Effects of Coupling between Lateral and Torsional Motions in Seismic Response of Buildings

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***Abstract*- The goal of the present paper is to study the adequacy of torsional provisions in the international buildings code (IBC) for irregular building taken into account effect of the angles of seismic attacks. The responses of the frame-shear-wall twelve-story asymmetric building under earthquake loading by using equivalent lateral force procedure and dynamic response spectrum analysis have been studied intensively in this present research paper. This study performs static and dynamic response analyses of building models under earthquake ground motions compatible with the design response spectrum defined in the international buildings code. The dynamic response spectrum was scaled according to the code static base shear. The static and dynamic base shear with different angles of seismic attacks has been calculated. The scaling factors, angles of seismic attacks, accidental storey torsions, storey shear, dynamic and static base shear have been evaluated here. The torsional moment at different storey levels for dynamic analysis has been estimated and compared with the static values.**

***Index Terms*— asymmetric building, torsional response, eccentricity, response spectrum analysis, angles of seismic attacks, seismic codes.**

I. INTRODUCTION

The torsional response was the main reasons for the damage and collapse of irregular buildings under major earthquake. Structural irregularities are considered as one of the main reasons for the poor seismic performance of buildings. Most codes require special treatment of structure with significant irregularities. There are two types of the main irregulars in the buildings: plan irregularities (in the horizontal plane) and vertical irregularities (in the vertical plane). The crucial effect in the seismic response of building with plan irregularity was torsional effects, (Fajfar et al., Herrera et al.). The torsional response of asymmetric ductile buildings with the effect of the angle of seismic attack was studied by Crisaful et al. It was analysed the building using static and dynamic analysis under the different angle of seismic attack ranged between 0º to 180º. The floors rotation and element ductility results were discussed. The seismic codes along the world such as IBC-2006, UBC-97 and IS: 1893 and others considered the torsional effect in the seismic design of buildings with plan irregularity in order to avoid unpredicted failures brought by torsion that's it is may affect the outer frame's columns, but it was not discussed the building response with different angle of seismic attacks. The goal of this research paper is to study the adequacy of torsional provisions in the IBC-2006 seismic codes for irregular building with angles of seismic attacks. The seismic response was studied for frame-shear-wall building asymmetric plan systems with different eccentricities in both horizontal directions. The requirements of orthogonal effects for earthquake loadings were considered in the design of the above building. This building had irregular geometric and mass properties within the plan and along the height. This building was assumed to be located in Abu-Dhabi in United Arab Emirates (UAE). The base shears were computed using IBC-2006.

II. SYSTEM AND GROUND MOTIONS

A. General Description of the Building

The building is a hospital having 12 storeys. In general, Universal Column (UC356) steel columns were used to support the floor framing (Table (1)). Some location supporting heavy loads have built-up columns consisting of plated UC sections or box sections. The typical elevated floor slabs consist of 110 mm normal-weight concrete topping cast on 80 mm, thick metal deck for a total slab thickness of 190 mm (Fig. (1)). A combination of reinforced concrete shear walls, structural steel braced frames and structural steel moment frames were used for the primary lateral resistance. The building has two rectangular concrete cores at the main elevators. The typical planes and elevation of the selected building are given in Fig. (2). The building has a line of steel braced frames along the grid C (Fig. (2)).

B. Mathematical Modelling of the building

The building is idealized in ETABS software as three dimensional linear model by using finite element method (Fig. (3)). Bare frames analysis is pursued which neglect the effect of the stiffness of infill walls on the structural response. Masses are lumped at each floor level and bases of the frames are assumed to be a hinge with respect to the translational movement for modeling. The line two nodes frame element with six degrees of freedom per nodes are used in the models of columns and beams. Shear walls are modeled with four nodes shell elements. Slabs are modeled as a deck by using shell element considered membrane action only in order to ensure no contribution of the flexural stiffness of the lateral systems and ensure one-way loading distribution.

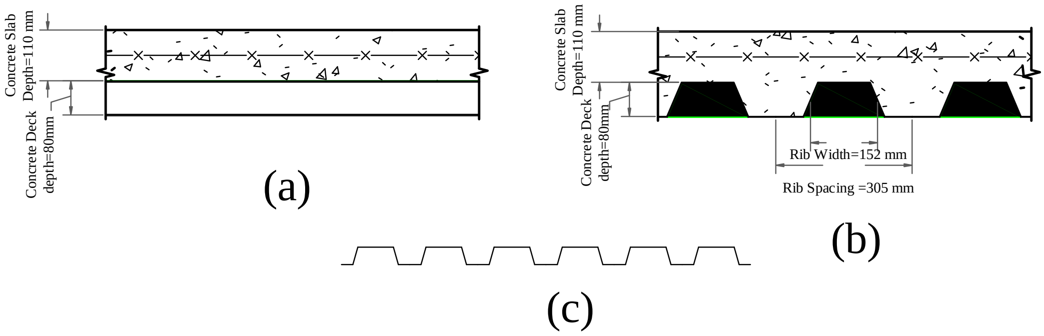


Fig. 1 Floor deck detail (a) longitudinal (b) transverse (c) steel roof deck.

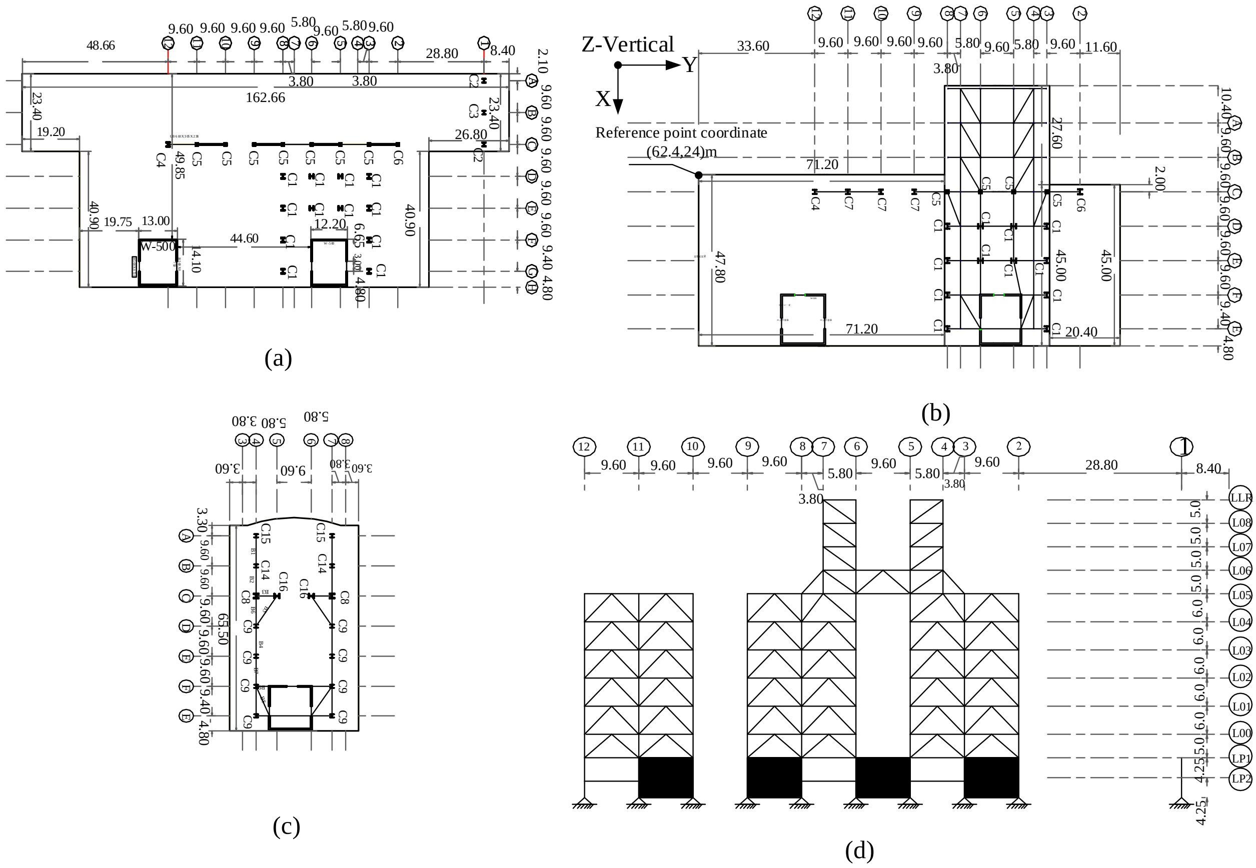


Fig. 2 Typical planes and elevation of the selected building (a) ground floor (b) 5th floor (c) roof (d) steel braced frames along the grid C.

