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Research Paper

COMPARATIVE STUDY OF SEISMIC FORCES BASED ON STATIC AND DYNAMIC ANALYSIS AS PER IS: 1893 -2002

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Earthquake and its occurrence and affects, its impact and structural response have been studied for many years in earthquake history and is well documented. The structural engineers have tried to examine the various procedures, with an aim to resolve the complex dynamic effect of seismically induced forces in structures, for designing of earthquake resistant structures in a refined and easy manner. The objective of the present study is to assess the lateral forces based on static analysis and dynamic analysis. Two case studies have been presented and lateral forces, base shear are compared. The results thus obtained are tabulated and compared.

Keywords: Seismic Coefficient Method, Response Spectrum Method, Base Shear, Storey Moment

INTRODUCTION

The philosophy of seismic design can be summarized as:

i) The design philosophy adopted in the code is to ensure that structures possess at least a minimum strength to

- Resist minor earthquake (< DBE), which may occur frequently, without damage;
- Resist moderate earthquake (DBE), without significant structural damage through some non-structural damage;
- Resist major earthquake (MCE) without collapse.

"Design Basis Earthquake (DBE) is defined as the maximum earthquake that reasonably can be expected to experience at the site once during lifetime of the structure. The earthquake corresponding to the ultimate safety requirements is often called as Maximum Considered Earthquake (MCE). Generally, the DBE is half of MCE"

Attempts have been made by researchers to study the affect of lateral forces by

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comparing the static analysis and dynamic analysis. (Srikanth *et al.*, 2013) have carried out the study on a building (plan area 22.5 m x 30 m) and compared the forces by static and dynamic analysis and found out the static analysis is giving more values. Further, studies are conducted by Patil *et al.*, on high rise buildings by response spectrum.

METHODS OF ANALYSIS

When a structure is subjected to ground motions in an earthquake, it responds by vibrating. The random motion of the ground caused by an earthquake can be resolved in any three mutually perpendicular directions: the two horizontal directions (x and y) and the vertical direction (z). This motion causes the structure to vibrate or shake in all three directions; the predominant direction of shaking is horizontal.

Structures designed only for vertical shaking, in general, may not be able to safely sustain the effect of horizontal shaking. Generally, however, the inertia forces generated by the horizontal components of ground motion require greater consideration in seismic design. Hence it is necessary to ensure that the structure is adequately resistant to horizontal earthquake shaking too.

The important elements of concern to a design engineer are calculation of seismic design forces and the means of providing sufficient ductility. In most structural engineering calculations, dead loads, live loads and wind loads can be evaluated with fair degree of accuracy. However, the situation with regard to earthquake forces is entirely different.

Earthquake Loads (EL's) are inertia forces related to mass, stiffness, and energy absorbing (e.g., damping and ductility) characteristics of the structure. The design seismic loading recommended by the building codes is in the form of static lateral loading, which depends upon the weight, gross dimensions, and the type of structure, as well as seismicity of the area in which it has to be built. These static design loads are used to determine the strength of the structure necessary to withstand the dynamic loads induced by earthquakes.

Equivalent Lateral Force Method (Seismic Coefficient Method)

Seismic analysis of most structures is still carried out on the assumption that the lateral force is equivalent to the actual (dynamic) loading. This method only requires fundamental period. The periods and shapes of higher natural modes of vibration are not required.

The base shear, which is the total horizontal force on the structure, is calculated on the basis of the structure's mass, its fundamental period of vibration, and corresponding shape. The base shear is distributed along the height of the structure, in terms of lateral forces, according the provisions of code.

Response Spectrum Analysis

Response spectrum analysis is also known as modal method or mode superposition method. The method is applicable to those structures where modes other than the fundamental one significantly affect the response of the structure.

This method is based on the fact that, certain forms of damping – which are reasonable models for many buildings – the response in each natural mode of vibration can be computed independently of the others, and the modal responses can be combined to determine the total response. Each mode responds with its own particular pattern of deformation (mode shape), with its own frequency (modal frequency), and with its own modal damping.

It is applicable to analysis of forces and deformations in multi-storey buildings due to medium intensity ground shaking, which causes a moderately large but essentially linear response in the structure.

