering.

2. Least measure of work has been done on inelastic reaction of RCC structure, than on elastic response of asymmetrical RCC structures.

3. An elastic analysis can't predict reasonable estimates of inelastic deformation or damage in structures and failure mechanism in the structures

4. Inelastic methodology help in recognizing modes of failure also the potential for dynamic breakdown or progressive collapse of the RCC structure.

5. Nonlinear dynamic response history analysis is prepared to do giving the required information about the RCC structure, however it may be very time devouring.

6. RCC structures with symmetric plan are less vulnerable as compared to the asymmetric in the plan for RCC structure. Subsequently there is necessity to learn the behavior of

symmetrical & asymmetrical RCC structures and seismic performance of the RCC structures.

2.2 OBJECTIVE

In this dissertation work following objectives are studied which are given below :-

1. To figure out how to draw Base Surface and Torque Surface(BST).
2. To Study the adequacy of BST surface for analysis of Symmetrical & Asymmetrical RCC structures.
3. To compare the reaction of symmetrical and asymmetrical RCC structures using BST surface.

3. BASE SHEAR AND TORQUE (BST) SURFACE

The BST surface defines all combinations of base shear and torque that when applied statically lead to the collapse of the system. BST surface has two region which are given below & BST surface region is shown in fig.3.1

i) Interior Region: - This region shows the elastic behavior of the structure which is the combination of base shear & torque.

ii) Exterior Region: - This region contains the statically inapplicable combination of base shear & torque.

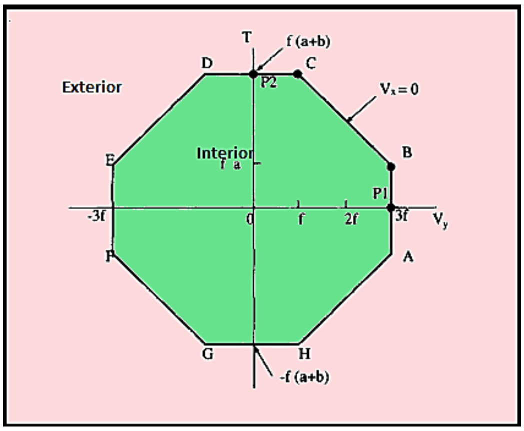


Fig -3.1: BST SURFACE REGIONS

3.1 BST SURFACE DEVELOPING PROCEDURE

BST surface gives the ultimate value for base shear and torque combination, thus the ultimate shear strength of resisting planes is required. To draw the BST surface, following equations are given by Juan c. De la llera and Anil k. Chopra (1995)

The equations are as follows,

"X1 = Vyo, Y1 = Vyo Xp + Tɹ (1- $\hat{Vx}$)

X2 = Vyu + Vyc Y2 = T0 - Tɹ $\hat{Vx}$

X3 = Vyu - Vyc Y3 = T0 - Tɹ $\hat{Vx}$

X4 = - Vyo Y4 = - Vyo Xp + Tɹ (1- $\hat{Vx}$) ......(3.1)

X5 = - X1, Y5 = - Y1

X6 = - X2 Y6 = - Y2

X7 = - X3 Y7 = - Y3

X8 = - X4 Y8 = - Y4

Where

1. $\hat{Vx}$ = Vx / Vxo is the normalized floor shear in the x-direction; Vxo = $\Sigma f x(i) M i=1$ is the lateral capacity of the stoey in the x-direction ; $fx(i)$ is the capacity of the ith resisting plane in x- direction and M is the number of resisting planes in x- direction.

2. Vyo = $\Sigma(i)Ni=1$ is the lateral capacity of the floor in the y-direction; $fy(i)$ is the capacity of the ith resisting plane in y-direction and N is the number of resisting planes in y direction

3. Vyc = is the capacity of the resisting planes in the y-direction passing through the center of mass (C.M.) of the system.

4. To = $\Sigma|(i)\ x(i)|Ni=1 + \Sigma|fx(i)y(i)|Mi=1$ is the torsional capacity of the system.

5. Tɹ = $\Sigma(i)y(i)Mi=1$ is the torque provided by the resisting planes in the orthogonal direction.

6. Xp= $\Sigma(i)\ x(i)Ni=1$/ Vyo is the strength eccentricity, or First moment of strength.

7. Vyu = $\Sigma(i)y(i)Mi=1,i\neq 2$ / $|x(i)|$ is donated as strength imbalance in the system"[1]

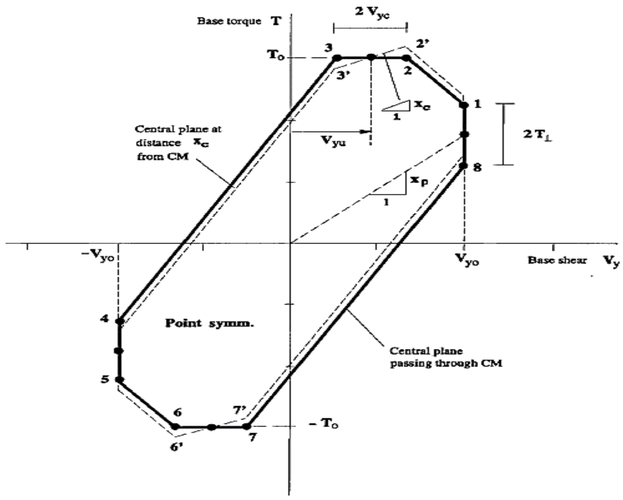


Fig -3.2: BST SURFACE OF PARAMETRIC REPRESENTATION

3.2 BST SURFACE VALIDATION

BST surface has been approved with BST surface for the RCC structure from the research paper introduced by Juan c. De la llera and Anil K. Chopra, 1995.