TABLE 1
COLUMNS SECTIONS

Colum ID	Section
C1	UC 356X406X818
C2	UC 356X406X393
C3	UC 356X368X202
C4	UC 356X406X744
C5	1000mmX1000mm at level Podium1 and Podium2 UC 356X406X467 at others
C6	1000mmX1000mm at level Podium1 and Podium2 UC356X406X634 at others
C7	UC 356X406X677
C8	UC 356X400X900
C9	UC 356X368X129
C14	UC 356X368X129
C15	UC 356X368X202
C16	UC 356X406X467

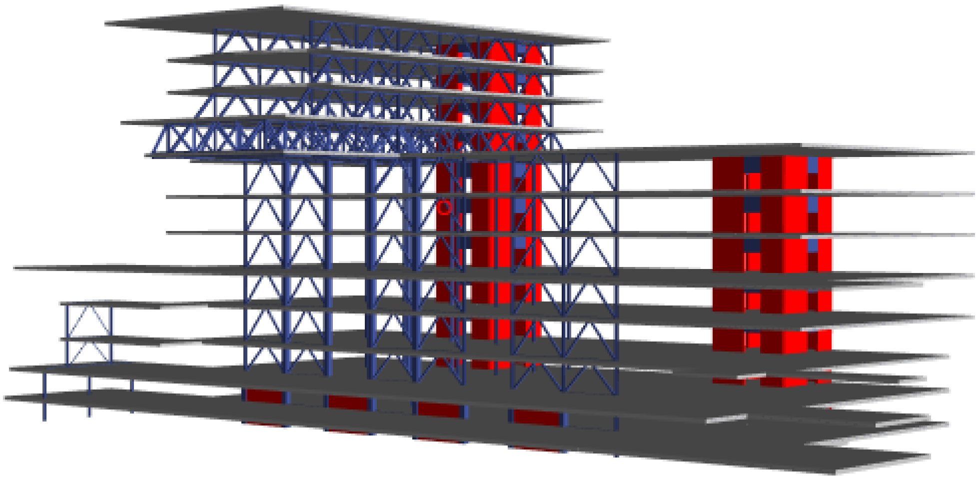


Fig. 3 Three dimensions view of the selected building.

C. Static and Dynamic Analysis

The elastic linear stiffness analysis is used in the code for analysis of building under lateral force due to earthquake loading. The results of this analysis will be displacement, internal forces, moment and shear whose values are approximately those of the design earthquake. The use of static analysis in seismic response of buildings with the plane and vertical irregularity gives inappropriate results in most cases. Therefore, the use of linear response spectrum analysis gives the better distribution of lateral forces within the floors takes into account system irregularities and mass distribution in buildings with the plane and vertical irregularity.

D. Seismic Loading Parameter

Seismic loads are in accordance with the IBC-2006 and ASCE 7-05 requirements and the parameters are given in Table (2).

E. Site Ground Motions

Based on the site-specific spectra results, the following are the calculated IBC-2006 parameters: SDS = 0.303, SD1 = 0.101, To = 0.07s, Ts =0.3s, and TL =7.0s. The spectral accelerations per IBC general spectrum for periods greater than TL are based on constant spectral displacement, and therefore reduce at an increased rate with the increase in the period, as shown in Fig. (4). The spectral ordinates of the horizontal design response spectrum as per IBC-2006.

TABLE 2
SEISMIC LOADING FACTORS

Parameter	Value
Building Latitude	24°29’40”N
Building Longitude	54°23’18”E
Occupancy Classification	IV
Importance Factor (Ie)	1.5
Site Class	C
Spectral Response Coefficients	SD_S = 0.303; SD_1 = 0.101
Seismic Design Category	C
Lateral Systems	Ordinary concrete shear walls and steel braced
Frames	not detailed for seismic resistance
Response Modification Coefficients	Concrete shear walls, R=4
	Steel braced frames, R=3
Analysis Procedure Used	Modal Analysis Procedure

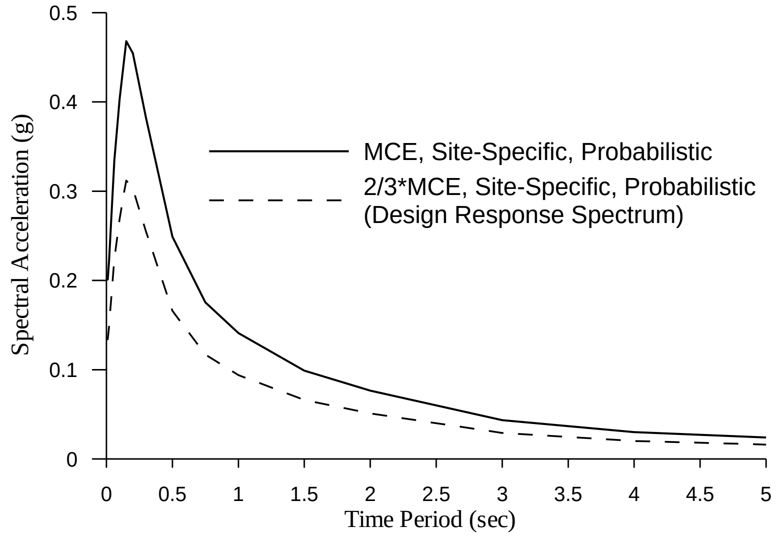


Fig. 4 Horizontal design response spectra.

III. CODE STATIC BASE SHEAR

Base shear calculated from the dynamic analysis carried out using ETABS software of the building, but the minimum base shear for which it needs to find out the demand as per IBC-2006 code and ASCE-7-05 as shown in Table (3). Base shear calculated using IBC-2006 is greater than it obtained from the dynamic analysis carried out using ETABS software. The variations of the static base shear coefficient (Cs) with the time period were shown in Fig. (5) in X and Y directions respectively.

IV. VERTICAL DISTRIBUTION OF LATERAL LOADS

The earthquake base shear present in Table (3) was used in the calculation of the vertical distribution of seismic force per each floor of the selected building. The seismic lateral force is given in Table (4). The response of the building was carried on under the lateral seismic forces (static) and under gravity loads. Accordingly, the static storey shear was calculated and shown in Fig. (6).

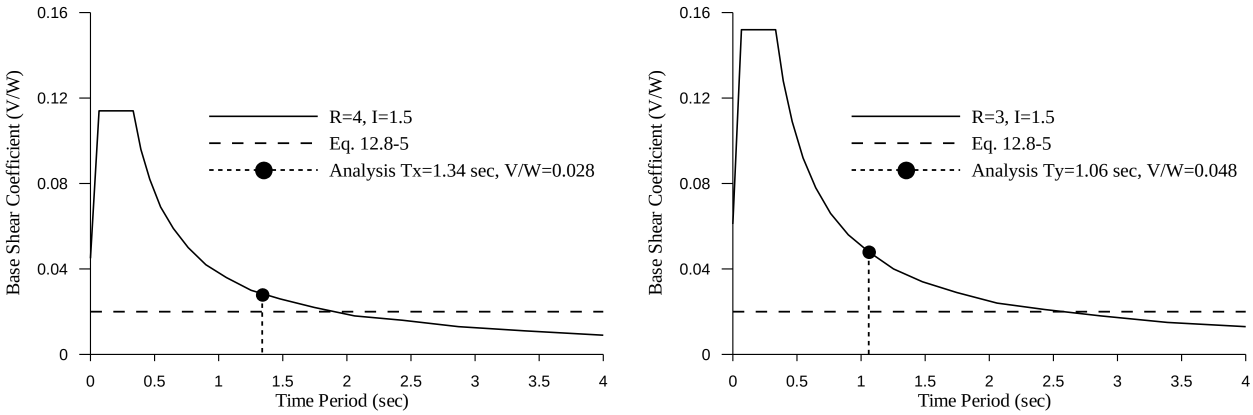
V. FLOOR AND STOREY ECCENTRICITIES

The center of mass (CM) and center of rigidity (CR) coordinate in X and Y direction were shown in Fig. (7) where the reference coordinate points are shown in Fig. (2-b). Accordingly, the floor eccentrics was obtained and shown in Fig. (8).

