International Journal of Scientific Engineering and Research (IJSER)
ISSN (Online) : 2347-3878
Impact Factor (2018) : 5.426

Dynamic Analysis of High Rise Buildings Using Conjugate Gradient Method

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Abstract: ***High rise buildings (tall building) investment projects represent a component of the country's economy power and a sign of advantage to the country. So many countries have sought to achieve their progress through encouraging preparation of comprehensive plans to establish high rise investment projects to prove its economic power & prestige. This paper is concerned with the dynamic analysis of high rise building. The dynamic analysis is carried out, considering the parameter affecting the response. These parameters include: the variation of plane dimension and the variation of building system. The analysis is carried out to determine the dynamic analysis of high rise building using conjugate gradient method that are used for the reinforced concrete buildings due to gravity loads and earthquake loads. With a various system for modeling the structure. These systems are rigid frame, frame with shear wall, frame with central core, bracing system, guyed frame. The used complete program is verified for static and dynamic analysis is carried out the basic modeling techniques and assumption are made by "Etabs" program and make verification between stiffness method and energy method in 3D modeling. Design is made according to the "UBC" code. The structure efficiency is measured by, structural period of vibration, and base shear values. the recommendation of the structural systems is based upon limiting the seismic drift of the structure, minimizing the cost of the seismic force resisting elements, and increasing the lateral stiffness. The analysis is done by Fortran program based on minimization of total potential energy of structure using the method of conjugate gradient [1]***

Keywords: high rise buildings, conjugate gradient method, dynamic analysis, elcentroo earthquake

1. Introduction

Energy method is a unifying approach to the analysis of both linear and non- linear structures. The analysis is based on minimization of total potential energy of structure using the method of conjugate gradient [2]. It is an indirect method of analysis and valid for all types of structures. The energy method is applied to the analysis on high rise building structures. Both geometric and material nonlinearities are directly incorporated within the formulation, thereby accounting for large displacement and strains as well as c configuration changes due to the structural response. [3]

The tallness of a structure is relative and cannot be defined in absolute terms either in relation to height or the number of stories. The council of Tall Buildings and Urban habitat considers building having 9 or more stories as high-rise structures [4]. But, from a structural engineer's point of view the tall structure or multi-storied building can be defined as one that, by virtue of its height, is affected by lateral forces due to wind or earthquake or both to an extent. Lateral loads can develop high stresses, produce sway movement or cause vibration [5]. Therefore, it is very important for the structure to have sufficient strength against vertical loads together with adequate stiffness to resist lateral forces. So lateral forces affected by wind or seismic loading must be considered for tall building design along with gravity forces. Tall and slender buildings are strongly wind sensitive [6]. The progress of structural system for high rise buildings is not an easy task. Where, as the height of the building increase the importance of lateral loads action and increase the acceleration rate. There are two types of lateral loads, wind and seismic loads. Seismic loads play a vital role in designing the high-rise buildings, which have lightweight skeleton that cause excessive horizontal movements for occupants.

The structural system of a high-rise building is more effective and suitable more than low rise building in cost, housing and architecture. As result, we face the concept of tall building or high-rise building. High rise building plays an important role in present days and in structure have slender nature and sensitive to dynamic loads such as wind and earthquake. The simplified model for the behavior of high rise building is vertical cantilever out of the ground. In this model, the movement of inertia is calculated of each vertical element such as core, shear walls and columns such the lateral system.

In the early structures at the beginning of 20th century, the structure members are assumed to design under gravity force only. Today, however, by the advanced of structural design systems, building weight is reduced, and the slenderness ratio of the building is increased, so it must be necessary to take into account the lateral forces at designing the high-rise buildings such as wind and earthquake loads.

Especially for the tall building we must considered the slenderness, which increase the flexibility, building suffer from lateral loads resulting from wind and earthquake. As a general rule, we must choose the more necessary and proper structure system for the building for resisting the lateral loads. Currently, there are many structural systems can be used for resisting the lateral loads of high rise buildings.

2. Applications

2.1 Basics

1) The analysis is carried out using UBC code for seismic elcentroo record by CG method for various systems.
2) The dynamic analysis is carried out using the conjugate gradient method by minimization of total potential energy [1].
3) Comparison between Building with different lateral stiffness systems to get economical and efficient lateral stiffness system.

2.2 Main assumptions for the analysis

- Material: concrete is used to behave linearly elastic material. The modulus of elasticity Ec will be taken as 4700 fc. where, the specified compressive strength of concrete fc is assumed equal to 35 mpa, are used in practical applications of tall buildings. The concrete cover will be taken 2 cm.
- Floor slab: slabs designed to be rigid in plane, with thickness equal to 20 cm in all models.
- Constraints: supporting bases of all the structural models are fixed supports.

Dynamic Properties of the lateral load" EL CENTRO Earthquake":
1) Output time step = 0.02sec.
2) Total time of earthquake =53.76sec.
3) Number of output time step = 2673.
4) Maximum time for dynamic analysis = 90 sec.
5) PGA=3.417m/sec2=0.35g at 2.14seconds.