3.2.1 SYMMETRICAL RCC STRUCTURE

Given data :-

Plan Dimension :- 18m × 9m

All resisting planes dimensions :- 7m × 0.25m

concrete grade :- M30

Shear stress :- 0.37 N/mm2

Minimum reinforcement in resisting planes :- 0.25%

Shear strength of resisting planes is calculated as f = 0.37 × 7000 × 250 × 10-3 = 647.5kN

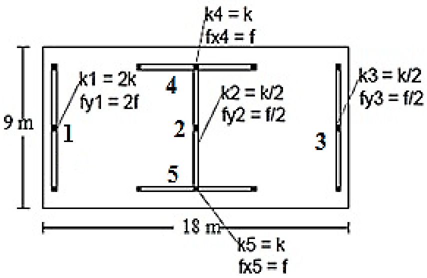


Fig -3.3: SYMMETRICAL RCC STRUCTURE WITH SINGLE FLOOR IN PLAN

The coordinates of the BST surface are utilizing by using Eq.(3.1) and are presented in Table-3.1

Table -3.1: SYMMETRICAL RCC STRUCTURE PLAN COORDINATES OF BST SURFACE

X1,Y1	1942.5, 4532.5
X2,Y2	647.5, 16187.5
X3,Y3	-647.5, 16187.5
X4,Y4	-1942.5, 4532.5
X5,Y5	-1942.5, -4532.5
X6,Y6	-647.5, -16187.5
X7,Y7	647.5, -16187.5
X8,Y8	1942.5, -4532.5

3.2.2 ASYMMETRICAL RCC STRUCTURE

In the symmetrical structure asymmetry developed by changing the shear strength of resisting plane 1 from f to 2f and for resisting planes 2 and 3 from f to f/2 as shown in Figure 3.4

The strength eccentricity ep = (f × 9) (1/2 - 2) / (3f) = - 4.5 m

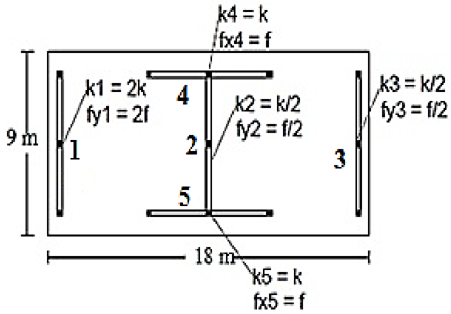


Fig -3.4: ASYMMETRICAL RCC STRUCTURE WITH SINGLE FLOOR IN PLAN

3.3 PROBLEM DEFINITION FOR BASE SHEAR AND TORQUE SURFACE

The RCC structure has plan dimensions of 22.5 m × 22.5 m and bay width of 4.5 m as shown in Figure 3.5. The RCC structures have been designed as per IS 456 (2000). Asymmetry has been introduced by gradually changing the column sizes.

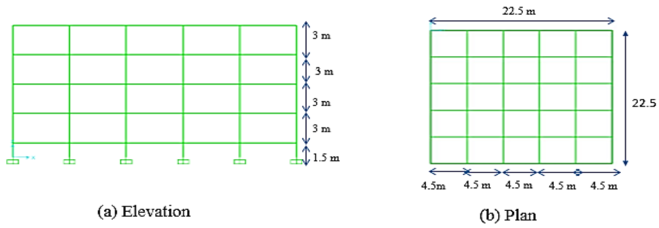


Fig -3.5: G+3 RCC structure considered for BST Analysis

For BST analysis,

i) 1 symmetrical G+3 floor RCC structure in plan

ii) 6 uniaxial asymmetrical G+3 floor RCC structures in plan

iii) 12 biaxial asymmetrical G+3 floor RCC structures

iv) 1 RCC structure with vertical asymmetry are analysed using BST surface. The BST surfaces are plotted using equation (3.1). By using Response Spectra analysis, Base shear is calculated using software SAP2000 and it is compared with Base shear from BST surface. First G+3 RCC structure symmetric in plan is designed for residential purpose using software STAAD Pro.V8i.

A G+3 floored RCC frame with following properties:

i. RCC frame with 5 bays in both directions and G+3 floored

ii. Floor to floor height is 3m and bay width is 4.5m

iii. Depth of foundation from plinth level is 1.5m

iv. Reinforcement – Fe 415 and Concrete – M25

v. Column Size – 600 mm × 600 mm

vi. Beam Size – 600 mm × 230 mm

vii. Response Spectra- IS: 1893 (Part 1)-2002

viii. Soil strata- Medium Rock

ix. Zone – IV

x. Importance Factor- 1

xi. Dead load = 2 kN/m2 and Live load = 4 kN/m2 on each floor

xii. Modal Combination – Square Root of Sum of Squares (SRSS)

xiii. Directional Combination - Square Root of Sum of Squares (SRSS)

xiv. Load Combination as per IS: 1893 (Part 1): 2002

: 1.5 (DL+LL)

: 1.2 (DL + LL ± EL)

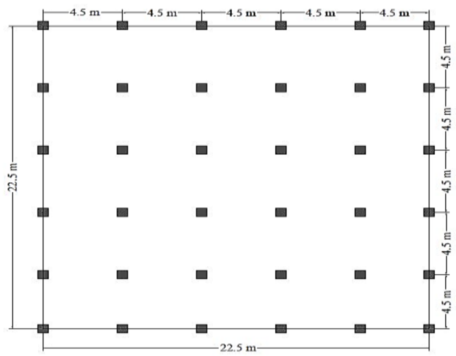
: 1.5 (DL± EL)

: 0.9 DL ± 1.5EL

Asymmetry is introduced in different RCC structures by changing the column sizes.

3.3.1 SYMMETRICAL RCC STRUCTURE IN PLAN

BST surface for symmetric G+3 floor RCC structure is drawn by using Eq. (3.1). The RCC structure has plan dimensions of 22.5 m × 22.5 m and bay width of 4.5 m. and its BST surface is as shown in Figure 4.1. The RCC structure has been designed as per IS 456 (2000).The column sizes are in the range of 400 mm × 400 mm to 550 mm × 550 mm after designing. For achieving symmetry in both X and Y directions the columns are taken as square in size of dimensions 600 mm × 600 mm. The percentage reinforcement provided all columns is 0.8%. Hence for 0.8% reinforcement and M 25 grade concrete, shear stress is worked out as 0.57 N/mm2 (IS 456, 2000). Shear strength of one column is calculated as f = 0.57 × 600 × 600 × 10-3 = 205.2 kN.



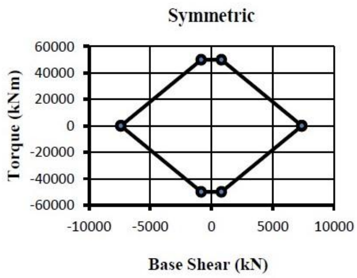


Fig -3.6: G+3 FLOOR RCC SYMMETRICAL STRUCTURE WITH PLAN AND BST SURFACE

3.3.2 UNIAXIAL ASYMMETRICAL RCC STRUCTURE IN PLAN

6 asymmetrical RCC structures are considered for the analysis. The asymmetry is introduced by changing the shear strength of columns by gradually increasing the sizes of some columns from 600 mm × 600 mm to 900 mm × 900 mm.