Both, the equivalent lateral force procedure (Seismic Coefficient Method) and the response spectrum analysis procedure, are based on the same basic assumptions and are applicable to buildings that exhibit a dynamic response behavior in reasonable conformity with the implications of the assumptions made in the analysis. The main difference lies in the magnitude of the base shear and distribution of the lateral forces.

In the response spectrum method the force calculations are based on compound periods and mode shapes of several modes of vibration, in the equivalent lateral force method, they are based on an estimate of fundamental period and formulae for distribution of forces which are appropriate for buildings with regular distribution of mass and stiffness over height.

IS 1893 -2002 PROVISIONS – EQUIVALENT LATERAL FORCE METHOD AND RESPONSE SPECTRUM METHOD

Static Analysis (Equivalent Lateral Force Method)

This method of finding design lateral forces is also known as the static method or the equivalent static method or the seismic coefficient method. This procedure does not require dynamic analysis, however, it accounts for the dynamics of building in an appropriate manner.

Design Spectrum: The design horizontal seismic coefficient A_h for a structure shall be determined by the following expression:

$$A_h = \frac{ZIS_a}{2Rg}$$

Z = Zone Factor given in Table 2, IS 1893 (Part 1) :2002 is for the Maximum Considered Earthquake (MCE) and service life of structure in a zone.

I = Importance Factor, depending upon the functional use of the structures, characterized by hazardous consequences of its failure, post earthquake functional needs, historical value or economic importance (Table 6) IS 1893 (Part 1) : 2002.

R = Response reduction factor, depending on the perceived seismic damage performance of the structure, characterized by ductile or brittle formations. However, the ratio (I/R) shall not be greater than 1.0 (Table 7). The value of R for buildings is given in Table 7. IS 1893 (Part 1): 2002.

S_a / g = Average response acceleration coefficient for rock or soil site as given in Figure 2 and Table 3 IS 1893 (Part 1) : 2002 based on appropriate natural periods and damping of structure. These curves represent free field ground motion.

Design Seismic Base Shear

The total design lateral force or design seismic base shear (V_B) along any principal direction shall be determined by the following expression

$V_B = A_h W$

where A_h = Design horizontal acceleration spectrum value as per 6.4.2, IS 1893 (Part 1): 2002 using fundamental natural period T_a as per 7.6 in the considered direction of vibration; and

W = Seismic weight of the building as per 7.4.2

Fundamental Natural Period

The approximate fundamental natural period of vibration (*T*a), in seconds, of a moment resisting frame building without brick infill panels may be estimated by the empirical expression: [Clause 7.6.1, IS-1893 (2002)]

$T_a = 0.075\, h^{0.75}$ for RC Frame Building

$= 0.085\, h^{0.75}$ for Steel Frame Building

where h = Height of the building in m. 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.

The approximate fundamental natural period of vibration (T_a), in seconds, of all other buildings, including moment-resisting frame buildings with brick infill panels, may be estimated by the empirical expression: [Clause 7.6.2, IS-1893 (2002)]

$$T_a = \frac{0.09\,h}{\sqrt{d}}$$

where,

h = Height of building, in m.

d = Base dimension of the building at the plinth level, in m, along the considered direction of the lateral force.

Distribution of Design Force: The design base shear is computed for the whole building, and it is then distributed along the height of the building. The lateral forces at each floor level thus obtained are distributed to individual lateral load-resisting elements.

Vertical distribution of base shear to different floor levels IS 1893 (Part 1):2002, Clause 7.7.1. The base shear (V_B) is distributed along the height of the building as per the following expression

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{j=1}^{n} W_j h_i^2}$$

where, Q_i = Design lateral force at floor i,

W_i = Seismic weight of floor i,

h_i = Height of floor i measured from base, and

n = Number of storeys in the building, i.e., number of levels in which the masses are located.

Dynamic Analysis

Dynamic analysis may be performed either by response spectrum method or by time history method. In the response spectrum method, the peak response of a structure during an earthquake is obtained directly from the earthquake response (or design) spectrum. This procedure gives an approximate peak response which is quite accurate for structural design purposes.