TABLE 3

STATIC BASE SHEAR CALCULATION AND DYNAMIC BASE SHEAR SCALING

Remarks		X-direction		Y-direction	
Time period calculation (Approximate period, Ta, Upper limit period, C_uTa, where $T_a = C_t * h_n^x$ (Eq.12.8.7)---ASCE-7-05,hn=63.50m=208.33ft)		Ct =	0.02	Ct =	0.02
		x =	0.75	x =	0.75
		Ta =	1.10	Ta =	1.10
		CuTa =	1.86	CuTa =	1.86
		Rx-dir:	4	Ry-dir:	3
		Tanalysis,x:	1.34	Tanalysis,y:	1.06
		Tdesign,x =	1.34	Tdesign,y =	1.06
		kx =	1.42	ky =	1.28
Calculation of Seismic Response Coefficient (Cs)	(Eq. 12.8-2) --- ASCE-7-05	0.1137		0.1516	
	(Eq. 12.8-3) --- ASCE-7-05	0.028228		0.047579	
	(Eq. 12.8-4) --- ASCE-7-05	n/a		n/a	
	(Eq. 12.8-5) --- ASCE-7-05	0.020011		0.020011	
	(Eq. 12.8-6) --- ASCE-7-05	n/a		n/a	
Design Seismic Response Coefficient		0.028228		0.047579	
Base Shear using the Equivalent Lateral Force (VELF): unit(kN)		17292		29146	
Base Shear From The Required Modal Combination (Vt computed with R = 1 and I = 1)		31796		33878	
Scale to: Combined Response For The Modal Base Shear (VDYN)		14698		24774	
Controlled values		0.85VELF		0.85VELF	



(a) (b)

Fig. 5 Seismic response coefficient (a) X-direction (b) Y-direction.

TABLE 4
VERTICAL DISTRIBUTION OF LATERAL LOADS

Storey					X-direction		Y-direction	
Floor	Label	weight, wi (kN)	height (m)	elevation, hi (m)	Floor Seismic Force, Fi (kN)	Storey Shear, Vi (kN)	Floor Seismic Force, Fi (kN)	Storey Shear, Vi (kN)
Roof	LLR	21050	5.0	63.5	1681	1681	2637	2637
8th Floor	L08	19836	5.0	58.5	1409	3090	2237	4874
7th Floor	L07	19856	5.0	53.5	1243	4333	1998	6872
6th Floor	L06	26835	5.0	48.5	1461	5794	2381	9253
5th Floor	L05	108355	6.0	43.5	5055	10849	8364	17617
4th Floor	L04	50479	6.0	37.5	1908	12757	3222	20840
3rd Floor	L03	45929	6.0	31.5	1355	14112	2346	23185
2nd Floor	L02	67446	6.0	25.5	1474	15586	2628	25813
1st Floor	L01	50479	6.0	19.5	754	16340	1395	27209
Ground	L00	57890	5.0	13.5	513	16853	999	28208
Podium 1	LP1	76367	5.0	8.5	351	17203	729	28937
Podium 2	LP2	68066	3.5	3.5	89	17292	209	29146

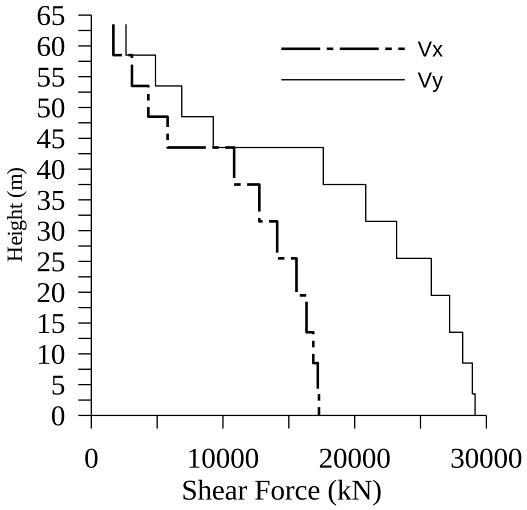


Fig. 6 Static storey shear due to static base shear in X and Y direction (Vx, Vy) for the building.

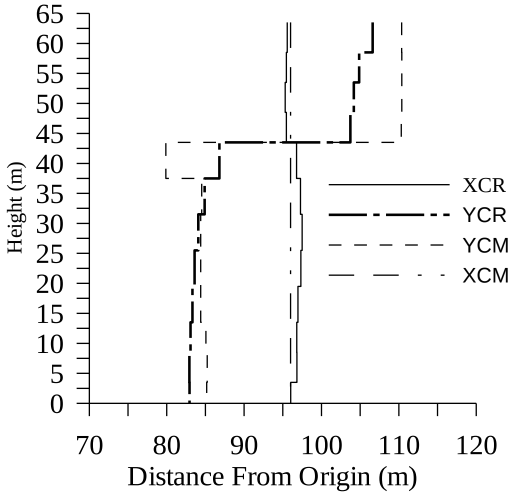


Fig. 7 Location center of mass (CM) and center of rigidity (CR) for each floor.

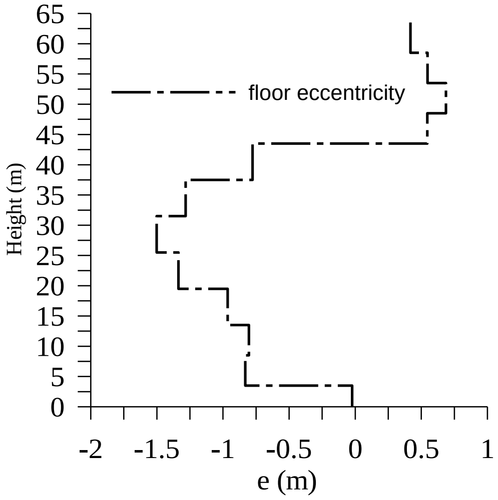


Fig. 8 Floor eccentricities of the building.

VI. DESIGN ECCENTRICITY

In most seismic codes, the torsional effects are taken into account in the design of buildings under earthquake loading through the design eccentricity. Therefore, the design eccentricity needs to be defined in two orthogonal directions by using the following equation (Goel and Chopra 1990);

$$e_d = \alpha\, e \pm \beta\, b \quad (1)$$

where; e= calculated eccentricity between the locations of the center of mass and the center of rigidity, b= maximum dimension of the floor at the right angles to the direction of the lateral force under consideration. The coefficient α is to take into account the dynamic amplification of structural (static) eccentricity, and the factor β accounts for accidental effect. Different codes give different α, and β values. The Eurocode 8, IBC-2006 and the Turkish Earthquake Design Code is considering the values of α = 1.0 and β =0.05, while the National Building Code of Canada and the Mexico City Building Code are considering the values α = 1.5 and β= 0.05. Australian and New Zealand seismic codes specify the values of α = 1.0 and β =0.1. Further, if torsional irregularity exists, as defined in IBC-2006, the effects shall be accounted for by increasing the accidental torsion at each level by an amplification factor, A_x, determined from the following formula;

$$A_x = \left[\frac{\delta_{max}}{1.2 * \delta_{av}}\right]^2 \quad (2)$$

where; δ_{max} = the maximum horizontal displacement at level i computed assuming (A_x = 1). δ_{av} = the average of the horizontal displacements at the extreme points of the building at each level computed assuming the amplification factor equal to one. The torsional amplification factor value is greater or equal to one and less than or equal to three. The more critical loading case for each building element shall be considered for design. In the present study, the value of A_x was calculated in the above equation.

VII. STATIC ACCIDENTAL STOREY TORSIONS

The torsional due to earthquake forces, random distribution of live load masses and properties variation of building properties are the main reasons to lead for building irregularity. Therefore, the accidental torsional loads need to consider in the building design. The static accidental storey torsion is given in Table (5). Tx and Ty are storey torque due to static base shear in X and Y direction respectively (Fig. (9)).