1. The asymmetric RCC structure No.1 has five lines of columns with column sizes of 600 mm × 600 mm (Not selected columns in Figure 3.7) and remaining one line of columns with column sizes of 700 mm × 700 mm (selected columns in Figure 3.7). The Center of Mass (C.M.) is at (11.25 m, 11.25 m). Center of Stiffness (C.S.) is at (12.65 m, 11.25 m), thus percentage asymmetry produced is 6.22 %. The shear strength of columns of size 700 mm × 700 mm is calculated similar to that of column size 600 mm × 600 mm; f = 0.57 × 700 × 700 × 10-3 =279.3 kN

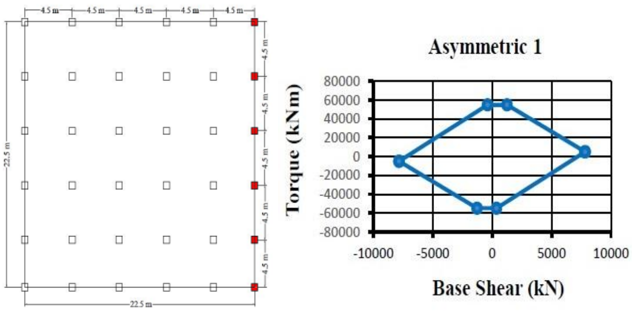


Fig -3.7: G+3 FLOOR RCC UNIAXIAL ASYMMETRICAL STRUCTURE NO 1 WITH 6.22% STRNGTH ITS PLAN AND BST SURFACE

2. The considered asymmetric RCC structure No.2 has four lines of columns with column sizes of 600 mm × 600 mm (Not selected columns in Figure 3.8) and remaining two lines of columns with column sizes of 700 mm × 700 mm (selected columns in Figure 3.8), hence percentage asymmetry produced is 8.85 %.

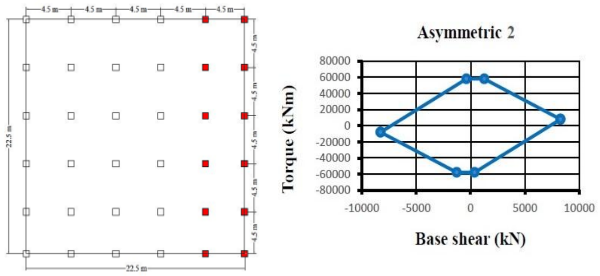


Fig -3.8: G+3 FLOOR RCC UNIAXIAL ASYMMETRICAL STRUCTURE NO 2 WITH 8.85% STRNGTH ITS PLAN AND BST SURFACE

3. The considered asymmetric RCC structure No.3 has five lines of columns with column sizes of 600 mm × 600 mm (Not selected columns in Figure 3.9) and remaining one line of columns with column sizes of 800 mm × 800 mm (selected columns in Figure 3.9), thus percentage asymmetry produced is 13.24 %. The shear strength of column having size 800 mm × 800 mm is calculated similar to that of column size 600 mm × 600 mm; f = 0.57 × 800 × 800 × 10-3 = 364.8 Kn

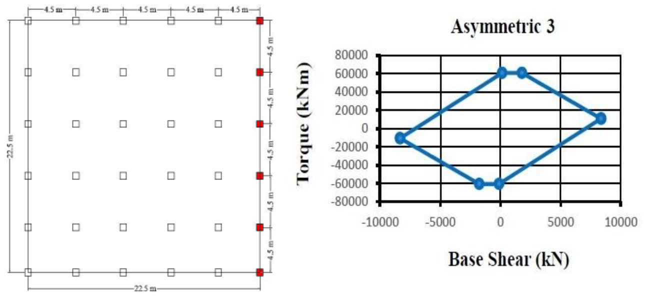


Fig -3.9: G+3 FLOOR RCC UNIAXIAL ASYMMETRICAL STRUCTURE NO 3 WITH 13.24% STRNGTH ITS PLAN AND BST SURFACE

4. The considered asymmetric RCC structure No.4 has four lines of columns with column sizes of 600 mm × 600 mm (Not selected columns in Figure 3.10) and remaining two lines of columns with column sizes of 800 mm × 800 mm(selected columns in Figure 3.10), with percentage asymmetry of 16.75%

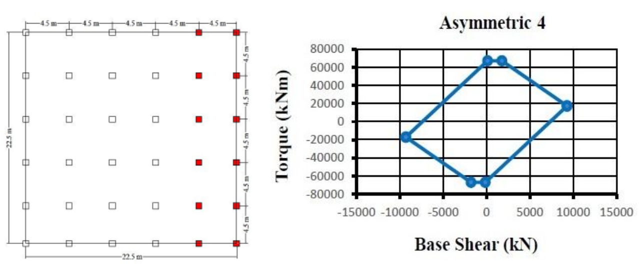


Fig -3.10: G+3 FLOOR RCC UNIAXIAL ASYMMETRICAL STRUCTURE NO 4 WITH 16.75% STRNGTH ITS PLAN AND BST SURFACE

5. The considered asymmetric RCC structure No.5 has five lines of columns with column sizes of 600 mm × 600 mm (Not selected columns in Figure 3.11) and remaining one line of columns with column sizes of 900 mm × 900 mm (selected columns in Figure 3.11), with percentage asymmetry of 20.18 %. The shear strength of column having size 900 mm × 900 mm is calculated similar to that of column size 600 mm × 600 mm; f = 0.57 × 900 × 900 × 10-3 = 461.7 Kn

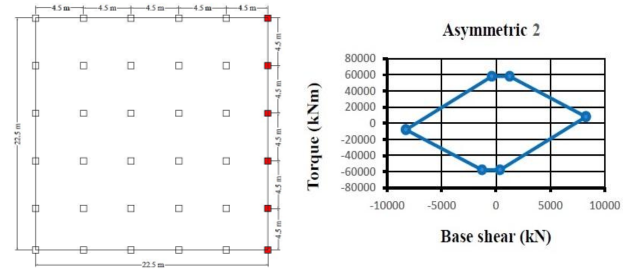


Fig -3.11: G+3 FLOOR RCC UNIAXIAL ASYMMETRICAL STRUCTURE NO 5 WITH 20.18% STRNGTH ITS PLAN AND BST SURFACE

6. The considered asymmetric RCC structure No.6 has four lines of columns with column sizes of 600 mm × 600 mm (Not selected columns in Figure 3.12) and remaining two lines of columns with column sizes of 900 mm × 900 mm (selected columns in Figure 3.12), producing 23.02% asymmetry