Dynamic analysis is classified into two types, namely, *Response spectrum method* and *Time history method*

Dynamic analysis shall be performed to obtain the design seismic force, and its distribution to different levels along the height of the building and to the various lateral load resisting elements, for the following buildings:

a) *Regular buildings* — Those greater than 40 m in height in Zones IV and V, and those greater than 90 m in height in Zones II and III.

b) *Irregular buildings* — All framed buildings higher than 12 m in Zones IV and V, and those greater than 40 m in height in Zones II and III.

Dynamic analysis may be performed either by time history method or by the response spectrum method. However in either method, the design base shear V_B shall be compared with a base shear V_b calculated using fundamental period T_a, where T_a fundamental natural period of vibration. Where V_B is less than V_b, all the response quantities (for example member forces, displacements, storey forces, storey shears and base reactions) shall be multiplied by V_b / V_B.

CASE STUDIES

Two building are studied, each situated in Zone II and Zone III. The geometrical dimensions, member properties and member node connectivity are modeled in the analysis program

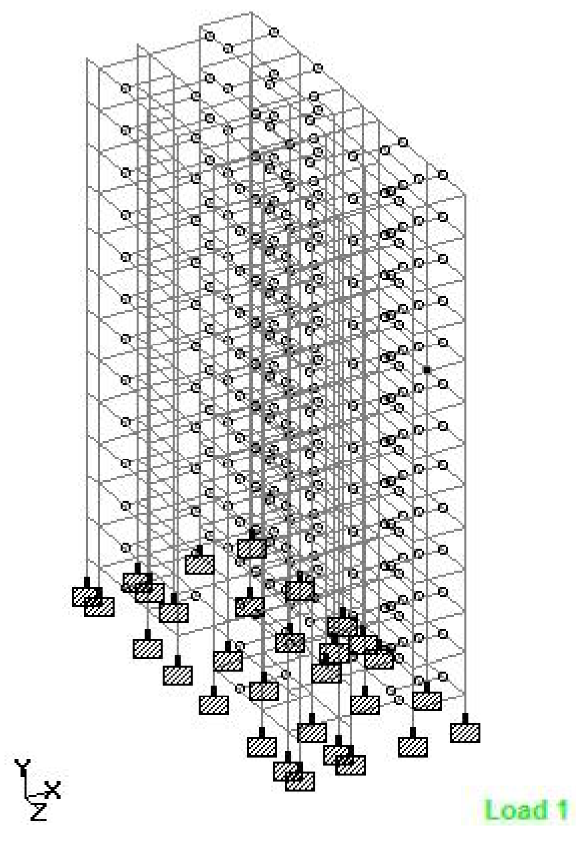
Case Study 1

The building is shown in Figure 1. The building consists of Stilt Floor + 11 floors (Total 12 Floors). The building is 42.25 m height with large base area resting on the hard soil stratum. The soil bearing capacity as per the soil report is 400 KN/sq.m at a depth of 2.0 m from NGL. The structure is situated in Zone II.

The structure is modelled as space frame with loadings DL, LL, wind load as per the codes. The earthquake loading for calculation of seismic weight is applied as member weights. Alternatively, these loads can be applied as joint weights (Lumped mass for each floor ascertained by assigning pin supports at floor nodes).

In the present study, the earthquake loads are applied as member weights.