2.3 Method of analysis TPE by C.G method

The total potential energy of a structure may be written as: [7]

$$W=U+V \quad (1)$$

Where U is the elastic or strain energy stored in the structure, and V is the potential energy of the loading. The TPE may also be expressed as:

$$W = U_f + U_p + V \quad (2)$$

Where: U_f is the strain energy stored in the flexural elements such as columns and beams, and Up is the strain energy stored in pin-jointed members and cables.

$$W = \sum_{n=1}^{f}\sum_{s=1}^{12}\sum_{r=1}^{12}\left(\frac{1}{2}\bar{x}_s k_{sr}\bar{x}_r\right)_n + \sum_{n=0}^{p}\left(U_o + T_o e + \frac{EA}{2L_o}e^2\right)_n - \sum_{n=1}^{N} F_n x_n \quad (3)$$

Where
F= number of flexural members;
P= number of pin- jointed members and cable link;
Xn=element displacement vector due to applied load only
Xs or xr=element of displacement vector of flexural member including the effect of pretension in the cables;
Ksr= element of stiffness matrix in global coordinate of flexural members;
U0=initial stain energy in a pin-jointed member or cable link due to pretension;
T0=initial force in a pin-jointed member or cable link due to pretension;
Δt= increment in force in a pin-jointed number or cable link due to applied load only;
Fn= element in applied load vector;
N= total number of degrees of freedom of all joints;
L0= the unstained initial length of pin-jointed members or cable link;
E= modulus of elasticity;
e=elongation of pin-jointed members or cable links due to applied load only; gradient vector [g]

$$[g_i]_n = \sum_{n=1}^{f_n}\sum_{r=1}^{12}\left(k_{sr}x_r\right)_n + \sum_{n=1}^{p_n}\left(T_0 + \frac{EA}{L_0}e\right)_n \left[\frac{\partial e_n}{\partial x_i}\right]_n - [F_i]_n \quad (4)$$

2.4 Verification example

TEZCAN [8] analyzed the space frame shown in fig. (1). he used a Newton Raphson iteration scheme to achieve the solution tangent to deflection curve. Table (1), (2) and (3) indicate a good agreement between TEZCANS work and present method. The result also showed that the proposed method is more efficient since the cable element has fourth order convergence during all iterations.

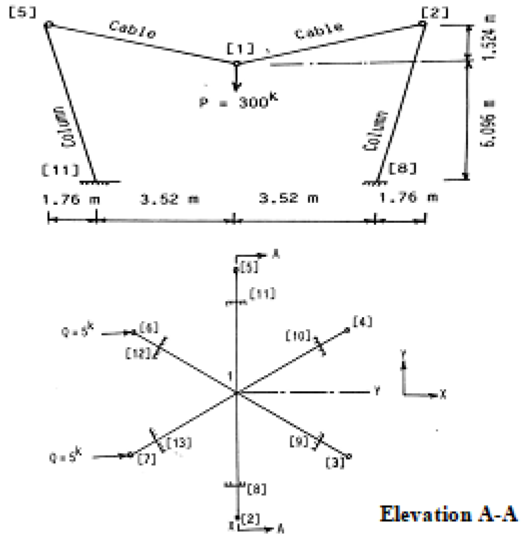

Figure 1: A Space frame data

Table 1: Properties of section used

columns	*cables*
IX=0.00275m4	I=0
IY=0.000982m4	A=0.00129m2
J=0.0000993m4	
A=0.08081m2	E=2.0682*1011N/M2

Table 2: Displacement for frame (TEZCAN) [8]

Joint Number	*Deflection in mm*				
	Cycle Number				
	Axes	1	2	3	4
1	Y	0.2761	0.2649	0.2819	0.2821
	Z	68.3730	52.9780	44.1498	43.3958
5	X	19.2854	17.9491	14.5446	14.3061
	Y	0	0.0124	0.0262	0.0278
	Z	4.4349	3.9072	3.2050	3.1468
6	X	9.0262	8.3378	6.5623	6.4351
	Y	17.3794	16.2306	13.3417	13.1394
	Z	4.4993	3.9638	3.2657	3.2075

Table 3: Displacement for frame, REF, [1]

Joint Number	*Deflection in mm*			
	Cycle Number			
	Axes	1	2	3
1	Y	0.2693	0.2818	0.2813
	Z	42.6980	43.2492	43.2356
5	X	14.1152	14.2931	14.2872
	Y	0.0220	0.0284	0.0281
	Z	3.2429	3.1439	3.1426
6	X	6.4934	6.4174	6.5623
	Y	12.8739	13.1342	13.1223
	Z	3.3078	3.2047	3.2022

2.5 Studied examples

Table 4: properties of seven various considered examples from Figure 2 to 8

Figure Number	*Height of towers m*	*No of stories*	*Dimension in plane cm*	*Slab thickness*	*Beam dimensions*	*Column dimension*	*Allowable stress*	*Type of tower*	*Note*
Fig. (2)	30	10	30*30	20 cm	40*40	50*50	35 mpa	R.C column	
Fig. (3)	120	40	36*42	20 cm	40*40	50*50	35 mpa	Shear wall t=30 cm	
*Fig. (4)	120	40	20*20	20 cm	S.I.B 300	S.I.B 300	35 mpa	Tower with bracing	
Fig. (5)	120	40	20*20	20 cm	40*40	50*50	35 mpa	Composite shear wall or core	
**Fig. (6)	120	40	20*20	20 cm	30*30	30*30	35 mpa	R.C tube system	
***Fig. (7)	120	40	20*20	20 cm	S.I.B 300	S.I.B 300	35 mpa	Guyed tower***	
***Fig. (8)	120	40	10*10	20 cm	S.I.B 300	S.I.B 300	35 mpa	Guyed tower ***	

*Steel material for column and beam with vertical bracing 2 angles 60*60*10 at each story, fall=2100t/cm2. ** R.C tube system
***cables (lower, middle and higher cables fixed at the floor of story no. 13, 26 and 40, respectively)

This study is focused about the following systems:

It contains:
Rigid frame systems;
1. Shear walled frame systems;
2. Central core frame systems;
3. Rigid frame with vertical bracing system;
4. Tubular system;
5. And Guyed frame; all analyzed towers have 10 and 40 stories.