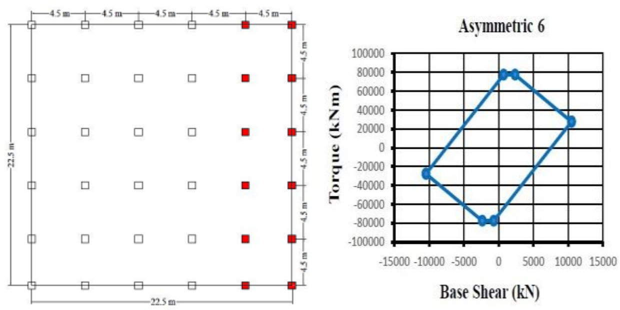


Fig -3.12: G+3 FLOOR RCC UNIAXIAL ASYMMETRICAL STRUCTURE NO 6 WITH 23.02 % STRNGTH ITS PLAN AND BST SURFACE

The BST surface of uniaxial asymmetric RCC structures No.1 to RCC structures No.6 are superimposed on BST surface of that Symmetric RCC structure (Figure 3.6) as shown in Figure 3.13

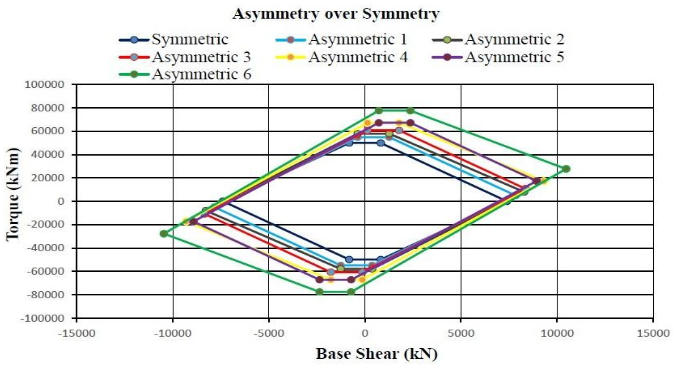


Fig -3.13: BST SURFACE FOR ALL UNIAXIAL ASYMMETRICAL RCC STRUCTURE PLAN OVER SYMMETRICAL RCC STRUCTURE

3.3.3 BIAXIAL ASYMMETRICAL RCC STRUCTURE IN PLAN

12 no of G+3 floor biaxial asymmetrical RCC structures in plan are considered for the analysis. The asymmetry is introduced by changing the shear strength of columns by gradually increasing the sizes of some columns from 600 mm × 600 mm to 900 mm × 900 mm.

1. The biaxial asymmetric RCC structure No.1 is shown in Figure 3.14 with column sizes of 600 mm × 600 mm (Not selected columns in Figure 3.14) and column sizes of 700 mm × 700 mm (selected columns in Figure 3.14), thus percentage asymmetry produced in × and Y directions respectively are 4.70%, 4.70%.

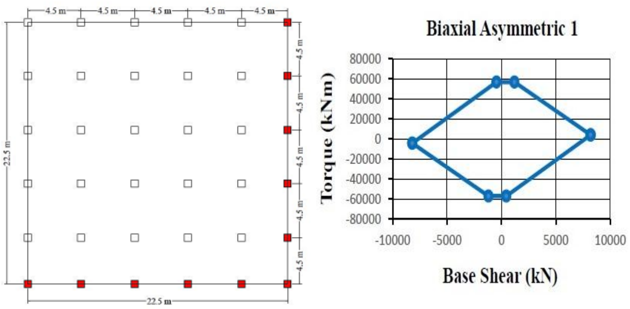


Fig -3.14: G+3 FLOOR RCC BIAXIAL ASYMMETRICAL STRUCTURE NO 1 WITH 4.70 % STRNGTH ITS PLAN AND BST SURFACE

2. The biaxial asymmetric RCC structure No.2 is shown in Figure 3.15 with column sizes of 600 mm × 600 mm (Not selected columns in Figure 3.15) and column sizes of 700 mm × 700 mm (selected columns in Figure 3.15), thus percentage asymmetry produced in X and Y directions respectively are 5.14%, 5.14%

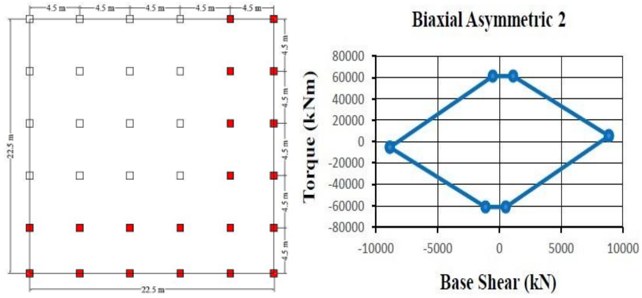


Fig -3.15: G+3 FLOOR RCC BIAXIAL ASYMMETRICAL STRUCTURE NO 2 WITH 5.14 % STRNGTH ITS PLAN AND BST SURFACE

In the similar way, column dimensions are configured for columns of dimensions 800 mm × 800 mm and 900 mm × 900 mm. all biaxial asymmetric RCC structures from RCC structure No. 3 to RCC structure No. 6 have been analysed using BST surface. The BST surface of Biaxial asymmetric RCC structures No.1 to RCC structures No.6 are superimposed on BST surface of that Symmetric RCC structure (Figure 3.6) as shown in Figure 3.16

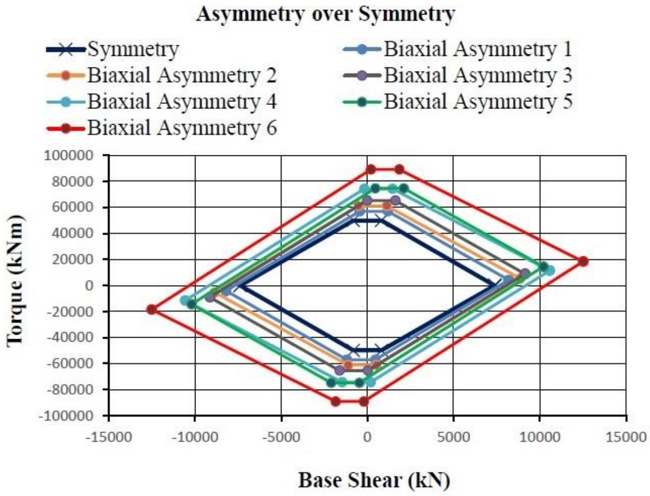


Fig -3.16: BST SURFACE FOR ALL BIAXIAL ASYMMETRICAL RCC STRUCTURES OVER SYMMETRICAL RCC STRUCTURE IN PLAN

3. The biaxial asymmetric RCC structure No.7 is shown in Figure 3.17 with column sizes of 600 mm × 600 mm (Not selected columns in Figure 3.17) and column sizes of 700 mm × 700 mm (selected columns in Figure 3.17), thus percentage asymmetry produced in X and Y directions respectively are 4.70 %, 4.70 %

