Evolution of Seismic Behaviour of High Rise Structure With Inclined Intersecting Members

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Abstract *- The inclined intersecting member is a framework of diagonally intersecting steel, concrete or timber members that is used in the construction of buildings. A triangulated configuration is formed in the inclined intersecting member structural systems because of the modules. These modules effectively carry all the loads i.e. lateral as well as gravity and distribute them in a very uniform and regular pattern by axial action of the inclined intersecting member. In this paper, analytical study of 24 storey building with regular floor plan of 18m×18m size with conventional frame structures and conventional tube structures in comparison with inclined intersecting member (IIM) frame structures and inclined intersecting member tube structures respectively are carried out. There are fourteen models for the study. For modelling and analysis ETABS software is used. For analysis, linear dynamic approach i.e. response spectrum method is performed as per IS 1893 (Part I): 2002. The comparison of analysis of results in terms of top story displacement, story drift, base shear and time period is presented.*

Keywords - Linear dynamic approach, storey, displacement, story drift, E-TABS, base shear, time period

I. INTRODUCTION

The inclined intersecting member (IIM) is a frame work of diagonally intersecting metal, concrete or wooden beams that is used in the construction of buildings and roofs. It requires less structural steel than a conventional steel frame Hearst tower in new-york city, designed by Sir Norman Foster, uses 21 percent less steel than a standard design. The inclined intersecting member (IIM) obviates the need for columns and can be used to make large column-free expanses of roofing. Another iconic building designed by Sir Norman Foster, 30 St Mary Axe, known as "The Gherkin", also uses the inclined intersecting members (IIM) system.

II. DEVELOPMENT OF THE INCLINED INTERSECTING MEMBER

In the modern world, "Inclined Intersecting Member" are gaining more popularity because of its structural flexibility and elegance in appearance. Structural engineers and architects have now made considerable progress in the trends following "IIM" structures. The vertical columns in the periphery of a structure are eliminated in "IIM" structures. This is the main extinguishing difference between "IIM" and other forms of buildings. A triangulated configuration is formed in the "IIM" structural systems because of the modules and these modules effectively carry all the loads i.e. lateral as well as gravity and distribute them in a very uniform and regular pattern. For instance, structural performance of braced tubes and "IIM" structures are very familiar in a manner that both systems are able to carry lateral loads very efficiently with their structural member's axial actions. While bending rigidity in braced tubes is provided primarily by vertical perimeter columns, bending rigidity in "IIM" is provided by diagonals which also provide shear rigidity because the system is typically composed of only diagonals. Indeed, the "IIM" systems can be called the evolution of braced tube structures with large diagonal members that spread over the periphery. In addition, by using diagonals, less amount of material is used. Also, due to elimination of columns, much space is available to make the structure more flexible. Diagrids provide increased stability due to triangulation.

Figure 1- Inclined Intersecting Member Model

The combination of gravity and lateral load bearing systems potentially provides more efficiency. Also, the reduced weight of the superstructure can translate into a reduced load on the foundations. A "IIM" module has a diamond shape which contains a number of stories. Modules are classified into 4 different groups including small modules (2-4 stories), mid-size modules (6-8 stories), large modules (more than 10 stories) and irregular modules. Moreover, "IIM" angle is the angle of diagonal members. Modules and angles both play a key role in structural, architectural and aesthetic concepts of these structures. Modified diagonalized core system buildings – "IIM"- only began to appear in contemporary steel design around the year 2003. All three of the initial examples –The London GLA, Swiss Re and the Hearst Tower – were in development in the offices of Foster+Partners at the same time and the engineering expertise of ARUP was integral to all three projects. Interestingly, all made use of unique variations of the system by virtue of their three dimensional geometry suggesting that the "IIM" form could potentially support even more daring feats.

III. AIM AND OBJECTIVES OF THE STUDY

The aim of the study is the achievement of an acceptable probability that structures being designed will perform satisfactorily during their intended life. With an appropriate degree of safety, they should sustain all the loads and deformations of general construction and use and shall have adequate durability and resistance to effects of fire, wind, earthquake and any other forces acting upon.
The objectives of proposed work are as follows,

1. To study the seismic performance of High-rise building by response spectrum method using conventional RC framed structure.
2. To study the seismic performance of High-rise building by response spectrum method using RC diagonal intersecting member (Diagrid).
3. To study the seismic performance of High-rise building by response spectrum method using tabular sections inclined intersecting member (Diagrid).
4. To compare the seismic performance of High-rise building in above objectives

IV. METHODOLOGY AND ANALYSIS

The 24-storey (G+23) commercial building is having 18m x 18m plan dimension. Total height of building is 86.4m. The building is kept symmetrical in both principal directions in plan and the all the columns provided of square in size to avoid tensional response under pure lateral forces. For modelling and analysis of "IIM" structure ETABS software is used. The end condition for "IIM" is assumed as hinged. The support conditions are assumed as fixed. The design earthquake loading for the RC framed building and the structural response were computed using the response spectrum method in accordance with the latest Indian Standard criteria for earthquake resistant design of structures IS 1893 (Part 1): 2002.
Following general geometric data are involved for all the models.

