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Optimization & Design of High Rise Building with Different Structural Framing Systems Subjected To Seismic Loads

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Abstract
Due to excessive displacements of tall buildings occasioned by lateral loads, lateral load resisting systems are usually provided to curtail the load effect. The resistance may be offered by Frame Action, Shear Walls, or combined Walls and Frames (also known as Dual System). In this study, 3D structural modelling base software STAAD-PRO was used to generate and analyze three-dimensional building models for the assessment of the relative effectiveness of the various lateral load resisting systems. Five models were used, one for moment resisting frame & 04 models each for the lateral load resisting systems. Each model consisted of G +10 storey frame structure having total height of 33.0 m. Each building sample was subjected to three-dimensional analysis for the determination of both the lateral displacements at storey top and interstorey drifts. The results of the work showed that the dual system was the most efficient lateral-load resisting system based on deflection criterion, as they yielded the least values for lateral displacements and inter-storey drifts. The moment frame was the least stiff of the resisting systems, yielding the highest values of both the lateral displacement and the inter-storey drift.
Index Terms— Moment Frame, Shear Wall, Dual System, Inter-Storey Drift, Lateral Displacement, Seismic Load

I. INTRODUCTION

In general, as the height of a building increases, its overall response to lateral load (such as wind and earthquake) increases. When such response becomes sufficiently great such that the effect of lateral load must be explicitly taken into consideration in design, a multistory building is said to be tall. Tall buildings are prone to excessive displacements, necessitating the introduction of special measures to contain these displacements. The lateral load effects on buildings can be resisted by Frame action, Shear Walls, or Dual System. Peak inter-storey drift and lateral displacement (or side sway) are two essential parameters used for assessing the lateral stability and stiffness of lateral force resisting systems of tall buildings. Selection of such a strong and stiff enough deformation resisting systems that will curtail the drift within acceptable code limits should be the main motive of structural designers.

As it is well known to most of structural engineers who are familiar with the types of structural systems for resisting wind and seismic loads, they are called Shear systems- such as:

1-Frames:
• This is a frame system of rigid beams subjected to lateral loads where the developed moments in the middle of the columns are not existent and the shear forces will be distributed proportionally with the moment of inertia of the columns and the lateral displacements will be proportional to these forces.

2-Shear walls:
• These systems resist the lateral loads with the shear walls whether these walls are separated or connected by beams.

The distribution of shear forces is proportional to the moment of inertia of the cross sections of the walls; the displacements in each floor or level are the result of the flexural deformations in the walls.

3-Dual systems
• These systems are the result of combining the two latter systems to resist the lateral load, in these systems the shape of the deformations will differ from those in frames and walls systems, where effecting interacted forces occur and change the shape of shear and moment diagrams. One of the advantages of this combination is that the frames support the walls at the top and control their displacement. Besides, the walls support the frames at the bottom and decrease their displacement.

In other words, the shear force of the frames is bigger at the top than it is at the bottom and it goes the other way round for the walls. We rarely find shear systems as complete shear walls without regular frames (beams and columns), or absolute frames without service walls or elevator walls.

It has been mentioned in the international and local codes that in case we have regular frames of beams and columns along with shear walls to resist the lateral loads, the resistance of these members (the frames) to the lateral loads can be neglected, and it will be considered in the calculations only to
resist the vertical loads, but we should conform to the codes conditions relating to the minimum reinforcement and the allowed displacement of these beams and columns.

And the purpose of our research is to find out if we can neglect the presence of walls (concrete or masonry) if they are together with the frame system, where the frame system resists all the lateral shear forces and the walls will be considered just to bear the vertical load, and what are the provisions for these walls and their effect on the frames load.

II. RESEARCH TOPIC & OBJECTIVE DEMONSTRATION

The Dual system is the one that both shear walls and frames participate in resisting the lateral loads resulting from earthquakes or wind or storms, and the portion of the forces resisted by each one depends on its rigidity, modulus of elasticity and its ductility, and the possibility to develop plastic hinges in its parts. Knowing that the frame is a group of beams and columns connected with each other by rigid joints that can resist shear and moments, and the shear wall is
considered as a cantilever free on the top and fixed in the bottom.

The structural resisting system might be only shear walls for resisting the lateral load and we can neglect the regular frames.

The structural resisting system might be only frames for resisting the lateral load and it is called Moment Resisting Frames.