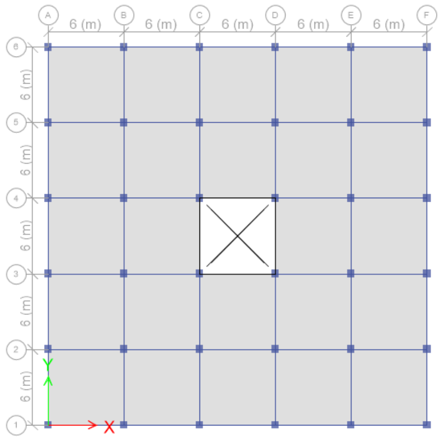

Figure 2: Ten stories reinforced concrete tower

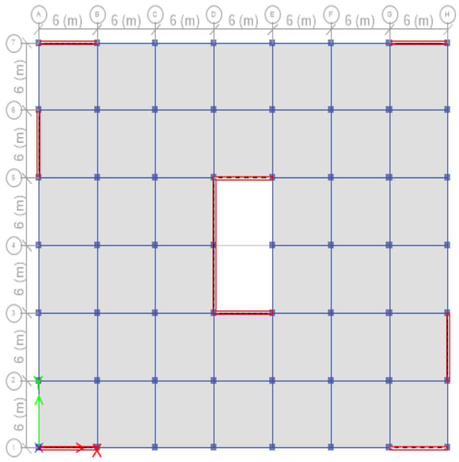

Figure 3: Forty stories reinforced concrete tower

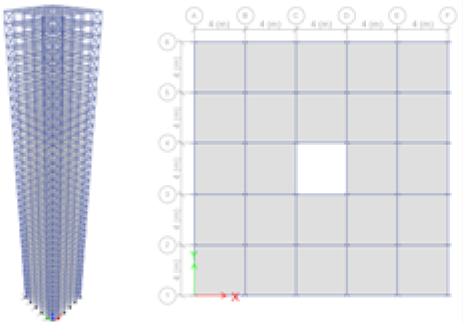

Figure 4: Forty steel structure with vertical bracing

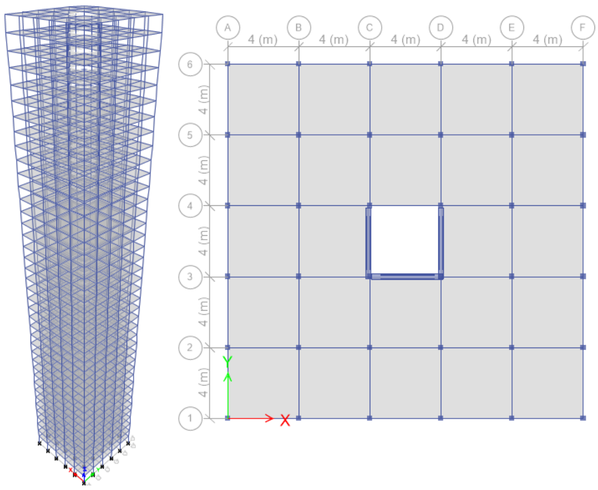

Figure 5: Forty reinforced concrete tower with central core

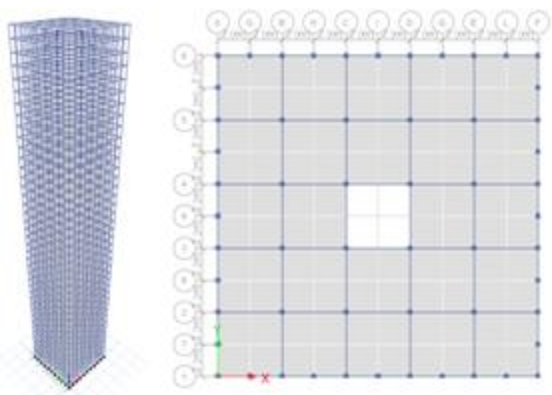

Figure 6: Forty reinforced concrete tube system

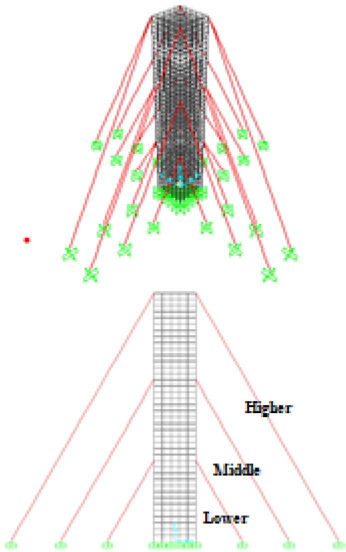

Figure 7: Forty guyed frame steel tower

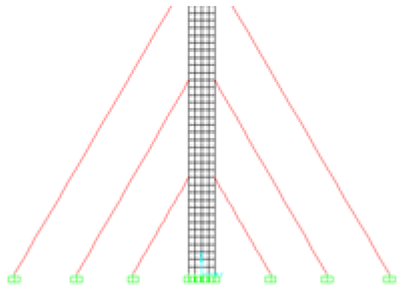

Figure 8: Forty guyed frame steel tower 10*10m

2.6 Cable properties in guyed frames

All cables in the structure are spiral cables with an outer diameter d=116mm, modulus of elasticity E=1472t/m2, steel area A=0.007862m2, own weight W=0.66t/m and minimum breaking load =1048.7ton.