1) A 24-storey building is modeled with 18m x 18m plan dimension. It is having 86.4 m of total height with 3.6 m height of each storey taken for all models.
2) The slab thickness is taken 120 mm for all models. The height of parapet wall is taken 1m.
3) Characteristic strength of concrete is 35 N/mm^2
4) Characteristic strength of steel is 415 N/mm^2
5) Building frame is Special moment resisting frame (SMRF)
6) Density of concrete: 25 KN/m^3
7) Density of masonry wall: 20 KN/m^3
8) Modulus of elasticity for concrete: 27386128 KN/m^2
9) End supports are taken as fixed. Hinged condition is applied to "IIM".
10) The angle of "IIM" is decided on the basis of the storey module. Here, three different storey module is considered, that is 1-storey module, 2-storey module and 4-storey module as shown in Figure 3.6, 3.7 and 3.8. The "IIM" model comprises of glass cladding as facade along the periphery. The "IIM" eliminates all exterior vertical columns in the periphery of the building, while interior columns are present. The angle is obtained from the height of the storey module to the base width of "IIM", that is,

For example:

[1] 1-storey module then,
Angle (θ) = $\tan^{-1}$ (height of module / base width) Angle (θ) = $\tan^{-1}$ (3.6/3) Angle (θ) = 50.19°

[2] 2-storey module then,
Angle (θ) = $\tan^{-1}$ (height of module / base width) Angle (θ) = $\tan^{-1}$ (7.2/3) Angle (θ) = 67.38 °

[3] 4-storey module then,
Angle (θ) = $\tan^{-1}$ (height of module / base width) Angle (θ) = $\tan^{-1}$ (10.8/3) Angle (θ) = 78.23°

Table 1. Element sizes for normal structures

Member	Member No.	"IIM" Structure	Conventional Structure
Beam	B	300 mm X 450 mm	300 mm X 450 mm
Column	C	500 mm X 500 mm	500 mm X 500 mm
"IIM" (Concrete)	D	400 mm X 400 mm	--
"IIM" (Steel)	D	350 mm steel pipe section with 12 mmthick	--

Table 2. Element sizes for tube structures

Member	Member No.	"IIM" Structure	Conventional structure
Beam	B_1	300 mm x 600 mm	300 mm x 600 mm
	B_2	300 mm x 450 mm	300 mm x 450 mm
	B_3	230 mm x 500 mm	230 mm x 500 mm
Column	C_1	750 mm x 750 mm	750 mm x 750 mm
	C_2	450mm X 450mm	450mm X 450mm
"IIM" (Concrete)	D	400 mm x 400 mm	--
"IIM" (Steel)	D	350 mm steel pipe section with 12mm thick	--

V. LOADS AND LOAD COMBINATIONS

a) Dead load:

The dead load in a building shall comprise the weight of all walls, partitions, floors, roofs and all other permanent constructions in the building. In this study, as per IS875-1987, Part I, the unit weight of reinforced concrete made with sand and gravel or crushed natural stone aggregate is taken as 25kN/m2.

Dead load due to slab:

a) Self-weight of slab (D X 25) = 0.12 X 25 = 3 kN/m^2 Water proofing = 1.5 kN/m^2
Floor finish = 1 kN/m^2

Total D.L. on terrace level = 5.5 kN/m^2

b) Self-weight of slab (D X 25) = 0.12 X 25 = 3 kN/m^2 Floor finish = 1 kN/m^2
Total D.L. on floor level = 4 kN/m^2
Dead load due to brickwork:
230mm thick brick walls with 12.5 mm plaster on both sides with height of 3.15m.
i.e. 115 + 2 X 12.5 = 140mm. Consider wall thickness = 150mm 0.15 X 20 kN/m^3 X 3.15 = 9.45 kN/m
Terrace parapet walls: 0.15 X 1 X 20kN/m^3 = 3 kN/m
Dead load due to Glass cladding
Toughened glass used for curtain walls of high rise building with 12 mm thickness and density of 2500 kg/m^3
0.012 X 24.5 X 3.15 = 0.92 = 1 kN/m
D.L. is taken same for all the models.