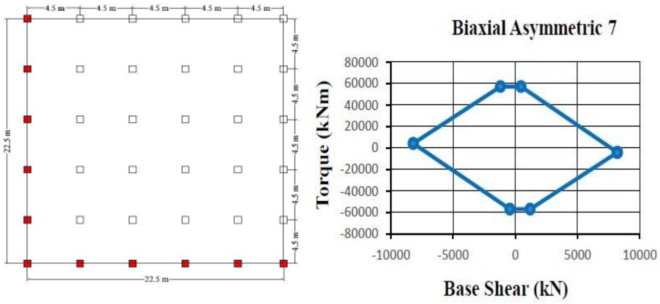


Fig -3.17: G+3 FLOOR RCC BIAXIAL ASYMMETRICAL STRUCTURE NO 7 WITH 4.70 % STRNGTH ITS PLAN AND BST SURFACE

4. The biaxial asymmetric RCC structure No.8 is shown in Figure 3.18 with column sizes of 600 mm × 600 mm (Not selected columns in Figure 3.18) and column sizes of 700 mm × 700 mm (selected columns in Figure 3.18), thus percentage asymmetry produced in X and Y directions respectively are 5.14 %,5.14 %.

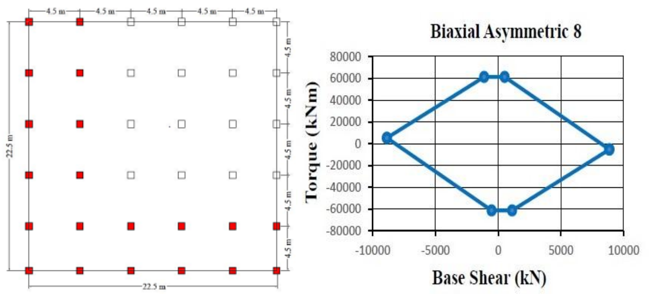


Fig -3.18: G+3 FLOOR RCC BIAXIAL ASYMMETRICAL STRUCTURE NO 8 WITH 5.14 % STRNGTH ITS PLAN AND BST SURFACE

In the similar way, column dimensions are configured for columns of dimensions 800 mm × 800 mm and 900 mm × 900 mm. all biaxial asymmetric RCC structures from RCC structure No. 9 to RCC structure No. 12 have been analysed using BST surface. The BST surface of Biaxial asymmetric RCC structures No.7 to RCC structures No.12 are superimposed on BST surface of that Symmetric RCC structure (Figure 3.6) as shown in Figure 3.19

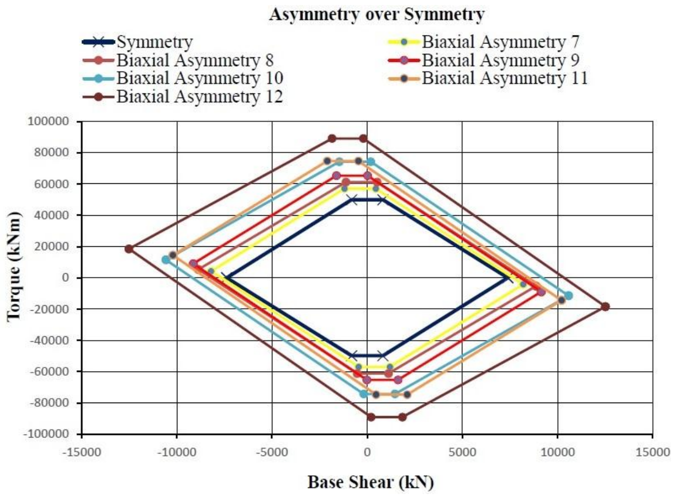


Fig -3.19: BST SURFACE FOR ALL BIAXIAL ASYMMETRICAL RCC STRUCTURES OVER SYMMETRICAL RCC STRUCTURE IN PLAN

From superimposed BST surfaces presented in Figure 3.13, Figure 3.16 and Figure 3.19.

i. The BST surface is symmetrical for RCC structure symmetrical in plan.

ii. As asymmetry in RCC structure increases, the orientation of BST surface changed making it skewed compared to BST surface of symmetrical RCC structure.

iii. The orientation of BST surface for asymmetrical RCC structures explain that RCC structure rotates about those columns which having higher strength than other columns.

iv. BST surface can be used to find whether RCC structure is symmetrical or asymmetrical.

3.3.4 RCC STRUCTURE WITH VERTICAL ASYMMETRY

One RCC structure with vertical asymmetry is considered for BST surface analysis. To introduce vertical asymmetry, symmetric RCC structure (Figure 3.6) is modified keeping same column dimensions are 600 mm × 600 mm and beam dimensions are 600 mm × 230 mm. The elevation and plan of vertical asymmetric RCC structure are presented in Figure 3.19 and Figure 3.20 respectively. The BST surface for each floor is presented in Figure 3.21