VIII.TIME PERIODS AND PARTICIPATION FACTORS

The time periods of vibration and mass participation factors obtained from the dynamic analysis for this building are given in Table (6). When response spectrum analysis is carried on, at least 90 percent of the participating mass is included in the solution of response for each principal direction (IBC-2006). For this building, twenty-six modes are required to satisfy the 90 percent specification in both the X and Y horizontal directions. The mass participation for the first mode is 11% and 18% in X and Y-directions respectively. The total mass participation for all the twenty-six modes considered is 97% and 94% in X and Y-directions respectively.

IX. ANGLE OF SEISMIC ATTACK

The present IBC code does not specify the method can be used to define principal directions for three dimension irregular building. The design base shear for irregular building can be different in each direction, therefore, the scale horizontal design response spectrum can be produced with a different ground motion for each direction. Further, the dynamic analysis approach used in current IBC code in one direction can give underestimate design force, for above reasons, the angles of seismic attack are estimated in the current research paper in order to evaluate different scale factor. The principal direction of the mode shape is calculated as shown in Fig. (10) and it is summarized in Table (7). Accordingly, the angles of seismic attack (ϴ1 and ϴ2) were obtained for each mode. ϴ1 and ϴ2 are the directions of mode shapes with respect to X and Y horizontals directions and it was represented the angle of seismic attack in two orthogonal directions 1 and 2.

TABLE 5
STATIC ACCIDENTAL STOREY TORSIONS

Floor	X-direction				Y-direction			
	Ly (m)	Ax	Ax*Mta,X (kN.m), (at level)	Tx,Cumulative, (kN.m)	Lx (m)	Ax	Ax*Mta,Y (kN.m) , (at level)	Ty,Cumulative, (kN.m)
LLR	176.8	1	14855	14855	201.2	1	26525	26525
L08	176.8	1	12459	27313	201.2	1	22504	49028
L07	176.8	1	10986	38299	201.2	1	20092	69121
L06	176.8	1	12916	51215	201.2	1	23949	93070
L05	176.8	1	44686	95900	201.2	1	84132	177202
L04	176.8	1	16862	112762	201.2	1	32413	209614
L03	176.8	1	11977	124739	201.2	1	23592	233207
L02	176.8	1	13029	137768	201.2	1	26435	259641
L01	176.8	1	6662	144430	201.2	1	14034	273676
L00	176.8	1	4533	148963	201.2	1	10052	283728
LP1	176.8	1	3100	152063	201.2	1	7335	291063
LP2	176.8	1	784	152846	201.2	1	2100	293163

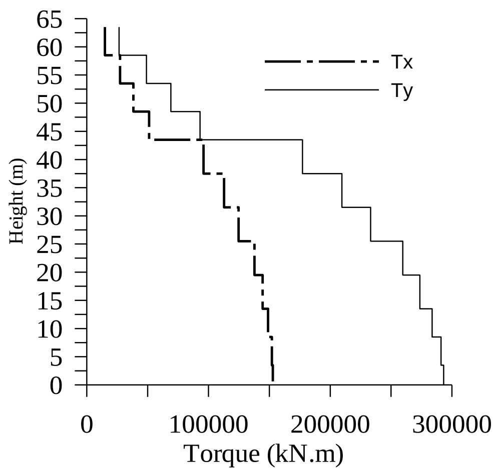


Fig. 9 Storey torque due to static base shear in X and Y directions.

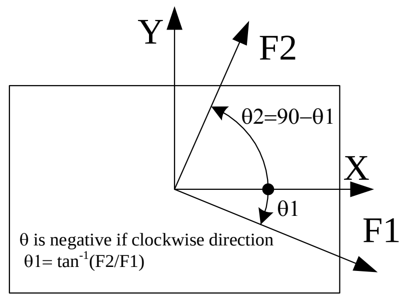


Fig. 10 Directions of mode shapes and angle of seismic attack.

TABLE 6
DYNAMIC CHARACTERISTICS OF THE BUILDING

Mode	Period (sec)	Cumulative Sum of Mass Participation Factors (Percentage)	
		X-Direction	Y-Direction
1	1.74	11	18
2	1.38	65	29
3	1.06	69	56
4	0.74	69	63
5	0.60	71	63
6	0.54	73	64
7	0.53	73	64
8	0.47	75	64
9	0.45	75	65
10	0.41	78	65
11	0.39	82	65
12	0.36	86	67
13	0.33	86	68
14	0.32	86	72
15	0.30	87	72
16	0.29	91	73
17	0.28	92	73
18	0.27	93	75
19	0.25	94	77
20	0.25	94	78
21	0.22	95	79
22	0.20	95	84
23	0.17	95	87
24	0.16	96	89
25	0.14	97	89
26	0.13	97	94

TABLE 7
THE ANGLE OF SEISMIC ATTACK

Mode	F1(kN)	F2(kN)	Θ1(degree)	Θ2(degree)
1	411	528	52	142
2	2508	-1108	-24	66
3	208	572	70	160
4	0	-5	-89	1
5	178	39	12	102
6	154	70	24	114
7	81	-13	-9	81
8	156	-35	-13	77
9	9	36	76	166
10	464	-127	-15	75
11	521	39	4	94
12	583	-334	-30	60
13	10	52	79	169
14	2	31	87	177
15	174	-110	-32	58
16	664	282	23	113
17	162	99	31	121
18	78	-153	-63	27
19	151	212	54	144
20	93	-152	-59	31
21	97	100	46	136
22	7	-85	-85	5
23	62	185	72	162
24	69	-158	-66	24
25	328	113	19	109
26	17	-120	-82	8

X. SCALING OF DYNAMIC BASE SHEAR

The important issue in the seismic analysis by using the response spectrum method is scaling of dynamic base shear. In this study, the square root of the sum of the squares (SRSS) method is used for calculating the combined response for model base shear from the response spectrum method. The model base shear is needed to scale equal to 0.85 VELF/Vt when Vt is less than 85 percent of the base shear obtained from equivalent lateral force producer (Table 3). Different scale factors were obtained for the different angle of a seismic attack as given in Table (8). The variation of dynamic base shear with the angle of seismic attack are shown in Fig. (11). It is observed the angles of attacks equal (27°) and (160°) gives the maximum and minimum base shear for this selected building. Still further all values of dynamic base shear greater than the static base shear.

XI. STOREY SHEAR AND BASE SHEAR

Usually, seismic design considers the earthquake forces subjected in two orthogonal principal directions of the building. However, torsion response may occur in the irregular building because of the skew attack of earthquake force and it may lead to simultaneous yielding in both directions. Therefore, it is necessary to examine the design base shear and storey shear results with the different angle of seismic attack. For this reason, the building represented in Fig. (2) was analysed using equivalent lateral force procedure and response spectrum method and considering the variable angle of seismic attack between 0° and 180°. The static and dynamic base shears in the building obtained after completing the IBC torsional analysis are shown in Fig. (11). The dynamic base shears were magnified by factors given in Table (8) for the angle of seismic attack. It can be seen that the static base shear is smaller than the dynamic base shear. Figures (12) through (34) shows the effects of angle of seismic attack on the Storey shear. It can be observed that the storey shear of the static base shear is in lower value with that the storey shear of the dynamic base shear applied with the effect the angle of seismic attack. The effects are significant at the roof. The dynamic storey shear for the roof is significantly higher than that static storey shear (144%, 55%) for static base shear in X and Y direction respectively when the angle of seismic attack approaches to 54°.