 In the case of shear walls with the moment resisting frames, can we neglect the effect of these walls, and calculate the frames to resist the whole base shear.

 This is the subject of our research; the existence of some shear walls with moment resisting frames, could it be neglected and not taken into consideration for resisting the lateral loads, which means to calculate them only as gravity loads resisting members, and what are structural effects and changes resulting from that.

<u>*Objectives of Research*</u>

- To analyze a G +10 storey frame structure with 5 different structural framing systems for seismic & gravity loads, as per code IS 1893-2002 part I (Criteria for earthquake resistant structure.)
- To compare analytical data & design for a suitable framing system.
- To obtain more practical structural framing for high rise structures mainly located in HIGH SIESMIC ZONE (Zone V).
- To find out effectiveness of shear wall system to RCC buildings & to design the whole structure as per IS recommendations for high seismic locations.
- To get economical and efficient lateral stiffness system for high seismic prone areas.

III. BUILDING & ANALYSIS DESCRIPTION

The building consists of residential flat scheme construction of G+ 10 stories. Building consists of 4 flats at each floor with staircase block and lift giving access to each floor. The floor-to-floor height is 3.00 m. for each storey.

1. Five different structural combinations are analyzed as a space framed structure consisting of assembly of beams, columns & shear walls forming frames.
2. The diaphragm action resulting from the slab panels is not assigned to the model.
3. The supports are assigned according to the actual degrees of freedom at the support.
4. All the framed members will be provided with ductility detailing as per latest IS-13920. (Special Moment Resisting Frames)
5. All structural members are detailed in relevant R.C.C. drawings.

I. <u>Climatic condition:</u>

- Location of building - Darbhanga, Bihar, India
- Location exposure - MILD
- Monsoon duration - June to Sept.
- Temperature - Varies between 24˚C.-32 ˚C

<u>*II. Design Standard:*</u>

Unless otherwise noted, the designs are based on different methods according to the relevant latest Indian standards as given below.

*Limit State Method -for beams, columns, slabs, shear, walls etc.

*Working Stress Method -for overhead water tank

<u>*III. Load Parameters: (As per IS 875-1987)*</u>

Followings are the design consideration and assumptions:

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Dead Load: (As per IS 875-1987)

For concrete : 25 KN / m3
Floor finish : 1 KN / m2
Brick bat coba : 20 KN / m3
230 mm thk.wall including plaster. : 5.06 KN/m/m
115 mm thk.wall including plaster. : 2.53 KN/m/m

Live Load: (As per IS 875-1987) (udl's in Kn/m2)

Passages 3 KN / m2
Staircase 4 KN / m2
Other rooms 2 KN / m2
Lift machine room 12 KN / m2

Earthquake loads:-

These are calculated as per IS-1893-2002 (part 1), with following details:-

1. Zone : V
2. Seismic zone factor : 0.36
3. Response reduction factor : 5
4. Percentage damping : 5 %
5. Type of structure : Bldg. With SMRF
6. Importance factor : 1.0

IV. Materials Used:

1. Concrete M25
Reinforcement Fe 500 (TMT)

V. Load Combinations:

1. 1.5 x (D.L + 100 % L.L)
2. 1.2 x (D.L + LL + Eqx)
3. 1.2 x (D.L + LL + Eqy)
4. 1.5 x (D.L + Eqx)
5. 1.5 x (D.L + Eqy)
6. 0.9 DL+ 1.5Eqx
7. 0.9 DL+ 1.5Eqy

Criterion followed for adopting Sizes of Beams, Columns & Shear Walls:

Beams sizing criterion for all frames:
Beams:
1) Beams up to span 3.0 M. = 230 mm x 300 mm
2) Beams spanning 3.0 M. to 5.00 m = 230 mm x 500 mm
3) Beams spanning above 5.00 m = 300 mm x 600 mm
Columns & Shear Wall sizes for different frames:

Frame I: Moment Resisting Frame

All columns of lift & staircase area = 230mm x 500 mm
All corner columns & in passage area = 300 x 600 mm
Remaining Internal/external columns = 350 x 750 mm

Frame II, III, IV & V: (Dual Systems)

SW1X = 350 x 2050 mm
SW1Y= 350 x 1500 mm
Remaining Internal/external columns = 350 x 750 mm