b) *Live load:*

Table 4 Earthquake parameters

Terminology	Description
Zone	IV
Soil Type	Medium
Importance Factor	1
Damping	5%
Response reduction factor	5

Following are the load combinations have been used for the analysis as per IS1893 (Part 1): 2002

1. 1.5 (DL+LL)
2. (DL+LL+EQX)
3. . (DL+LL-EQX)
4. (DL+EQX)
5. (DL-EQX)
6. 0.9DL+1.5EQX
7. 0.9DL-1.5EQX

VI. USE OF ETABS SOFTWARE

ETABS is a program for linear, nonlinear, static and dynamic analysis, and the design of building systems. From an analytical standpoint, multi-storey buildings constitute a very special class of structures and therefore deserve special treatment. The concept of special program for building type structures was introduced over 40 years ago and resulted in the development of the ETABS series of computer program.

Features and Benefits of ETABS:

1. The input, output and numerical solution techniques of ETABS are specifically designed to take advantage of the unique physical and numerical characteristics associated with building type structures. As a result, this analysis and design tool expedites data preparation, output interpretation and execution throughput.
2. The need for special purpose program has never been more evident as Structural Engineers put non-linear dynamic analysis into practice and use the greater computer power available today to create larger analytical models.
3. Over the past two decades, ETABS has numerous mega-projects to its credit and has established itself as the standard of the industry. ETABS software is clearly recognized as the most practical and efficient tool for the static and dynamic analysis of multistory frame and shear wall buildings.

Table 3 Live Loads and their intensity

Description	Intensity
Live load at roof level	1.5 kN/m^2
Live load at other floor	4 kN/m^2

VII. METHODS OF ANALYSIS

Depending on the loading conditions and type of structure, the common elastic or inelastic analysis types are as follows:

1) Linear static analysis
2) Nonlinear-static analysis
   a. P-Delta analysis
   b. Pushover analysis
3) Linear dynamic analysis
   a. Linear time history analysis.
   b. Response spectrum analysis
4) Nonlinear-dynamic analysis
   a. Nonlinear time history analysis

As per IS-1893 (2002), the dynamic analysis is recommended for buildings depending upon seismic zone and height of building as given in Table 3.1. The values of damping for a building may be taken as 2 and 5 percent of the critical, for the purpose of dynamic analysis of steel and reinforced concrete buildings, respectively

VIII. RESULTS

Lateral displacement for CF, 1 SCDF, 2 SCDF and 4 SCDF

Storey No	CF	1 SCDF	2 SCDF	4 SCDF
24	0.463	0.95	0.742	0.588
23	0.578	0.972	0.783	0.689
22	0.69	0.99	0.816	0.738
21	0.784	1.004	0.847	0.815
20	0.858	1.013	0.87	0.845
19	0.919	1.016	0.883	0.894
18	0.968	1.012	0.895	0.908
17	1.009	1.003	0.89	0.933
16	1.045	0.989	0.894	0.948
15	1.076	0.97	0.873	0.961
14	1.103	0.947	0.872	0.949
13	1.127	0.921	0.84	0.949
12	1.147	0.892	0.837	0.961
11	1.165	0.861	0.797	0.959
10	1.18	0.827	0.794	0.928
9	1.192	0.79	0.747	0.916
8	1.201	0.751	0.746	0.931
7	1.209	0.707	0.693	0.924
6	1.217	0.658	0.692	0.875
5	1.225	0.601	0.628	0.858
4	1.232	0.537	0.625	0.882
3	1.231	0.461	0.54	0.869
2	1.172	0.374	0.533	0.793
1	0.745	0.255	0.372	0.614

Storey drift for CF, 1 SCDF, 2 SCDF and 4 SCDF

Storey No	CF	1 SCDF	2 SCDF	4 SCDF
24	0.463	0.95	0.742	0.588
23	0.578	0.972	0.783	0.689
22	0.69	0.99	0.816	0.738
21	0.784	1.004	0.847	0.815
20	0.858	1.013	0.87	0.845
19	0.919	1.016	0.883	0.894
18	0.968	1.012	0.895	0.908
17	1.009	1.003	0.89	0.933
16	1.045	0.989	0.894	0.948
15	1.076	0.97	0.873	0.961
14	1.103	0.947	0.872	0.949
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4	1.232	0.537	0.625	0.882
3	1.231	0.461	0.54	0.869
2	1.172	0.374	0.533	0.793
1	0.745	0.255	0.372	0.614