XII. CONCLUSIONS

The seismic analysis of selected building with the different angle of seismic attack suggested the following conclusions:

1) The base shear was maximum when the angle of seismic attack approaches to 27° because of the lateral strength of the building is minimum in this direction.
2) The base shear was minimum when the angle of seismic attack approaches to 160° because of the lateral strength of the building is maximum in this direction.
3) The angle of seismic attack needs to be considered in the base shear calculation.
4) The main principal directions need to be located by the exam different angles of seismic attack for irregular buildings.
5) Mode shapes effects significantly affect the angles of seismic attack, especially for irregular buildings.
6) The effects angle of seismic attack at storey shear is significant at the roof due to higher torsional effect at the roof

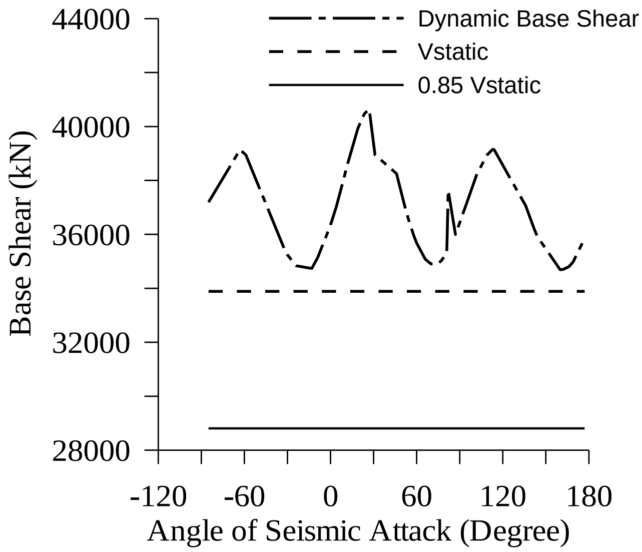


Fig. 11 Dynamic base shear with variables angle of seismic attack.

TABLE 8
SCALING FACTORS WITH DIFFERENT ANGLE OF SEISMIC ATTACK

Angle(degree)	F1(kN)	F2(kN)	Scale Factor
0	3369.79	1298.99	10.06
90	3297.57	1298.99	10.28
52	3046.41	1336.12	11.12
142	3571.16	1336.12	9.49
-24	3673.56	867.95	9.23
66	3256.14	867.95	10.41
70	3293.84	810.34	10.29
160	3666.27	810.34	9.24
12	3078.28	1686.08	11.01
102	3231.52	1686.08	10.49
24	2860.5	1869.64	11.85
114	3229.65	1869.64	10.49
-9	3551.46	976.01	9.54
81	3329.58	976.01	10.18
-13	3608.82	867.79	9.39
77	3327.84	867.79	10.18
76	3325.47	847.85	10.19
166	3620.46	847.85	9.36
-15	3630.98	831.43	9.33
75	3322.29	831.43	10.20
4	3273.7	1443.16	10.35
94	3274.39	1443.16	10.35
-30	3651.47	1042.58	9.28
60	3177.58	1042.58	10.67
79	3330.21	916.92	10.18
169	3582.24	916.92	9.46
87	3312.47	1187.18	10.23
177	3436.99	1187.18	9.86
-32	3636.17	1113.68	9.32
58	3146.72	1113.68	10.77
23	2872.39	1864.06	11.80
113	3225.55	1864.06	10.51
31	3281.57	1856.69	10.33
121	3281.57	1856.69	10.33
-63	3247.02	1875.24	10.44
27	2833.37	1875.24	11.96
54	3080.6	1262.08	11.00
144	3595.61	1262.08	9.43
-59	3281.57	1856.69	10.33
46	2946.81	1543.26	11.50
136	3486.72	1543.26	9.72
-85	3268.41	1477.42	10.37
5	3249.02	1477.42	10.43
72	3307.74	805.99	10.25
162	3655.65	805.99	9.27
-66	3229.65	1869.64	10.49
19	2932.92	1823.48	11.56
109	3217.46	1823.48	10.53
-82	3251.04	1574.2	10.42
8	3174.71	1574.2	10.67

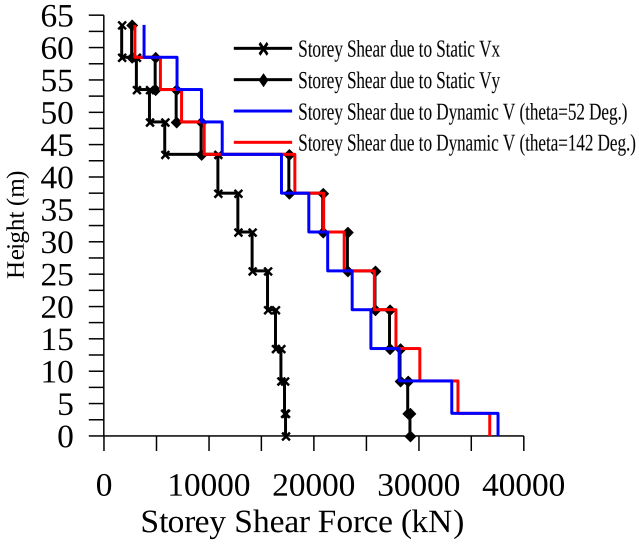


Fig. 12 Storey shear comparison with angle of attack (θ1=90°,θ2=142°).

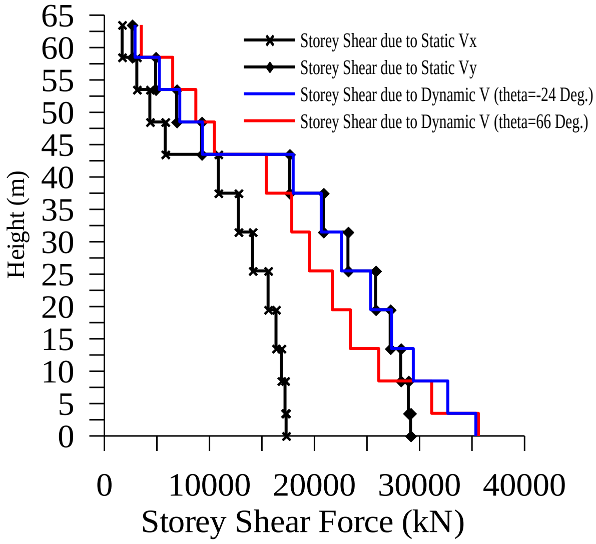


Fig. 13 Storey shear comparison with angle of attack (θ1=–24°,θ2=66°).

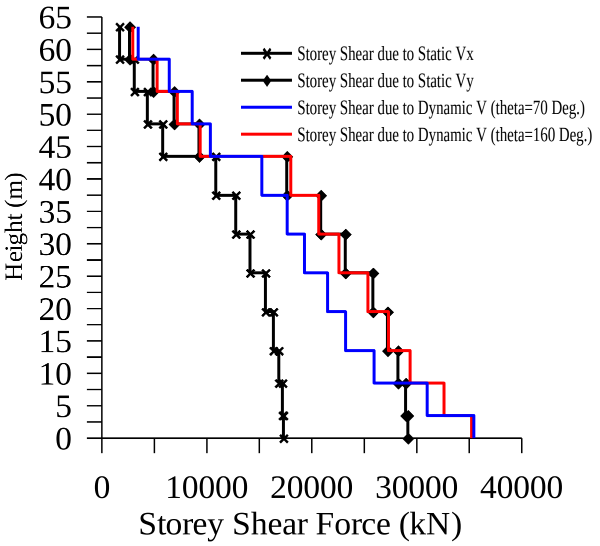


Fig. 14 Storey shear comparison with angle of attack (θ1=70°,θ2=160°).

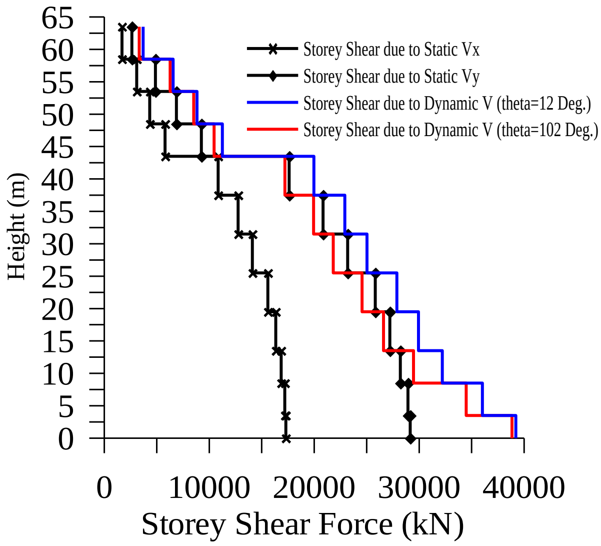


Fig. 15 Storey shear comparison with angle of attack (θ1=12°,θ2=102°).