IV. ARCHITECTURAL PLANS & DIFFERENT STRUCTURAL FRAMING SYSTEMS

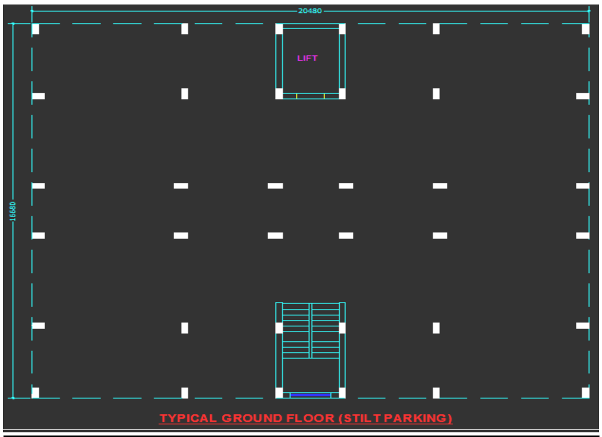


Fig. I Ground Floor (Stilt Parking)

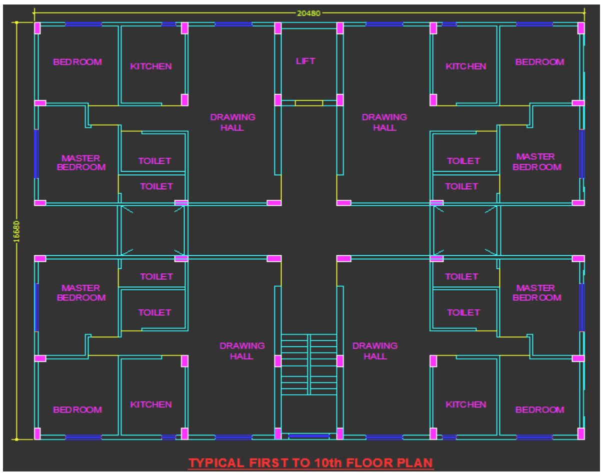


Fig. II Typical First To Tenth Floor Plan

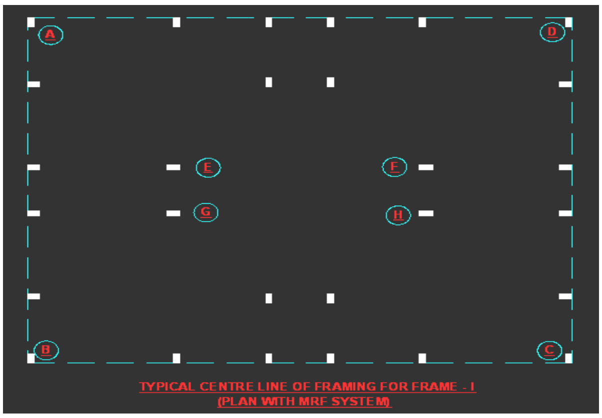


Fig. III Typical Framing for FRAME-I (Plan of Moment Resisting Frame)

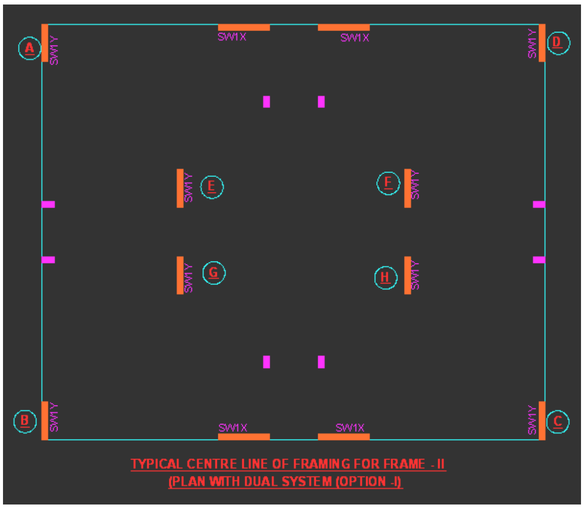


Fig. IV Typical Framing for FRAME-II (Plan with dual systems OPTION-1)