The initial tension is assumed after many tried circle of solutions as 2% to 7% of minimum breaking force to satisfy the following:

- To avoid compression of any cable element during any lateral loads. And the initial tension is enough.
- To maintain the required shape during erection (9).

2.7 Loads

Gravity loads: the building weight and its content is considered in dead load and calculated based on material densities by the program. While the live load is taken as 0.2ton/m2.

Lateral load: the structure subject to record of elcentroo earthquake EL-CENTRO SITE IMPERIAL VALLEY IRRIGATION DISTRICIT (COMP S00E) and the record values at equal time step 0.02 sec. making time history analysis of the models by using this record using sap 2000.

3. Damping

For our models, a constant 5 percent proportional damping was assumed, which is a reasonable assumption for concrete structures [10].

For cables:
The initial tension of cable in the first modeling fig (7) is taken as (31tons, 42tons, 63 tons) which present (3%, 4%, 6% of maximum breaking loads) respectively. The initial tension of cables on the last model is in fig (8) taken as (21tons, 52tons, 73 tons) which present (2%, 6%, 7% of maximum breaking loads) respectively.

4. Types of proposed analysis

Studying the static analysis of model one which have 10 stories under own weight and gravity loads .and make the correlation between the energy method and stiffness method.
Studying the dynamic analysis of the other models which have 40 stories under the action of earthquake load and provide the lateral stiffness element such as core and shear walls.

In dynamic analysis the following parameter are taken in to consideration:

Effect of decreasing area of structure the results showed that adding additional lateral stiffness element or using other systems as shown in the results.

Studying the dynamic analysis of slender building and using bracing systems and tubular system.

Modeling the slender structure with cables as known guyed frame structure

Effect of initial tension of cables. The results showed that: An increasing the initial tension in cables, the lateral movement of the structure and deflection decrease.

For this study the initial force is taken as (3%, 4%, 6%) of breaking force for and (2%, 6%, 7%) for model in fig (7), fig (8) respectively.

5. Analysis of results

The static and dynamic analysis of high rise building subject to earthquake is carried out .it can be summarized that:

The static analysis which carried out by stiffness method and energy method have the same results with small variance less than1% as shown in Figs (8) to figs (13).

As shown in fig (3) the reinforced concrete tower with height 120m subject to elcentroo earthquake load the tower must provided with additional lateral stiffness element to decrease the response.

The response of example 3 in fig (3) which are story displacement, inter story drift, overturning moment, base shear, acceleration and base moment from figs (15) to fig (20) respectively.

As shown in figs from (21) to (24) the comparison of the systems due to their response to evaluate the most proper system.

The lateral displacement of guyed frame system at height 120m is equal 0.05m and the other systems their displacement nearly from 0.3 to 0.4m.

The guyed frame system is more effective system using in high rise building to resist the lateral loads due to its small value of response.

The structure weight of guyed frame system is lighter than frame with vertical bracing, frame with core and tube system as shown in fig (27).

In dynamic analysis of guyed frames in fig (7), (8) the following parameter are taken in to consideration:
The effect of changing the initial tension in cables from 2% to 7% of the breaking force it’s noticed that an increase in the initial tension in cables increases the maximum stresses in members and the final tension in cables. On the other hand, the lateral sway of building and the vertical deflection decrease with increasing the initial tension. in this study increasing the initial tension of lower cables from 2% to 3% and other cable in two other levels remain constant the final tension in this cable increase from 53 ton to 56 ton as shown in fig (26).

For this study initial tension of cables is fixed at 3%, 4%, 6% of maximum breaking loads for the lower, middle, higher cables respectively in model shown in fig (7).

In this study case dimensions are reduced by half shown in fig (8), it would provide with cables with higher initial tension from 4%, 6% in middle and higher cables to 5%, 7%respectively as shown in fig (35).

The normal force of model in fig (8) as shown in fig (36) Varying the inclined angle of cables affected the response of the structure referenced in fig (30), fig (31), fig (32), fig (33).

Decreasing the inclines angles where all parameter remains constant cause to increasing the final tension in cables and increasing the stress in members in fig (30) to fig (33). For this study case the best inclined angles of cables =30 degree.

The guyed frame system has the least period of vibration and the maximum frequency than other system as shown in fig (28), fig (29).

6. Conclusion

The analysis of results of high rise building in this research, has led to the following conclusion:

The analysis which carried out showed the correlation between FEM, CGM the variance between them less than one percent

Under the seismic loads, when the heights of the structure increase, the lateral deflection and overturning moment increase.

When increasing the height of the structure the volume of concrete used is increased.

High rise buildings require additional material in order to limit the lateral deflection and overturning moment.

The stiffness and stability requirement become very important factor in designing the high-rise buildings.

The guyed frame system has response less than the other systems mentioned above.