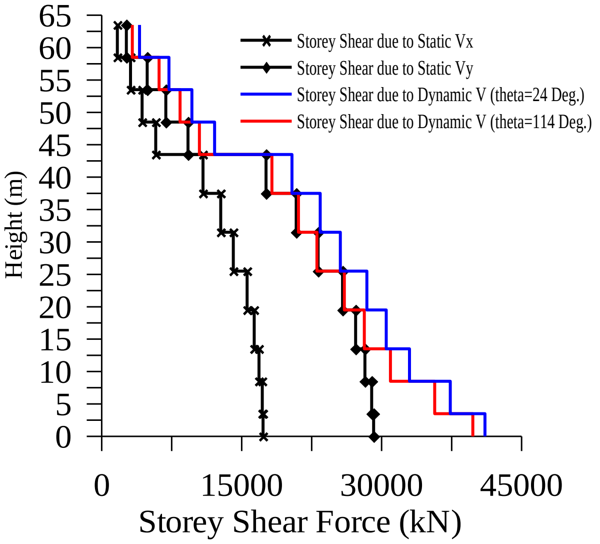


Fig. 16 Storey shear comparison with angle of attack (θ1=24°,θ2=114°).

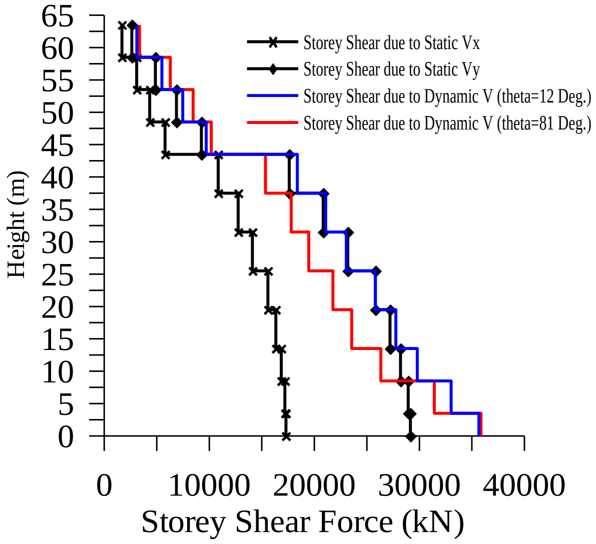


Fig. 17 Storey shear comparison with angle of attack (θ1=9°,θ2=81°).

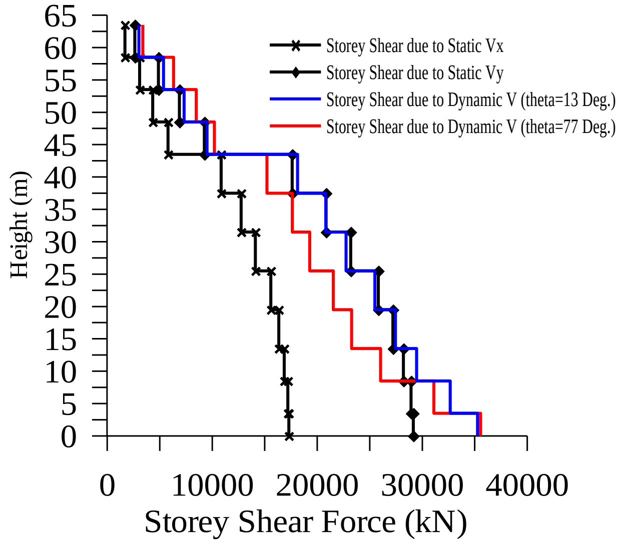


Fig. 18 Storey shear comparison with angle of attack ($\theta1=13^{o},\theta2=77^{o}$).

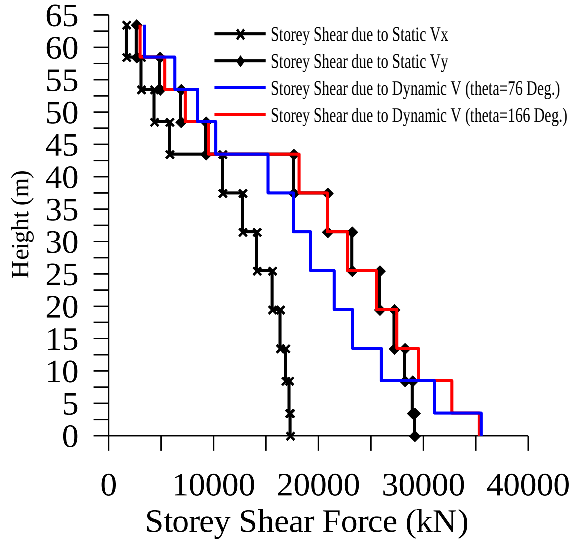


Fig. 19 Storey shear comparison with angle of attack ($\theta1=76^{o},\theta2=166^{o}$).

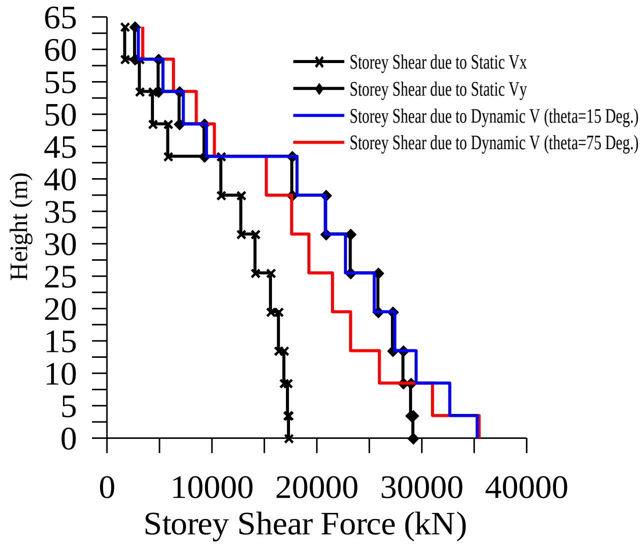


Fig. 20 Storey shear comparison with angle of attack ($\theta1=15^{o},\theta2=75^{o}$).

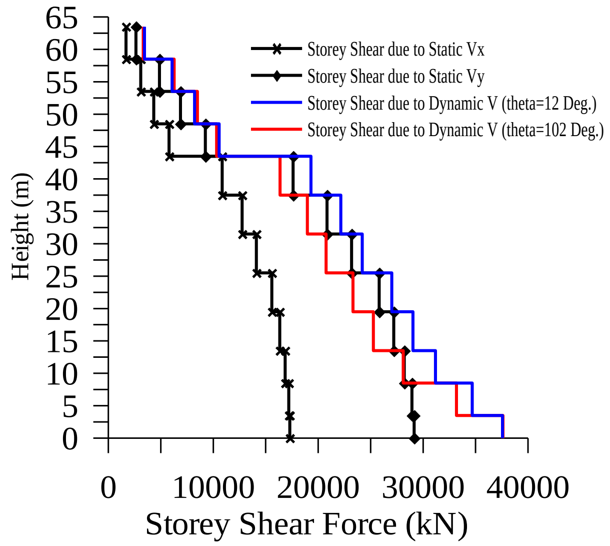


Fig. 21 Storey shear comparison with angle of attack ($\theta1=12^{o},\theta2=102^{o}$).

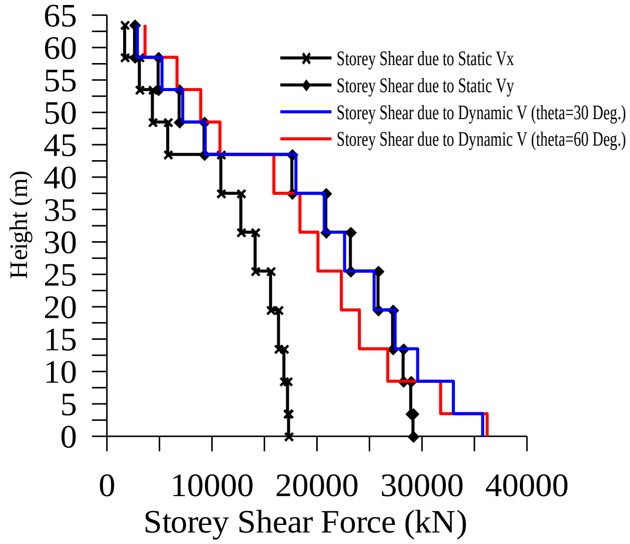


Fig. 22 Storey shear comparison with angle of attack ($\theta1=30^{o},\theta2=60^{o}$).