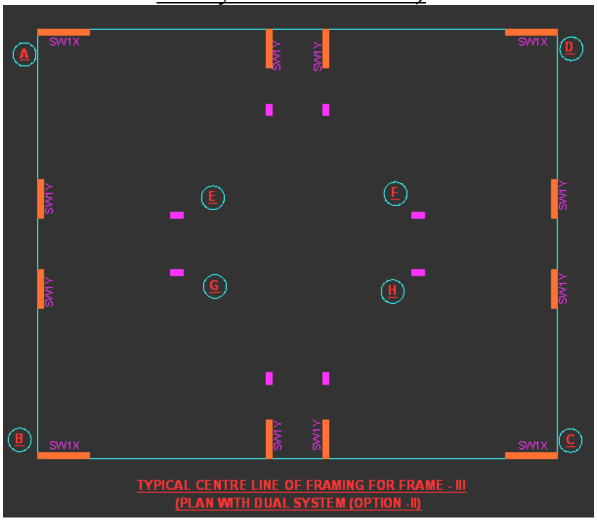


Fig. V Typical Framing for FRAME-III (Plan with dual systems OPTION-2)

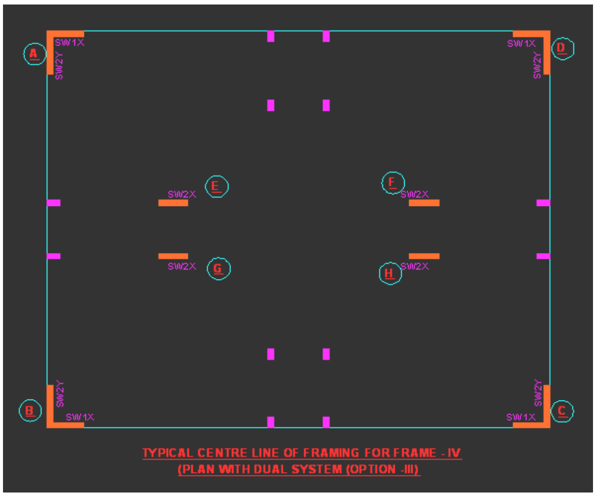


Fig. VI Typical Framing for FRAME IV (Plan with dual systems OPTION-3)

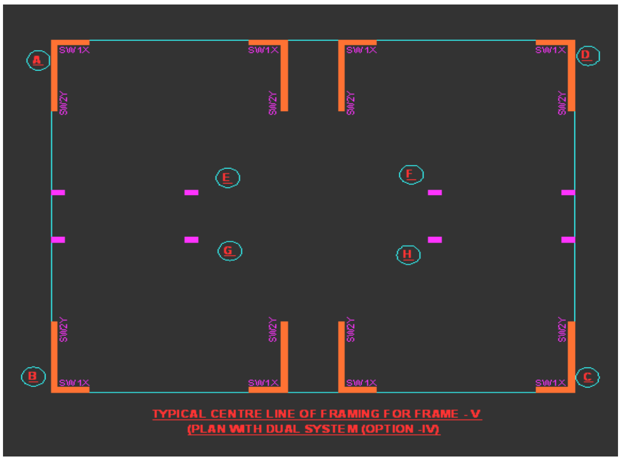


Fig. VII Typical Framing for FRAME V (Plan with dual systems OPTION-4)

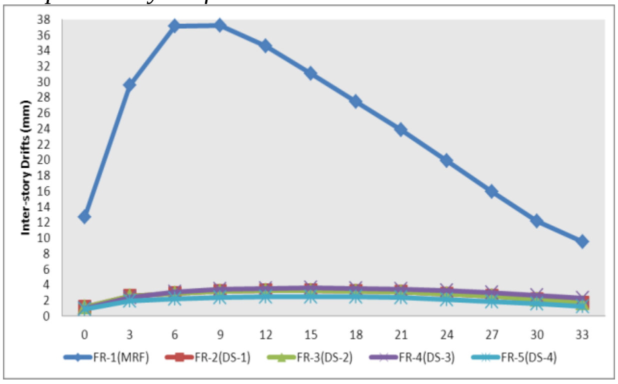
V. RESULTS & DISCUSSIONS

The variation of story drift, base shear, story deflection and time period is evaluated for all these models and compared with response spectrum method.