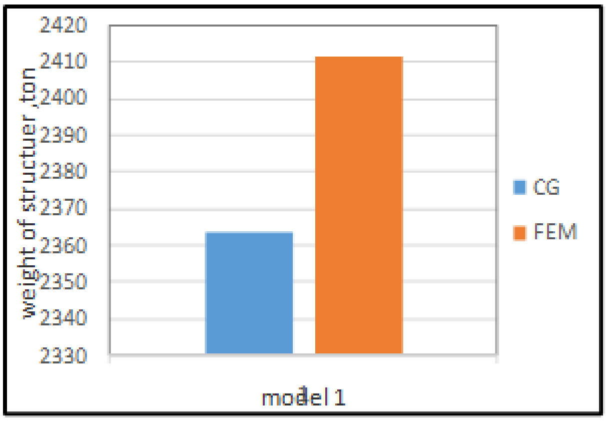

Figure 9: shows the base reaction (example 2)

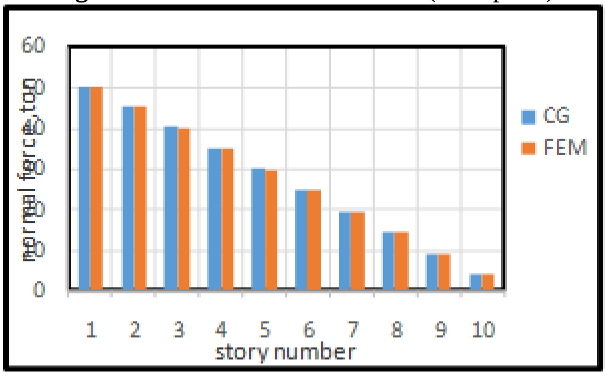

Figure 10: shows the normal force on col at x=0m, y=0m example 2

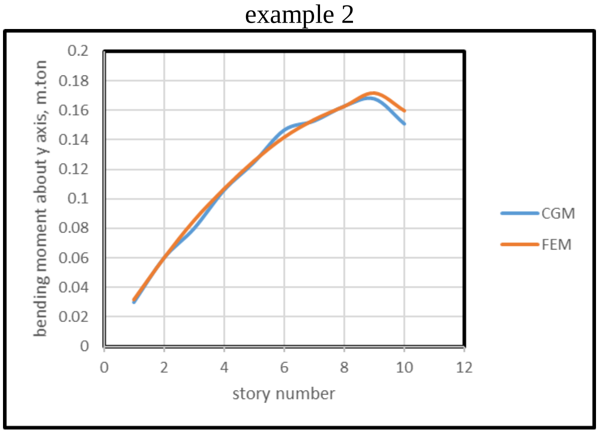

Figure 11: shows the member moment at x=0m, y=0m example 2

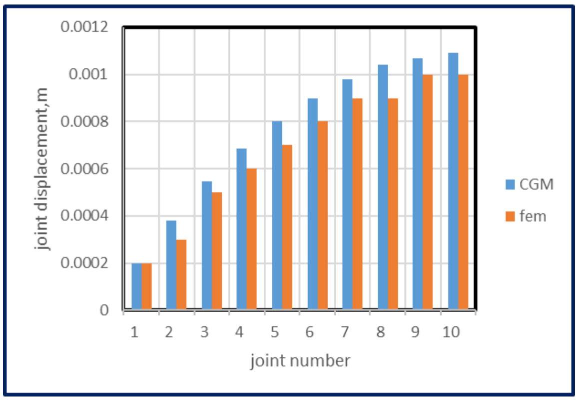

Figure 12: shows the joint displacement at x=0m, y=6m example 2

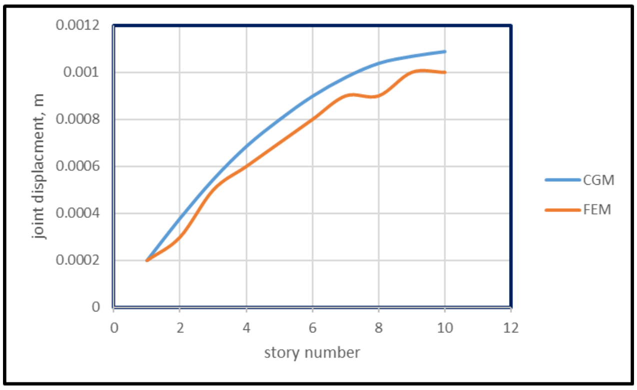

Figure 13: shows the joint displacement at x=6m, x=0m example 2

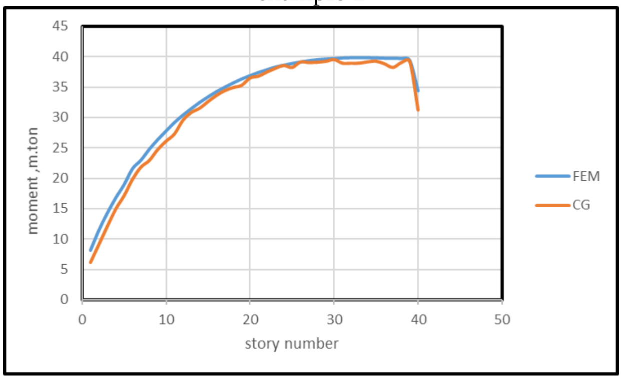

Figure 14: shows the moment of the horizontal members at x=0m, y=0m at each floor level example 3

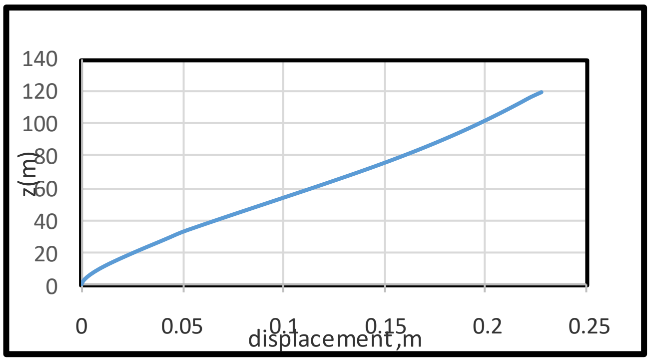

Figure 15: shows the maximum story displacement due to elcentroo earthquake at x=0m, y=0m example 3