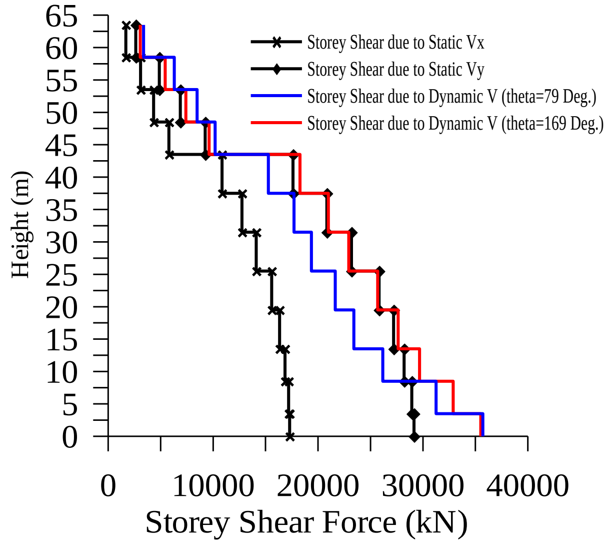


Fig. 23 Storey shear comparison with angle of attack ($\theta1=79^{o},\theta2=169^{o}$).

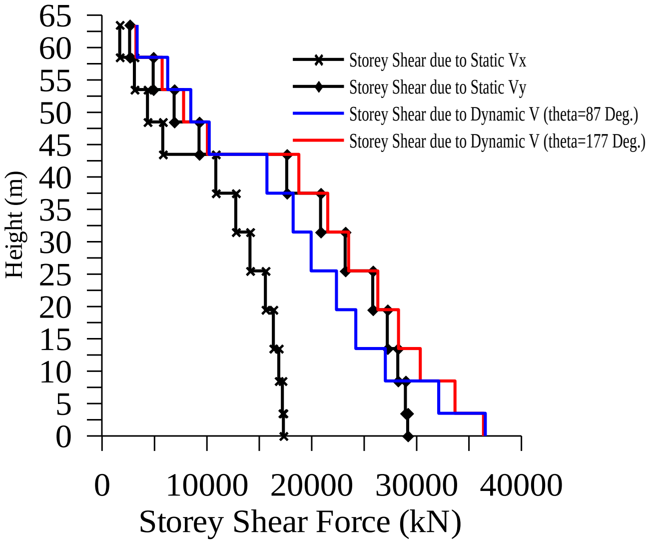


Fig. 24 Storey shear comparison with angle of attack (θ1=87°,θ2=177°).

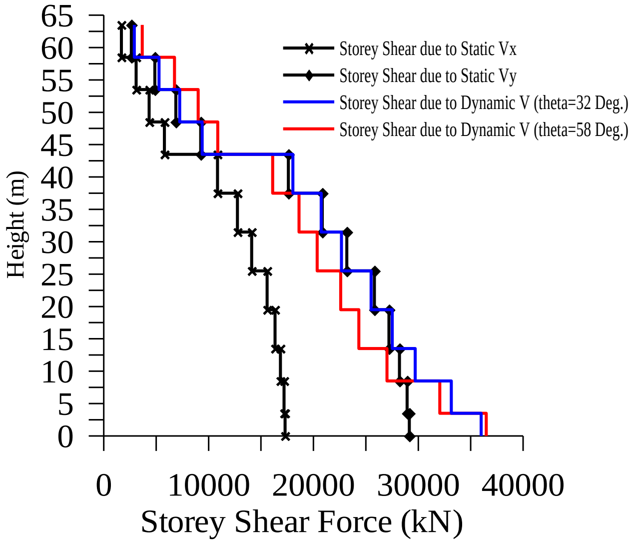


Fig. 25 Storey shear comparison with angle of attack (θ1=32°,θ2=58°).

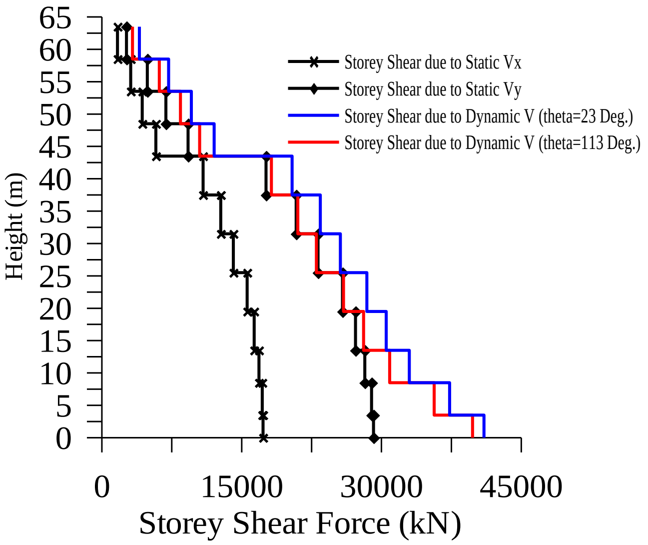


Fig. 26 Storey shear comparison with angle of attack (θ1=23°,θ2=113°).

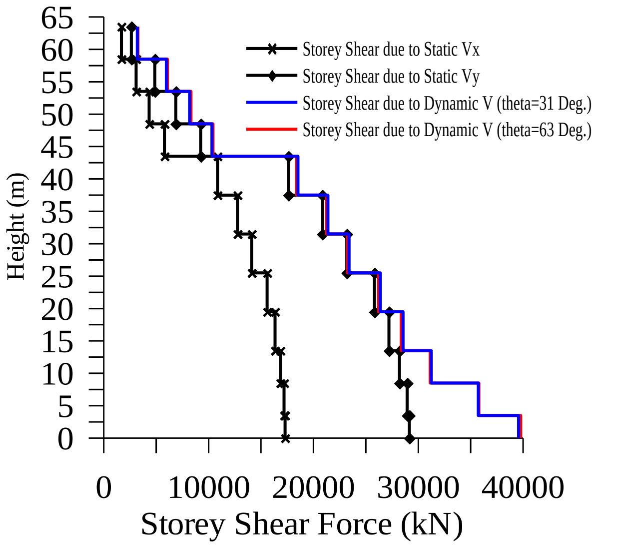


Fig. 27 Storey shear comparison with angle of attack (θ1=31°,θ2=63°).

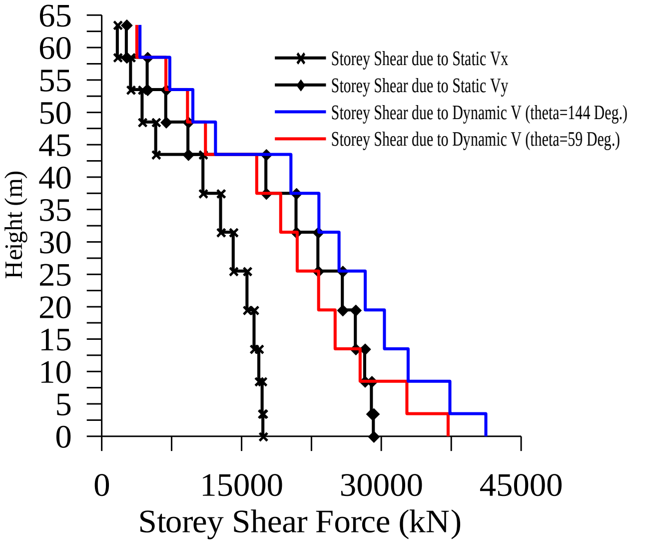


Fig. 28 Storey shear comparison with angle of attack (θ1=144°,θ2=59°).

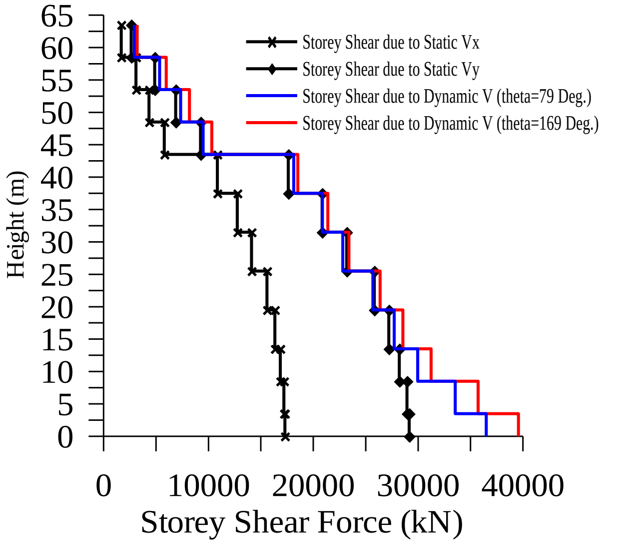


Fig. 29 Storey shear comparison with angle of attack (θ1=79°,θ2=169°).