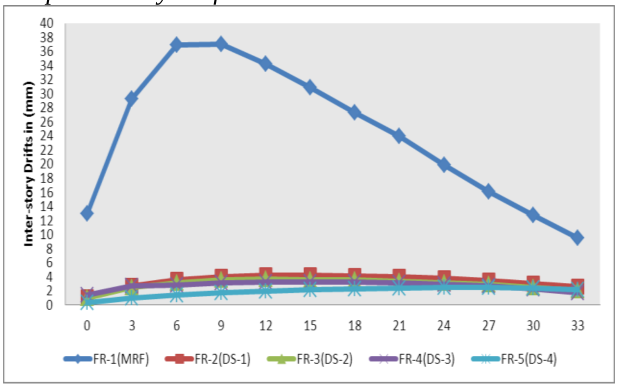
- Floor Levels VS Inter story Drifts

Following graphs displays variation in Inter storey drift for different floors/building heights. In these graphs bar graph shows values of storey drifts for bare frame (Frame-1) against floor levels, whereas, line graphs shows variation in drifts for all other structural framing systems.

Graph I: Story Drifts in X direction



Graph II: Story Drifts in Y direction



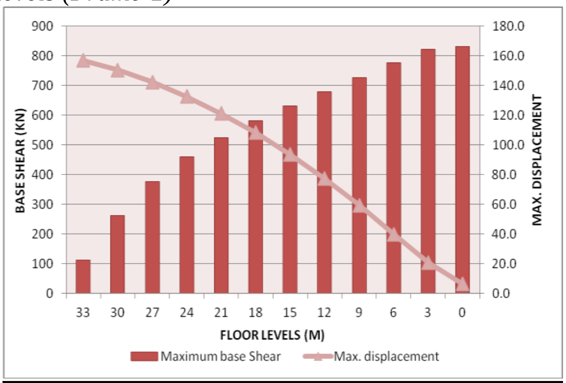
- <u>Story-wise Base shear VS Lateral Displacement.</u>

Following graphs & table displays variation in base shear & lateral displacement for different floors/building heights. In these graphs bar graph shows values of maximum base shear against floor levels, whereas, line graphs shows values of maximum displacement against floor levels.

Chart I: Story-wise Base shear VS Lateral Displacement

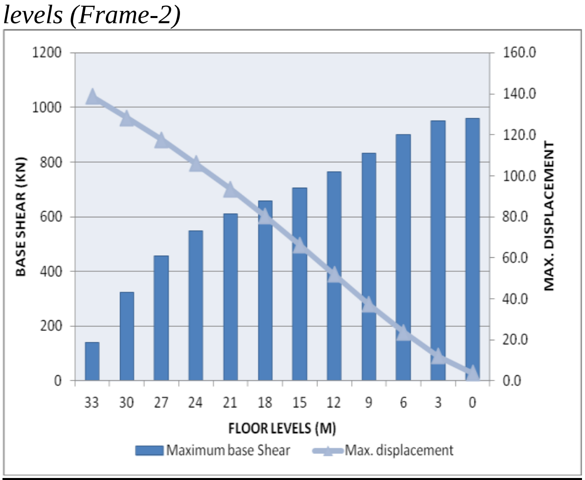
Story-wise base shear & corresponding displacement										
FRAMES	FRAME-I		FRAME-II		FRAME-III		FRAME-IV		FRAME-V	
	Vmax	Δmax	Vmax	Δmax	Vmax	Δmax	Vmax	Δmax	Vmax	Δmax
F. LEVEL	KN	mm	KN	mm	KN	mm	KN	mm	KN	mm
33	111.88	157.0	140.54	138.7	105.35	102.1	192.18	97.0	172.18	50.8
30	262.05	150.5	322.33	128.4	316.26	95.1	399.63	92.9	402.22	45.9
27	376.96	142.4	457.59	117.6	480.38	87.8	533.71	87.2	594.48	40.5
24	460	132.7	548.92	106.1	599.86	79.9	612.76	80.3	754.63	35.0
21	524.78	121.3	609.62	93.6	685.24	71.3	663.6	73.2	886.24	29.7
18	581.84	108.4	656.96	80.4	751.02	61.9	708.27	63.9	995.58	24.4
15	633.08	93.8	705.47	66.3	812.42	51.9	759.99	55.1	1091.31	19.3
12	679.54	77.5	763.77	51.9	879.35	41.5	826.72	46.1	1179.65	14.5
9	727.02	59.5	832.05	37.4	952.15	30.8	908.06	36.9	1260.91	10.1
6	777.97	40.2	899.89	23.8	1022.51	20.3	988.61	27.3	1331.59	6.3
3	822	20.9	950.22	12.1	1075.47	10.8	1045.97	17.2	1383.98	3.2
0	832.7	6.5	960.11	3.9	1085.74	3.5	1055.16	7.2	1394.15	1.1