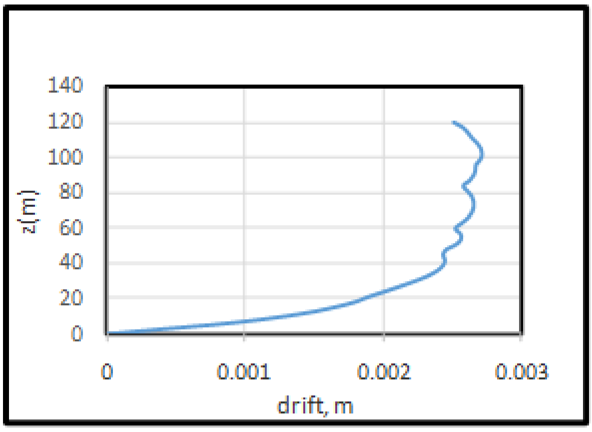

Figure 16: shows the inter story drift at each floor due to elcentro earthquake for example 3At x=0m, y=0m

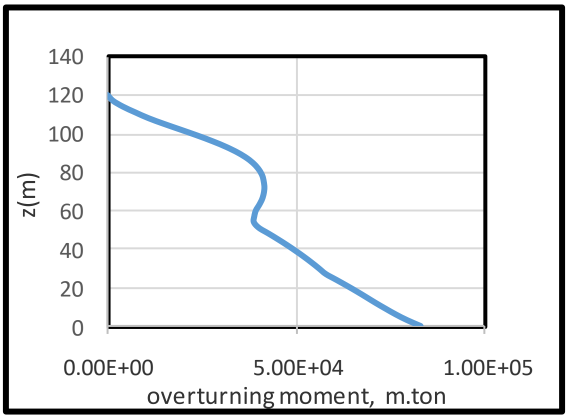

Figure 17: shows the overturning moment each floor due to elcentro earthquake example 3 at x=0m, y=0m

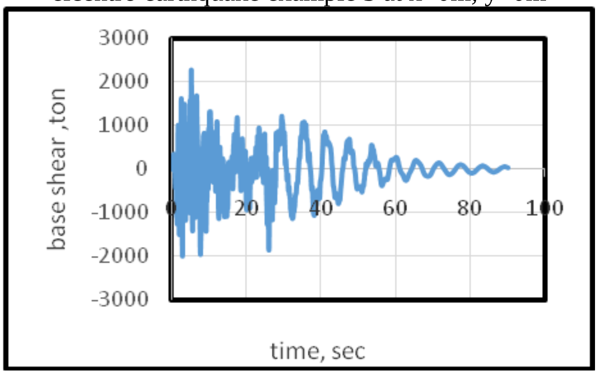

Figure18: shows the base shear due to elcentroo zearthquake example 3

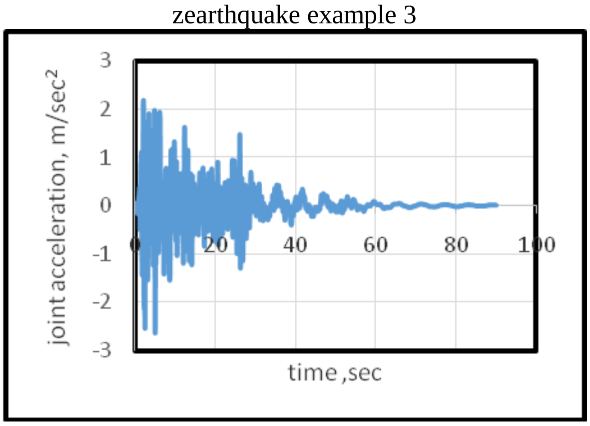

Figure 19: shows the joint acceleration at each time step due to elcentro earthquake of example 3 at x=0m, y=0m, z=120m

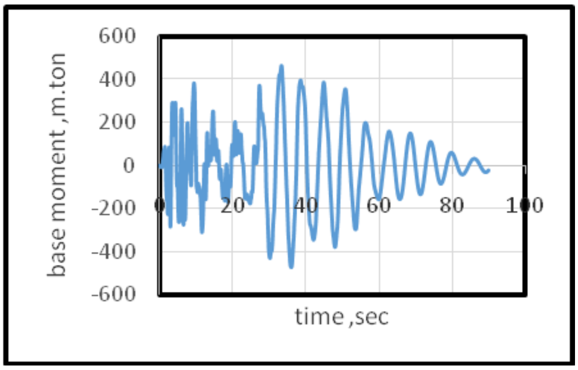

Figure 20: shows the base moment due to elcentroo earthquake example 3

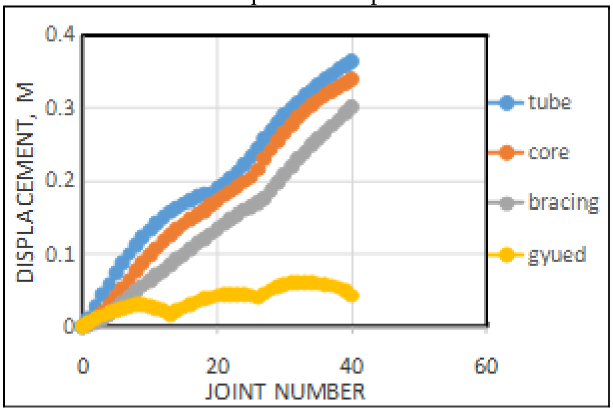

Figure 21: shows the comparison of joint displacement of examples (4, 5, 6, 7)