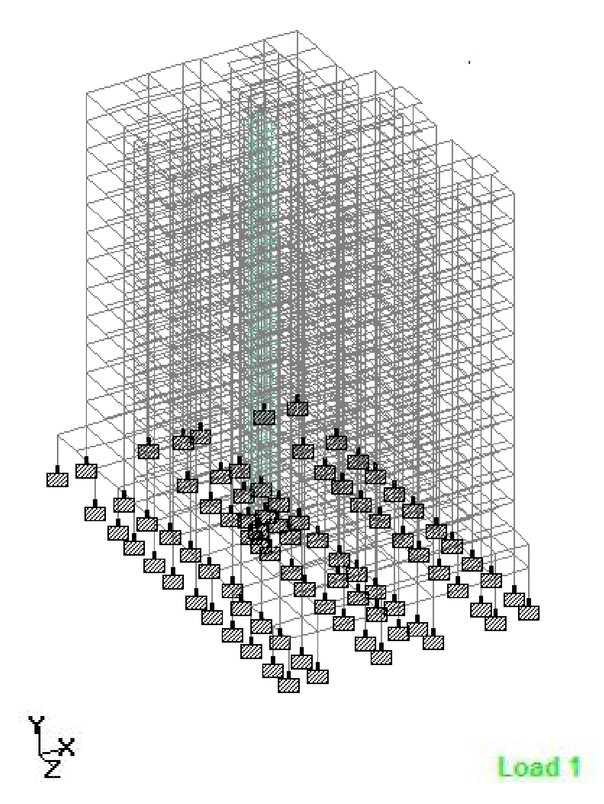
Figure 1: Case Study 1 Building



Case Study 2

The building consists of Basement+ Stilt Floor + 11 floors (Total 13 floors) . The building is 42.70 m height with large base area resting on the hard soil stratum. The soil bearing capacity as per the soil report is 400 KN/sq.m at a depth of 2.0 m from NGL. The structure is situated in Zone III.

Figure 2: Case Study 2 Building



DISCUSSION OF RESULTS

Case Study 1

- The base shear values obtained by dynamic analysis are comparable with the base shear obtained by static analysis in X – DIR and Z –DIR respectively. (Table 1 and 2).
- The values of storey shear obtained by dynamic analysis are lower compared to storey shear by static analysis. The variations of storey shears are shown in Figures 3 and 4.
- The storey moments at base obtained by dynamic analysis are lower compared to values obtained by static analysis. The variation in percentage is 12.49 and 11.02 in X – DIR & Z – DIR respectively (Table 1 and 2).
- The values of storey moments obtained by dynamic analysis are lower compared to storey moments by static analysis. The variations of storey moments are shown in Figures 5 and 6.

Case Study 2

- The base shear values obtained by dynamic analysis are higher compared to the base shear obtained by static analysis in X DIR, whereas the values of base shear from dynamic analysis is lower than static analysis in Z DIR. The variation in percentage is 4.41 and 1.06 in X – DIR and Z –DIR respectively (Tables 3 and 4).
- The values of storey shear obtained by dynamic analysis are lower compared to storey shear by static analysis. The variations of storey shears are shown in Figures 7 and 8.
- The storey moments at base obtained by dynamic analysis are lower compared to values obtained by static analysis. The variation in percentage is 9.69 and 12.04 in X – DIR and Z – DIR respectively (Tables 3 and 4).

The values of storey moments obtained by dynamic analysis are lower compared to storey moments by static analysis. The

Table 1: Comparison of Lateral Forces, Storey Shear and Storey Moments in X- DIR

Floor Height	Lateral Force (KN)		Storey Shear (KN)		Storey Moment KN-M	
	Static Analysis	Dynamic Analysis	Static Analysis	Dynamic Analysis	Static Analysis	Dynamic Analysis
42.25	218.813	171.96	218.813	171.96	711.142	558.870
39.00	244.464	202.69	463.277	374.65	2216.793	1776.483
35.75	203.667	158.83	666.944	533.48	4384.361	3510.293
32.50	166.592	125.22	833.536	658.70	7093.353	5651.068
29.25	133.238	105.88	966.774	764.58	10235.368	8135.953
26.00	103.606	93.08	1070.38	857.66	13714.103	10923.348
22.75	77.696	82.00	1148.076	939.66	17445.350	13977.243
19.50	55.508	72.62	1203.584	1012.28	21356.998	17267.153
16.25	37.042	69.62	1240.626	1081.90	25389.033	20783.328
13.00	22.298	69.25	1262.924	1151.15	29493.535	24524.565
9.75	11.276	59.02	1274.200	1210.17	33634.686	28457.618
6.50	3.978	48.49	1278.178	1258.66	37788.764	32548.263
3.25	0.067	19.51	1278.245	1278.17	41943.060	36702.315
BASE SHEAR - X DIR			**1278.25**	**1278.17**		

Figure 3: Comparison of Storey Shear – Static Analysis and Dynamic Analysis in X- DIR