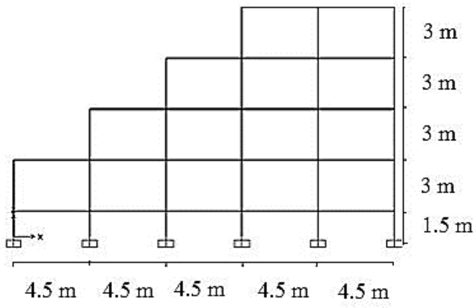


Fig -3.19: ELEVATION OF VERTICALLY ASYMMETRICAL RCC STRUCTURE

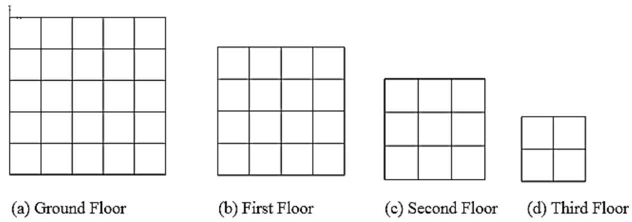
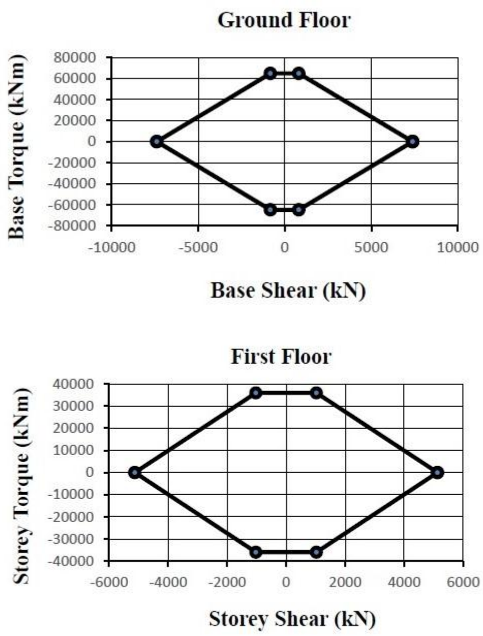
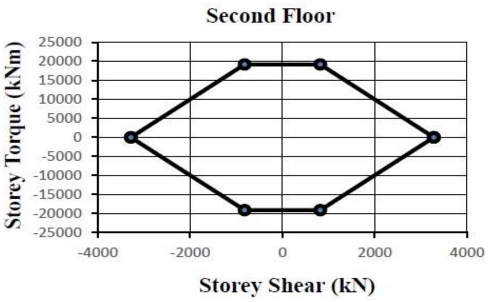


Fig -3.20: PLAN OF EACH FLOOR OF VERTICALLY ASYMMETRICAL RCC STRUCTURE WITH EACH BAY WIDTH OF 4.5 M.



International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 08 | Aug 2020 www.irjet.net p-ISSN: 2395-0072



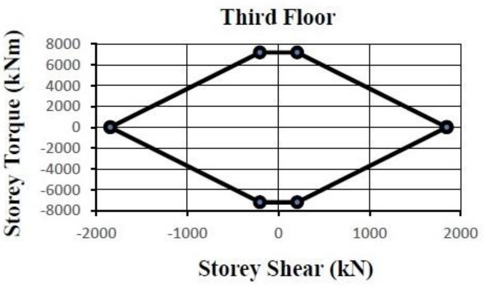


Fig -3.21: PLAN OF EACH FLOOR OF VERTICALLY ASYMMETRICAL RCC STRUCTURE WITH EACH BAY WIDTH OF 4.5 M.

From BST surface of vertical asymmetrical RCC structure,

i. The BST surface is symmetrical for all floors

ii. BST surface does not distinguish two floors, it only gives ultimate base shear and torque combination for floor under consideration.

iii. Thus, BST surface is not able to interpret whether RCC structure is vertically asymmetrical or not.

3.3.4 SUMMERY

Table 3.1 Comparison of Base Shear from BST surface, Response Spectra analysis and Seismic coefficient method for all RCC structures

Asymmetric Building No.	Percentage asymmetry (Uniaxial/ Biaxial)	Column dimensions (m)	Base Shear capacity using BST (V) (kN)	Base Shear using Response Spectra (V_B) (kN)	Base Shear using Seismic coefficient method ($\overline{V_B}$) (kN)	$\frac{V}{V_B}$	$\frac{\overline{V_B}}{V_B}$	$\frac{V}{\overline{V_B}}$
1	Symmetric	All columns of 0.6×0.6	7387.20	1654.40	1933.00	4.47	1.168	3.82
2	6.22	30 of 0.6×0.6, 6 of 0.7×0.7	7831.80	1661.40	1948.86	4.72	1.173	4.01
3	8.85	24 of 0.6×0.6, 12 of 0.7×0.7	8276.40	1670.10	1964.65	4.96	1.176	4.21
4	13.24	30 of 0.6×0.6, 6 of 0.8×0.8	8344.80	1667.43	1967.10	5.00	1.179	4.24
5	16.75	24 of 0.6×0.6, 12 of 0.8×0.8	9302.40	1685.00	2001.10	5.52	1.187	4.65
6	20.16	30 of 0.6×0.6, 6 of 0.9×0.9	8926.20	1672.70	1987.87	5.34	1.189	4.50
7	23.02	24 of 0.6×0.6, 12 of 0.9×0.9	10465.20	1700.32	2031.48	6.15	1.194	5.15
8	4.70, 4.70	25 of 0.6×0.6, 11 of 0.7×0.7	8202.30	1668.50	1962.04	4.92	1.175	4.18
9	5.14, 5.14	16 of 0.6×0.6, 20 of 0.7×0.7	8869.20	1682.00	1985.72	5.27	1.180	4.47
10	9, 9	25 of 0.6×0.6, 11 of 0.8×0.8	9142.80	1684.00	1995.46	5.43	1.185	4.58
11	8.74,8.74	16 of 0.6×0.6, 20 of 0.8×0.8	10579.20	1713.00	2046.46	6.18	1.195	5.17
12	12.60, 12.60	25 of 0.6×0.6, 11of 0.9×0.9	10208.70	1700.00	2023.13	6.00	1.190	5.05
13	11.10, 11.10	16 of 0.6×0.6, 20 of 0.9×0.9	12517.20	1742.00	2115.32	7.20	1.214	5.92
14	4.70, 4.70	25 of 0.6×0.6, 11 of 0.7×0.7	8202.30	1668.50	1962.01	4.92	1.175	4.18
15	5.14, 5.14	16 of 0.6×0.6, 20 of 0.7×0.7	8869.20	1682.00	1985.72	5.28	1.180	4.47
16	9, 9	25 of 0.6×0.6, 11 of 0.8×0.8	9142.80	1684.00	1995.45	5.43	1.185	4.58
17	8.74,8.74	16 of 0.6×0.6, 20 of 0.8×0.8	10579.20	1711.35	2046.47	6.18	1.195	5.17
18	12.60, 12.60	25 of 0.6×0.6, 11of 0.9×0.9	10208.70	1700.00	2023.13	6.00	1.190	5.05
19	11.10, 11.10	16 of 0.6×0.6, 20 of 0.9×0.9	12517.20	1742.00	2115.32	7.20	1.214	5.92

Table 3.1 compares the base shear from BST surface, Response Spectra analysis and Seismic coefficient method for all nineteen RCC structures. BST surface gives ultimate combination of Base Shear and Torque, thus base shear from BST surface analysis are five to seven times more than those from linear dynamic Response Spectra analysis and base shear from BST surface analysis are 3.5 to 6 times more than those from seismic coefficient method. Hence RCC structure is in purely elastic state. The RCC structures have more conservative column sizes to counteract adverse effects of torsion due to asymmetry. This is the reason for having higher capacity of RCC structure with respect to base shear and torque combination. The base shear from seismic coefficient method is more by 15 % to 22 % than that of Response spectrum analysis. From base shear values of nineteen RCC structures, it is observed that, as the asymmetry in RCC structure increases, base shear increases.