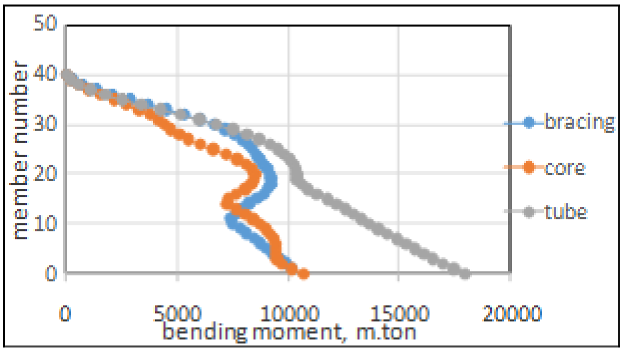

Figure 22: shows the overturning moment in examples (4, 5, 6)

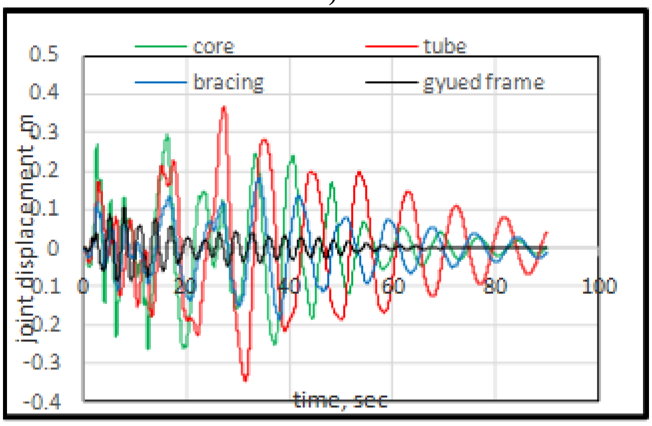

Figure 23: shows the joint displacement at x=0m, y=0m, z=120m for examples from (4, 5, 6, 7)

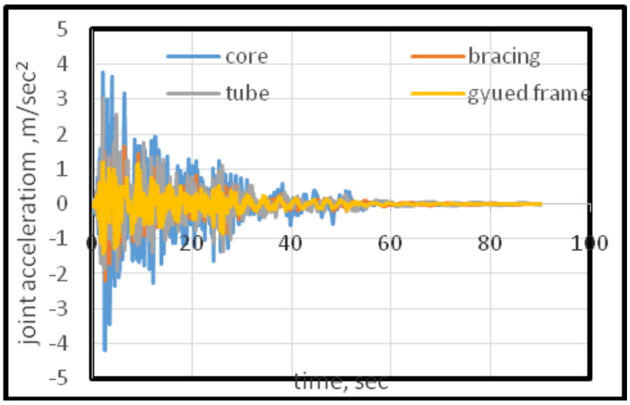

Figure 24: shows the joint acceleration for examples (4, 5, 6, 7) at x =0m, y=0m, z=120m

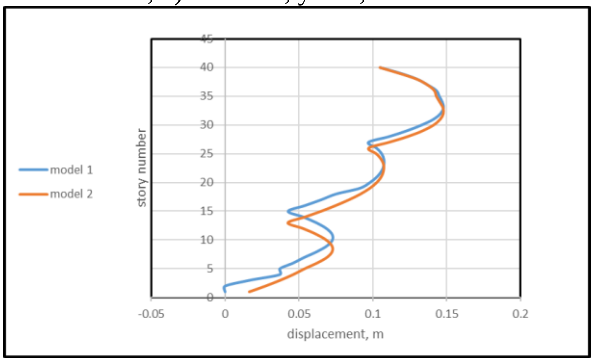

Figure 25: shows the lateral displacement for guyed frame example (7) with varying the initial tension of lower cable

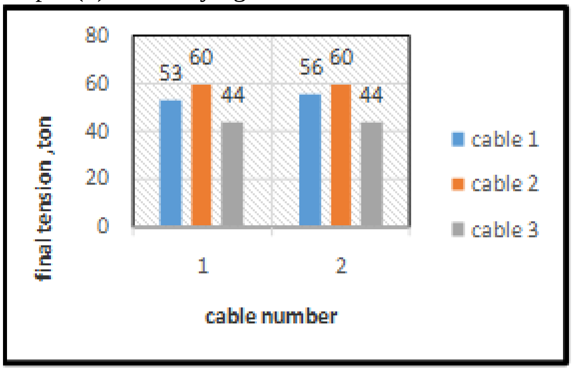

Figure 26: shows the final tension in cables in example 7 with increasing initial tension of lower cables

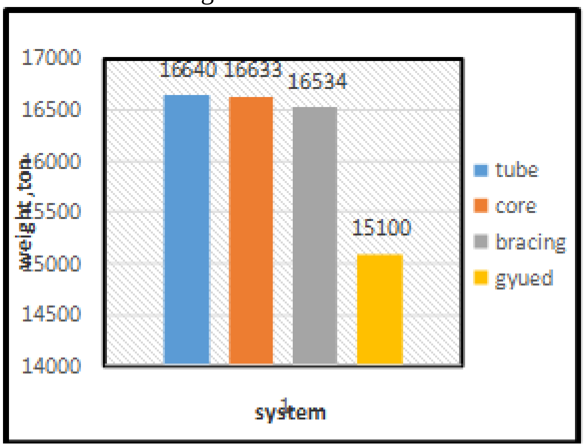

Figure 27: shows the weight of structure of system in example (4, 5, 6, 7)