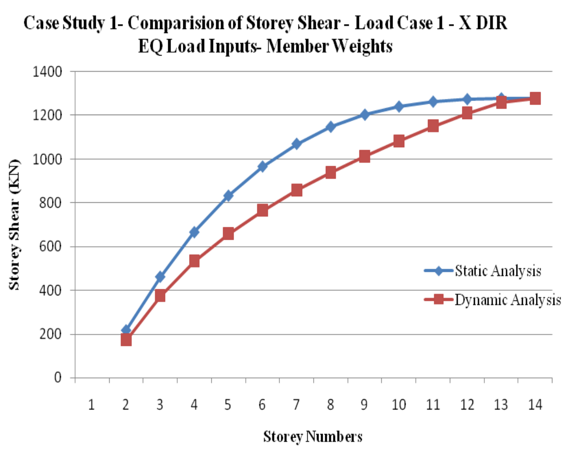


Figure 4: Comparison of Storey Shear - Static Analysis and Dynamic Analysis in Z- DIR

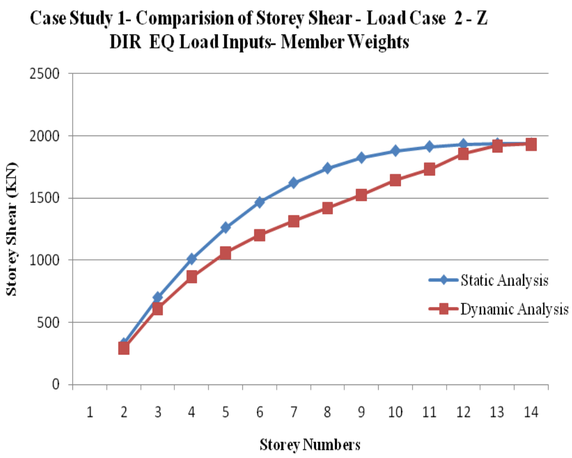


Table 2: Comparison of Lateral Forces, Storey Shear and Storey Moments in Z-DIR

Floor Height	Lateral Force (KN)		Storey Shear (KN)		Storey Moment KN-M	
	Static Analysis	Dynamic Analysis	Static Analysis	Dynamic Analysis	Static Analysis	Dynamic Analysis
42.25	331.346	291.30	331.346	291.30	1076.875	946.725
39.00	370.188	320.60	701.534	611.90	3356.860	2935.400
35.75	308.41	256.22	1009.944	868.12	6639.178	5756.790
32.50	252.267	192.37	1262.211	1060.49	10741.364	9203.383
29.25	201.76	142.60	1463.971	1203.09	15499.270	13113.425
26.00	156.889	112.97	1620.86	1316.06	20767.065	17390.620
22.75	117.655	103.07	1738.515	1419.13	26417.238	22002.793
19.50	84.056	108.39	1822.571	1527.52	32340.594	26967.233
16.25	56.093	118.26	1878.664	1645.78	38446.252	32316.018
13.00	33.766	87.42	1912.43	1733.20	44661.650	37948.918
9.75	17.075	122.62	1929.505	1855.82	50932.541	43980.333
6.50	6.024	65.10	1935.529	1920.92	57223.010	50223.323
3.25	0.101	13.59	1935.630	1934.51	63513.808	56510.480
BASE SHEAR - X DIR			**1935.63**	**1934.51**		

Figure 5: Comparison of Storey Moment - Static Analysis and Dynamic Analysis in X-DIR

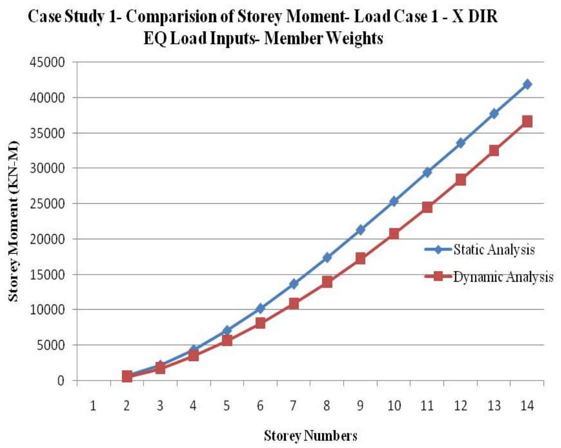


Figure 6: Comparison of Storey Moment - Static Analysis and Dynamic Analysis in Z-DIR