Table 3.2 Comparison of Torque from BST surface, Response Spectra analysis and Seismic coefficient method for all RCC structures

No.	% asymmetry	V	T	V_B	$\hat{T}$	$\overline{V_B}$	$\bar{\bar{T}}$	$\frac{T}{\hat{T}}$	$\frac{\bar{\bar{T}}}{\hat{T}}$	$\frac{T}{\bar{\bar{T}}}$
1	Symmetric	7387.20	49864	1654.40	42000	1933.00	40000	1.19	0.95	1.25
2	6.22	7831.80	54866	1661.40	52250	1948.86	49000	1.05	0.94	1.12
3	8.85	8276.40	57867	1670.10	56000	1964.65	54000	1.04	0.97	1.08
4	13.24	8344.80	60636	1667.43	60636	1967.10	58000	1.00	0.96	1.05
5	16.75	9302.40	67100	1685.00	67100	2001.10	60750	1.00	0.91	1.10
6	20.16	8926.20	67178	1672.70	67178	1987.87	67178	1.00	1.00	1.00
7	23.02	10465.20	77566	1700.32	77566	2031.48	77566	1.00	1.00	1.00
8	4.70, 4.70	8202.30	57032	1668.50	55000	1962.04	50000	1.04	0.91	1.14
9	5.14, 5.14	8869.20	61201	1682.00	57500	1985.72	55000	1.07	0.96	1.12
10	9, 9	9142.80	65305	1684.00	65305	1995.46	62000	1.00	0.95	1.05
11	8.74,8.74	10579.20	74283	1713.00	72050	2046.46	70000	1.04	0.97	1.07
12	12.60, 12.60	10208.70	74680	1700.00	74680	2023.13	74680	1.00	1.00	1.00
13	11.10, 11.10	12517.20	89108	1742.00	89108	2115.32	85200	1.00	0.96	1.05
14	4.70, 4.70	8202.30	57032	1668.50	55000	1962.01	50000	1.04	0.91	1.14
15	5.14, 5.14	8869.20	61201	1682.00	57500	1985.72	55000	1.07	0.96	1.12
16	9, 9	9142.80	65305	1684.00	65305	1995.45	62000	1.00	0.95	1.05
17	8.74,8.74	10579.20	74283	1711.35	72050	2046.47	70000	1.04	0.97	1.07
18	12.60, 12.60	10208.70	74680	1700.00	74680	2023.13	74680	1.00	1.00	1.00
19	11.10, 11.10	12517.20	89108	1742.00	89108	2115.32	85200	1.00	0.96	1.05

Table 3.2 compares Torque from BST surface, Response Spectra analysis and Seismic coefficient method for all RCC RCC structures. Each column of table presents specific parameter which is given below:

i. No. is Asymmetric RCC structure no.

ii. % asymmetry is Percentage asymmetry (Uniaxial/Biaxial)

iii. V is Base Shear capacity using BST surface (V) (kN)

iv. T is Torque capacity using BST surface (T) (kNm)

v. VB is base Shear using Response Spectrum analysis (VB)

(kN)

vi. $\hat{T}$ is torque capacity using BST for Base Shear value from Response Spectrum analysis ($\hat{T}$) (kNm)

vii. $V\bar{\bar{B}}$ is base shear using seismic coefficient method ($V\bar{\bar{B}}$) (kN)

viii. $\bar{T}$ is torque capacity using BST for base shear value from seismic coefficient method ($\bar{T}$) (kNm)

ix. $T\ \hat{T}$ is ratio of torque capacity using BST surface to torque capacity using BST for Base Shear value from Response Spectrum analysis.

x. $\bar{T}\hat{T}$ is ratio of torque capacity using BST for base shear value from seismic coefficient method to torque capacity using BST for Base Shear value from Response Spectrum analysis.

xi. $T\bar{T}$ is ratio of torque capacity using BST surface to torque capacity using BST for base shear value from seismic coefficient method.

Findings

1. $T\ \hat{T} > 1$ and $T\bar{T} > 1$ indicates that torque capacity given by BST surface represents true value of torque (capacity of RCC structure)

2. $\bar{T}\hat{T} \approx 1$ represents that torque capacity given by response spectrum analysis and seismic coefficient method is same. Thus without going for dynamic analysis using response spectrum analysis, value of torque can be obtained by seismic coefficient method.

4. STATIC PUSHOVER ANALYSIS

4.1 INTRODUCTION

In this chapter 1 symmetrical G+3 floor RCC structure in plan and 6 uniaxial asymmetrical G+3 floor RCC structures in plan of RCC material have been analysed using Static Pushover Analysis.

The assumptions made for static pushover analysis are

i) Soil structure interaction is not considered.

ii) Stiffness of masonry wall is not considered. BST surface fails to explain serviceability criteria – displacement of RCC structure, pushover analysis gives displacement of RCC structure hence pushover analysis is carried out.

4.2 PROBLEM DEFINITION FOR RCC STRUCTURE

4.2.1 PLAN SYMMETRICAL RCC STRUCTURE

The symmetric G+3 floor RCC structure is analysed by Static Pushover analysis and Performance point is plotted. The RCC structure has plan dimensions of 22.5 m × 22.5 m and bay width of 4.5 m as shown in Figure 3.6. The RCC structure has been designed as per IS 456 (2000).The column sizes are 600 mm × 600 mm and beam sizes are 600 mm × 230 mm.

4.2.2 PLAN ASYMMETRICAL RCC STRUCTURE

6 asymmetric G+3 floor RCC RCC structures are analysed by Static Pushover analysis and Performance point is plotted. The RCC structure has plan dimensions of 22.5 m × 22.5 m and bay width of 4.5 m. The asymmetry is introduced by changing the shear strength of columns by gradually increasing the sizes of some columns from 600 mm × 600 mm to 900 mm × 900 mm. The configuration of asymmetric RCC structures are shown in Figure 4.1 & Figure 4.2, these RCC structures with column sizes of 600 mm × 600 mm (not selected columns) and 700 mm × 700 mm (selected columns). In the same way, column dimensions are configured for columns of dimensions 800 mm × 800 mm and 900 mm × 900 mm.