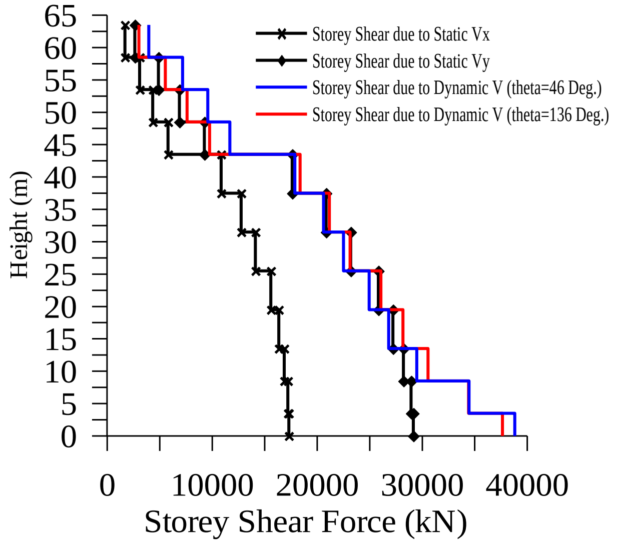


Fig. 30 Storey shear comparison with angle of attack (θ1=46°,θ2=136°).

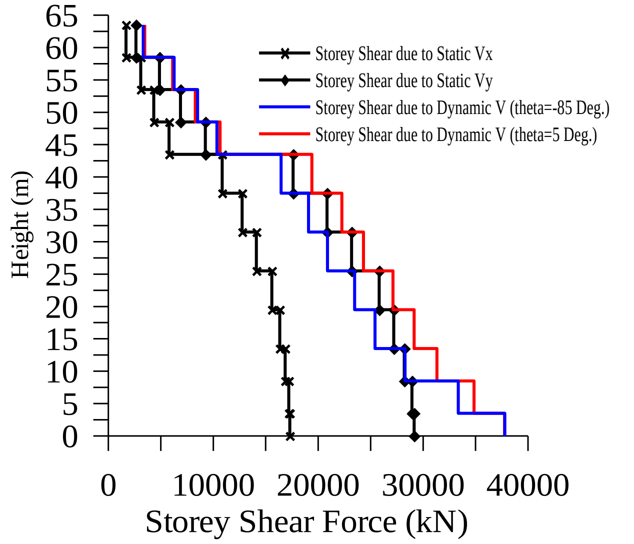


Fig. 31 Storey shear comparison with angle of attack (θ1=85°,θ2=5°).

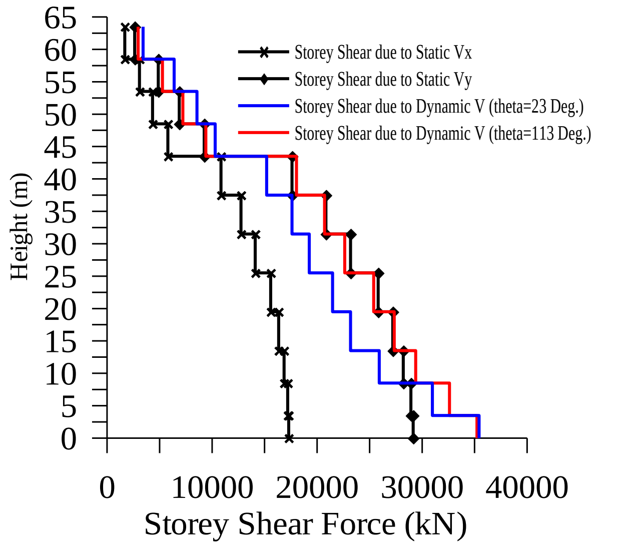


Fig. 32 Storey shear comparison with angle of attack (θ1=23°,θ2=113°).

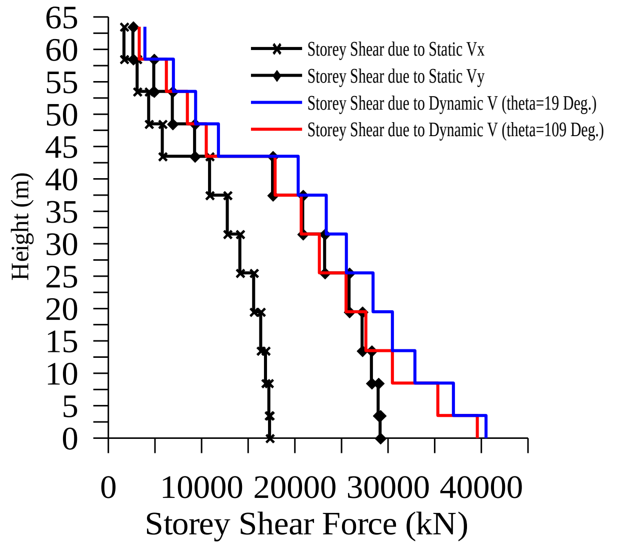


Fig. 33 Storey shear comparison with angle of attack (θ1=19°,θ2=109°).

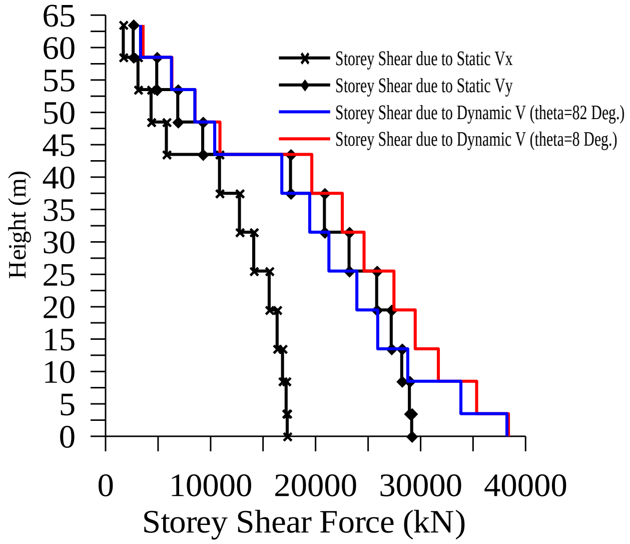


Fig. 34 Storey shear comparison with angle of attack (θ1=82°,θ2=8°).

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XIV. NOTATION AND ABBREVIATIONS

Ax torsional amplification factor
Cs seismic response coefficient
Ct building period coefficient
Cu coefficient for the upper limit on the calculated period
F1, F2 base reaction for response spectrum analysis with unit scaling design values of combined response.
Fi portion of the seismic base shear, V, induced at Level i
hi the height above the base to level i
hn height above the base to the highest level of the building
I occupancy importance factor
kx, ky an exponent related to the structure period
Lx, Ly maximum building dimension perpendicular to the direction of force under consideration
Mta accidental torsional moments
R Response Modification Coefficient
SD1 design spectral response acceleration parameter at a period of 1 .0 sec
SDS design spectral response acceleration parameter in the short period range
Ta approximate fundamental period of the building
TL long-period transition period
To 0.2 SD1/SDs
Ts SD1/SDs
Tx, Ty storey torque due to Static base shear in X and Y directions
VDYN scaling design values of the combined response
VELF base shear using the equivalent lateral force
Vi seismic design storey shear in any storey
Vt base shear from the required modal combination
Vx, Vy static base shear
W effective seismic weight of the building
wi portion of w that is located at or assigned to level i
XCM, YCM center of mass
XCR, YCR center of rigidity
δav average of the displacements at the extreme points of the building at level i
δmax maximum displacement at level i
ϴ1, ϴ2 angle of seismic attack, the 1-axis is in the direction of the seismic input and the 2-axis is normal to the direction of the loading

XV. BIOGRAPHIES

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