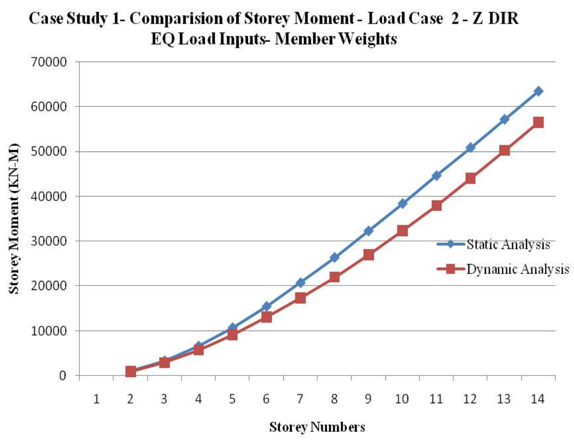


Table 3: Comparison of Lateral Forces, Storey Shear and Storey Moments in X- DIR

Floor Height	Lateral Force (KN)		Storey Shear (KN)		Storey Moment KN-M	
	Static Analysis	Dynamic Analysis	Static Analysis	Dynamic Analysis	Static Analysis	Dynamic Analysis
42.70	328.250	283.710	328.250	283.710	1001.163	865.316
39.65	575.328	504.860	903.578	788.570	3757.075	3270.454
36.60	556.834	496.750	1460.412	1285.320	8211.332	7190.680
33.55	467.896	383.530	1928.308	1668.850	14092.671	12280.673
30.50	387.087	275.100	2315.395	1943.950	21154.626	18209.720
27.45	313.540	197.920	2628.935	2141.870	29172.878	24742.424
24.40	247.736	148.410	2876.671	2290.280	37946.724	31727.778
21.35	189.795	167.850	3066.466	2458.130	47299.446	39225.074
18.30	139.442	197.980	3205.908	2656.110	57077.465	47326.210
15.25	96.834	210.780	3302.742	2866.890	67150.828	56070.224
12.20	61.974	193.840	3364.716	3060.730	77413.212	65405.451
9.15	34.860	172.160	3399.576	3232.890	87781.919	75265.765
6.10	16.895	205.500	3416.471	3438.390	98202.155	85752.855
3.40	4.579	128.980	3421.050	3567.370	107438.990	95384.754
0.00	0.009	4.850	3421.059	3572.220	119070.591	107530.302
BASE SHEAR - X DIR			**3421.059**	**3572.220**		

Figure 7: Comparison of Storey Shear - Static Analysis and Dynamic Analysis in X- DIR

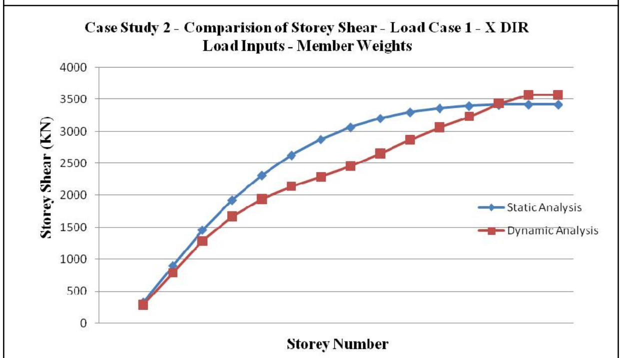


Figure 8: Comparison of Storey Shear - Static Analysis and Dynamic Analysis in Z- DIR