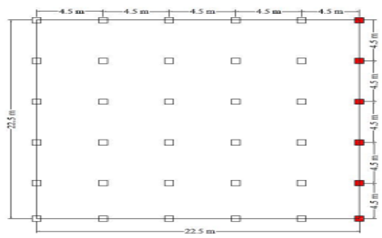


Fig -4.1: ASYMMETRICAL RCC STRUCTURE NO.1 WITH 6.22% STRENGTH ASYMMETRY IN PLAN

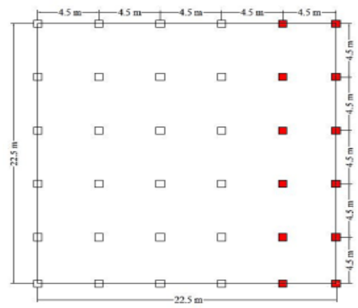


Fig -4.2: ASYMMETRICAL RCC STRUCTURE NO.1 WITH 8.85% STRENGTH ASYMMETRY IN PLAN

In Similar way, asymmetrical RCC structures 3 to 6 have been configured. Table 4.1 gives RCC structure Column dimensions and percentage asymmetry

Table 4.1 RCC Asymmetric RCC structures with Percentage asymmetry and column dimensions

Asymmetrical RCC structure No.	Percentage Asymmetry	Column Dimensions (m)
1	6.22 %	30 of 0.6 × 0.6, 6 of 0.7 × 0.7
2	8.85 %	24 of 0.6 × 0.6, 12 of 0.7 × 0.7
3	13.23 %	30 of 0.6 × 0.6, 6 of 0.8 × 0.8
4	16.75 %	24 of 0.6 × 0.6, 12 of 0.8 × 0.8
5	20.18 %	30 of 0.6 × 0.6, 6 of 0.9 × 0.9
6	23.01 %	24 of 0.6 × 0.6, 12 of 0.9 × 0.9

4.2.3 RESULT OF STATIC PUSHOVER ANALYSIS FOR RCC STRUCTURE

From static Pushover Analysis on 13 (12 asymmetrical in plan and 1 symmetrical in plan) G+3 floor RCC structures, Performance point has been plotted and asymmetrical RCC structures with symmetric RCC structure are compared. Table 4.2 shows Performance points of RCC structure considered.

Table 4.2 Performance points of Considered RCC structures.

RCC structure No.	RCC structure asymmetry	Performance point	
		Base Shear (kN)	Displacement (m)
1	Symmetrical	22419.36	0.074
2	6.22 %	23176.54	0.056
3	8.85 %	23597.07	0.054
4	13.23 %	23546.97	0.051
5	16.75 %	24810.02	0.048
6	20.18 %	24844.20	0.044
7	23.01 %	25739.34	0.041

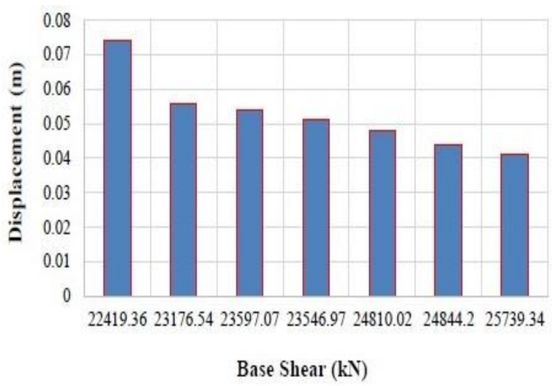


Fig -4.3: PERFORMANCE POINTS

For same RCC structure, as Asymmetry increases Base Shear increases and Roof displacement decreases.

Due to Asymmetry Ductile nature of RCC structure is lost and tendency of RCC structure to brittle failure increases.

5. CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSIONS

In the present study, BST Surface analysis, Response Spectra analysis and Static Pushover Analysis are carried out on G+3 floor RCC structures. Symmetrical as well as asymmetrical RCC structures are considered.

Based on the analysis results for all cases considered, following conclusions are drawn

5. 1.1 FROM BST SURFACE ANALYSIS

1. BST surface gives ultimate values of Base shear and Torque which gives an approximate perception to the designer about strength of RCC structure with respect to base shear and torque.

2. As the asymmetry in RCC structure increases, the orientation of BST surface changed making it skewed, compared to BST surface of symmetrical RCC structure.

3. The orientation of BST surface for asymmetrical RCC structures explains that RCC structure rotates about those columns, which have higher strength than other columns.

4. Shape of BST surface shows whether RCC structure is symmetrical or not.

5. Base shear values from linear static or dynamic analysis can be used to find ultimate value of torque by plotting that base shear value on BST surface.

6. By simply calculating the shear strength of RCC structure columns, behaviour of any RCC structure can be understood by drawing the BST surface.

7. Even without static or dynamic nonlinear analysis it is possible to compare the expected seismic performance of different structural configuration based on BST surface.

8. BST surface provides sufficiently general framework to explain the inelastic torsional behavior of RCC structure.

Thus, plotting BST surface proves to be a simple tool, to get reasonably accurate estimation of base shear and torque capacity of plan symmetric and plan asymmetric RCC structures.

5. 1.2 LIMITATIONS OF BST SURFACE

1. BST surface is not able to interpret whether RCC structure is vertically asymmetrical or not.

2. Displacement of the RCC structure at different floors cannot be calculated using BST surface.

5. 1.3 FROM STATIC PUSH OVER ANALYSIS

On RCC structures

For same RCC structure, as asymmetry increases base shear increases and displacement decreases.

Due to asymmetry ductile nature of RCC structure is lost and tendency of RCC structure to brittle failure increases

Thus, Static Pushover Analysis compares the behaviour of asymmetrical RCC structure with symmetrical RCC structure.

5. 1.4 SCOPE OF FUTURE WORK

1. Study of Inelastic region of BST surface.

2. Comparison of seismic behaviour of masonry asymmetrical RCC structure with masonry symmetrical RCC structure by using strut as masonry element in SAP2000.

3. Comparison of seismic behaviour of open ground floor masonry asymmetrical RCC structure with open ground floor masonry symmetrical RCC structure by using strut as masonry element in SAP2000.

4. Comparison of seismic behaviour of masonry asymmetrical RCC structure with open ground floor masonry asymmetrical RCC structure by using strut as masonry element in SAP2000.

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