Graph 3: Story Shear/Max. Displacement VS Floor levels (Frame-1)

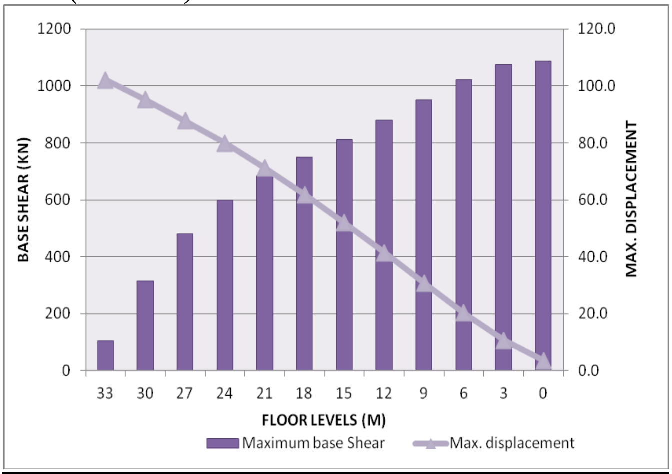


The parametric study to know base shear, story deflection, storey drift & time period in case of all models is performed here.

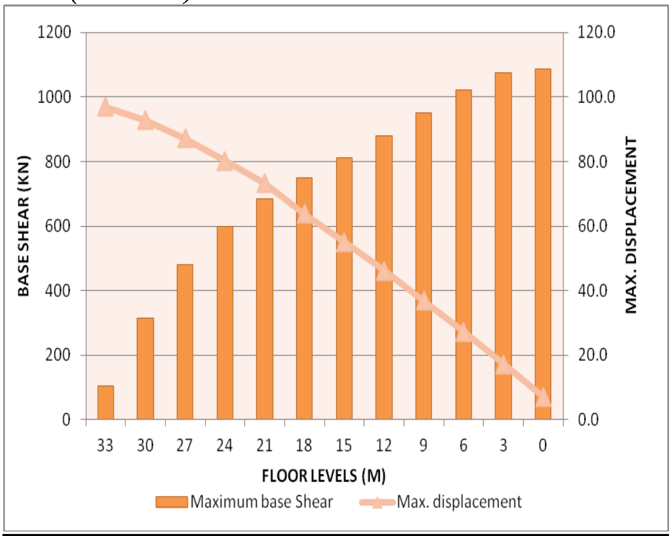
Graph 4: Story Shear/Max. Displacement VS Floor levels (Frame-2)



Graph 5: Story Shear/Max. Displacement VS Floor levels (Frame-III)



Graph 6: Story Shear/Max. Displacement VS Floor levels (Frame-IV)



Graph 7: Story Shear/Max. Displacement VS Floor levels (Frame-V)

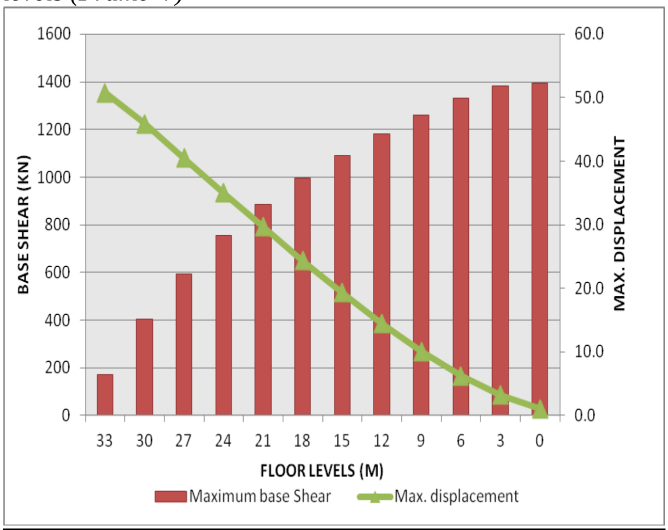
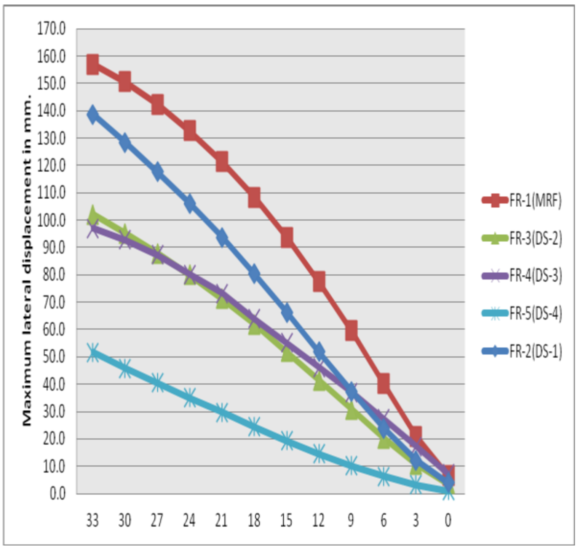