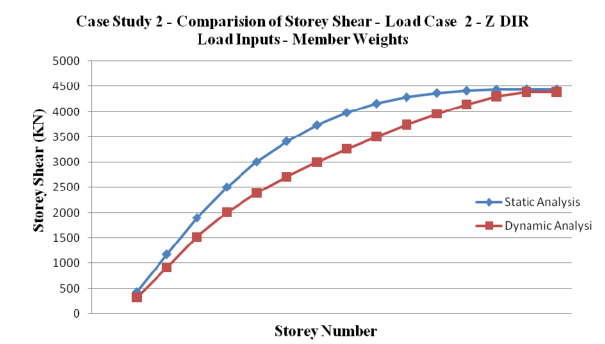


Table 4: Comparison of Lateral Forces, Storey Shear and Storey Moments in Z- DIR

Floor Height	Lateral Force (KN)		Storey Shear (KN)		Storey Moment KN-M	
	Static Analysis	Dynamic Analysis	Static Analysis	Dynamic Analysis	Static Analysis	Dynamic Analysis
42.70	426.149	318.080	426.149	318.080	1299.754	970.144
39.65	746.917	592.560	1173.066	910.640	4877.606	3747.596
36.60	722.907	609.550	1895.973	1520.190	10660.323	8384.176
33.55	607.443	485.070	2503.416	2005.260	18295.742	14500.219
30.50	502.534	384.390	3005.950	2389.650	27463.890	21788.651
27.45	407.053	321.400	3413.003	2711.050	37873.549	30057.354
24.40	321.622	290.360	3734.625	3001.410	49264.155	39211.654
21.35	246.401	265.000	3981.026	3266.410	61406.284	49174.204
18.30	181.029	246.900	4162.055	3513.310	74100.552	59889.800
15.25	125.715	235.010	4287.770	3748.320	87178.251	71322.176
12.20	80.457	216.030	4368.227	3964.350	100501.343	83413.444
9.15	45.257	178.110	4413.484	4142.460	113962.469	96047.947
6.10	21.934	159.530	4435.418	4301.990	127490.494	109169.016
3.40	5.945	88.650	4441.363	4390.640	139482.174	121023.744
0.00	0.009	3.270	4441.372	4393.910	154582.839	135963.038
BASE SHEAR -X DIR			**4441.372**	**4393.91**		

Figure 9: Comparison of Storey Moment - Static Analysis and Dynamic Analysis in X-DIR

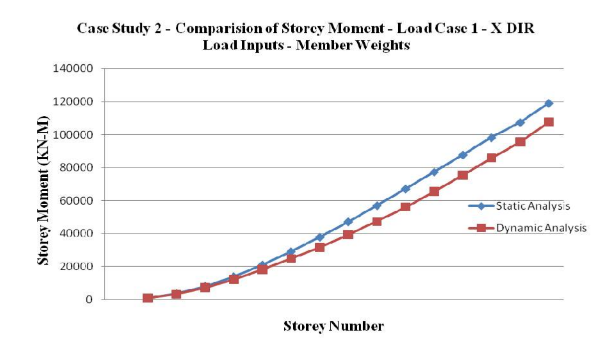
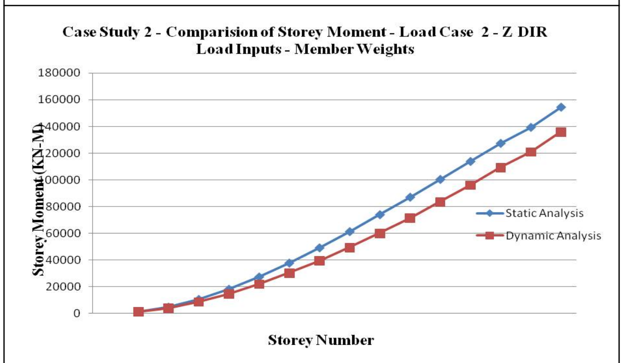


Figure 10: Comparison of Storey Moment - Static Analysis and Dynamic Analysis in Z-DIR



variations of storey moments are shown in Figures 9 and 10.

CONCLUSION

1. The base shear values obtained by Static Analysis (Seismic Coefficient Method) are comparable with values obtained by Dynamic Analysis (Response Spectrum Method) in Zone II. The base shear values obtained by Static Analysis (Seismic Coefficient Method) are less than the values obtained by Dynamic Analysis (Response Spectrum Method) in Zone III.
2. The storey shear values are high in Static Analysis (Seismic Coefficient Method) compared to storey shear in Dynamic Analysis (Response Spectrum Method) for upper floors. The response spectrum method may be employed for buildings in Zone II & III.
3. The storey moments are high in Static Analysis (Seismic Coefficient Method) compared to storey moments in Dynamic Analysis (Response Spectrum Method). The response spectrum method may be carried out for symmetric buildings in Zone II and III. This may approximately optimize the design as the values obtained by dynamic analysis are lower.
4. Further, comparative studies are to be carried out for regular buildings height between 40 m – 90 m situated in Zone II and III to evaluate the variation in lateral forces.

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