Storey shear for CF, 1 SCDF, 2 SCDF and 4 SCDF

Storey Level	CF	1 SCDF	2 SCDF	4SCDF
24	263.66	508.14	429.63	321.8
23	561.81	1045.69	903.97	689.13
22	794.22	1451.6	1283.19	982.33
21	968.17	1740.02	1570.72	1208.8
20	1102.38	1932.25	1781.59	1380.65
19	1210.44	2046.92	1929.71	1511.34
18	1300.4	2100.99	2028.49	1612.12
17	1380.56	2113.74	2088.41	1693.48
16	1456.57	2105.35	2125.39	1763.78
15	1529.12	2094.8	2152.8	1828.99
14	1599.06	2101.03	2183.32	1893.67
13	1667.86	2141.16	2226.39	1960.65
12	1734.28	2225.41	2292.5	2029.21
11	1798.38	2356.9	2387.46	2100.97
10	1862.05	2532.74	2509.83	2177.45
9	1923.15	2743.13	2659.35	2259.02
8	1983.33	2976.33	2831.98	2343.61
7	2046.8	3221.44	3019.69	2442.91
6	2110.95	3465.08	3213.22	2546.93
5	2183.72	3696.16	3406.62	2659.29
4	2259.85	3903.27	3585.26	2772.89
3	2344.21	4076.19	3741.8	2884.73
2	2411.96	4202.63	3858.82	2971.55
1	2457.44	4271.06	3925.72	3031.91

Time period for CF, 1 SCDF, 2 SCDF and 4 SCDF

Mode no.	CF	1 SCDF	2 SCDF	4 SCDF
1	3.6116	2.6736	2.5175	2.942
2	3.6116	2.6736	2.5175	2.942
3	2.9814	0.6221	0.9313	1.5687
4	1.1653	0.622	0.6847	0.907
5	0.6516	0.2878	0.3418	0.4845
6	0.456	0.1842	0.2313	0.3394
7	0.3474	0.1346	0.2249	0.2613
8	0.2793	0.1064	0.1745	0.2144
9	0.2342	0.0881	0.1403	0.1891
10	0.1748	0.0731	0.113	0.1612
11	0.1421	0.0561	0.084	0.1223
12	0.0863	0.0391	0.084	0.0838

IX. CONCLUSION

After the analysis the seismic performance of different models has been compared and the efficient angle of "IIM" is concluded. The work carried out 14 number of models are concluded in this study. The conclusions of the present study are as follows

1) Base shear: As compared to conventional buildings the base shear of "IIM" buildings are more. As compared to conventional buildings the base shear of 1SCDF and 1SSDF are more by 42.46% and 35.95% respectively. In "IIM" tube structures, as compared to conventional tube buildings the base shear of 1SCDTF and 1SSDTF are more by 43.76% and 40.44% respectively.
2) Lateral displacement: As the lateral loads are resisted by diagonal columns, the top storey displacement is less in "IIM" structure as compared to the conventional frame building. As compared to conventional buildings the diplacements of 2SCDF and 2SSDF are less by 24.21% and 22.51% respectively. In "IIM" tube structures, as compared to conventional tube buildings the displacement of 2SCDTF and 2SSDTF are less by 35.8% and 36.69% respectively. 2 storey "IIM" with an angle of 67.38° gives more resistance to lateral displacements as compared to other "IIM" frame structures.
3) Storey drift: As compared to conventional buildings the storey drift of 2SCDF and 2SSDF are less by 27.01% and 27.92% respectively. In "IIM" tube structures, as compared to conventional tube buildings the storey drift of 2SCDTF and 2SSDTF are less by 34.59% and 35.3% respectively. In "IIM" structure, 2 storey "IIM" with an angle of 67.38° gives more resistance to storey drift as compared to other "IIM" frame structures.
4) Axial forces and bending moments: Bending moments of interior column in "IIM" buildings are relaxed in "IIM" structure, although axial force is nearly same. This is due to internal column in "IIM" structure carry only gravity load and seismic force is resist by external diagonal column while in conventional both internal and external column resist gravity and seismic load.
5) Time period: As compared to conventional buildings the time period of 2SCDF and 2SSDF are less by 30.29% and 23.93% respectively. In "IIM" tube structures, as compared to conventional tube buildings the storey drift of 2SCDTF and 2SSDTF are less by 33.96% and 34.99% respectively. It is observed that the time period is minimum for the 2 storey "IIM" frame building in all cases. It means 2 storey "IIM" frame buildings with an angle of 67.38° are stiffer than other "IIM" buildings.

X. FUTURE SCOPE

1) Present study has been carried by linear dynamic analysis, Nonlinear dynamic analysis can be done.
2) In the present study regular "IIM" buildings in plan are considered, in further study irregular "IIM" buildings can be considered.
3) Performance of "IIM" building can be assessed by considering effect of soil structure interaction.
4) Cost estimation of "IIM" building can be carried out.

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