Chart 2: Comparison of Lateral displacement of Moment frame with other structural dual systems:

Comparison of lateral displacement in frame 1 with other lateral load resisting systems									
FRAMES	FRAME-I	FRAME-II	FRAME-III	FRAME-IV	FRAME-V	(Δ2-Δ1)/Δ2)*100%	(Δ3-Δ1)/Δ3)*100%	(Δ4-Δ1)/Δ4)*100%	(Δ5-Δ1)/Δ5)*100%
	Δ1max	Δ2max	Δ3max	Δ4max	Δ5max				
F. LEVEL	mm	mm	mm	mm	mm	%	%	%	%
33	157.0	138.7	102.1	97.0	51.6	-13.26%	-53.87%	-61.95%	-204.34%
30	150.5	128.4	95.1	92.9	45.9	-17.24%	-58.24%	-62.09%	-228.13%
27	142.4	117.6	87.8	87.2	40.5	-21.10%	-62.14%	-63.26%	-252.02%
24	132.7	106.1	79.9	80.2	35.0	-25.10%	-66.03%	-65.36%	-278.58%
21	121.3	93.6	71.3	73.2	29.7	-29.55%	-70.26%	-65.67%	-308.95%
18	108.4	80.4	61.9	63.9	24.4	-34.84%	-75.05%	-69.65%	-344.44%
15	93.8	66.3	51.9	55.1	19.3	-41.34%	-80.57%	-70.09%	-385.81%
12	77.5	51.9	41.5	46.1	14.5	-49.42%	-86.88%	-67.91%	-435.01%
9	59.5	37.4	30.8	36.9	10.1	-59.01%	-93.47%	-61.06%	-489.69%
6	40.2	23.8	20.3	27.3	6.3	-68.80%	-98.35%	-46.92%	-540.67%
3	20.9	12.1	10.8	17.2	3.2	-72.87%	-94.67%	-21.54%	-550.34%
0	6.5	3.9	3.5	7.2	1.1	-67.33%	-82.30%	10.45%	-515.14%

Graph 8: Maximum lateral displacement VS floor levels



VI. OBSERVATIONS & CONCLUSIONS

From the results of this work the following conclusions can be made:

- ❖ The base shear in frame V is the greatest as compared to other frames whereas moment frame shows least among all as the total dead load is less as compared to other frames.
- ❖ The lateral displacement in moment frame (Frame-I) is the greatest among the five lateral load resisting systems investigated. Amongst the lateral displacement in dual frames, frame V is the least while other frames have slightly higher values.
- ❖ Interstorey drift is greatest in moment frames and least in frame V amongst dual systems, in both directions as shown in graphs I and II.
- ❖ Among the building frames studied, the greatest interstorey drift occurred at the bottom third of the moment frames (i.e... maximum at floor levels II & III). For the all dual system frames the drift is greatest for the storeys located within the middle of the building height (i.e... maximum at floor levels V & VI).
- ❖ Around VIII specific nodes are also studied for all the frames & compared, amongst which frame I (Moment frame) shows maximum base moment as compared to other frames.
- ❖ In case of dual systems, frame IV shows least value of base moments & greatest value for support reaction, whereas frame II shows least value for support reaction.
- ❖ Nodal displacements at top story for these specific nodes are also studied & it is found that Moment frame (frame-I) shows highest displacement whereas frame V shows lowest.
- ❖ Frame-IV shows uniform displacement in both directions & is also within permissible limits.
- ❖ If all the parameters are taken into consideration to choose a safe, laterally stiff and economical frame then, frame IV of dual system is the most efficient solution.

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