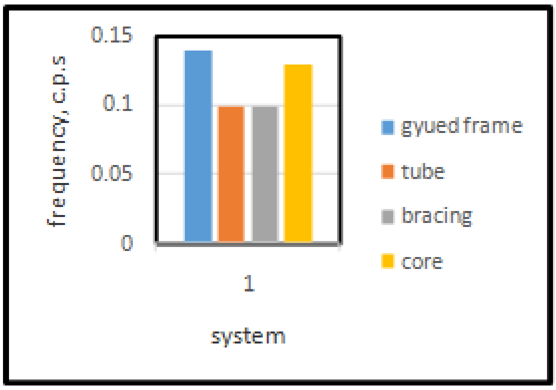

Figure 28: shows the structure frequency of system in example (4, 5, 6, 7)

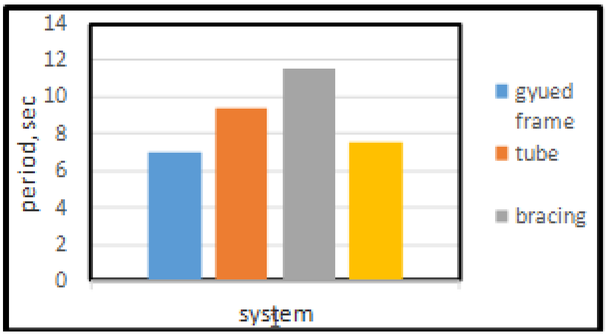

Figure 29: shows the structure period of system in example (4, 5, 6, 7)

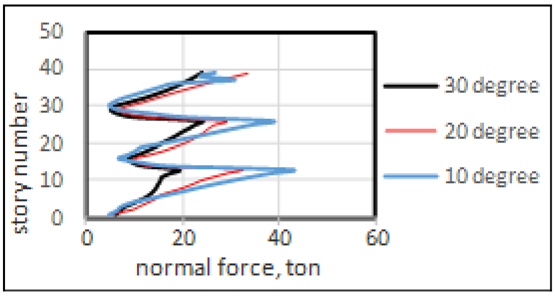

Figure 30: shows the normal force of vertical members at x=0m, y=0m in example (7)

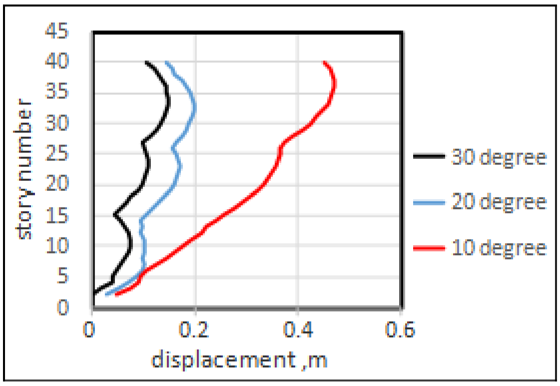

Figure 31: shows the lateral displacement of guyed frame for example (7) at x=0m, y=0m

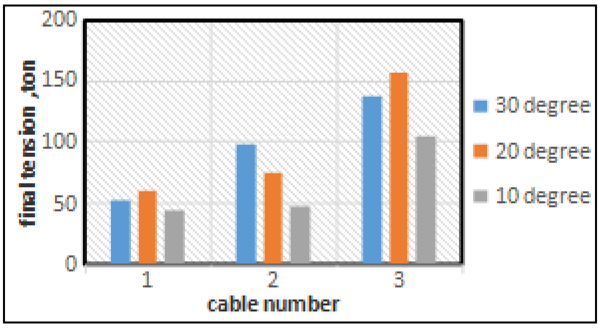

Figure 32: shows the final tension in cables between for example (7)

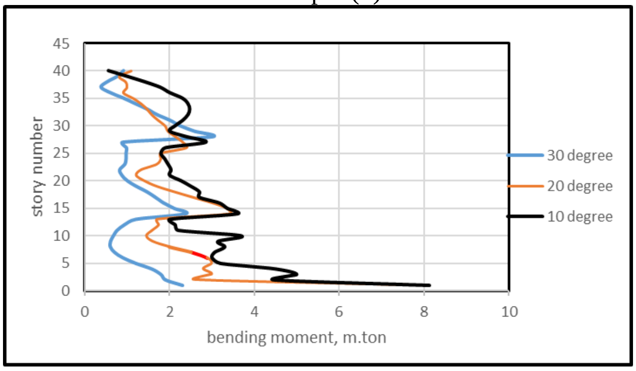

Figure 33: shows the bending moment of vertical members at x=0m, y=0m in guyed frame example (7)

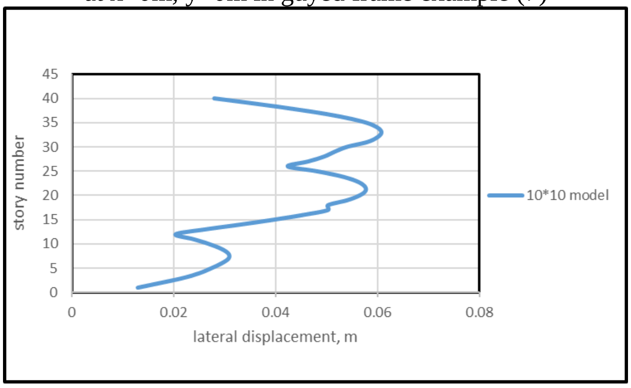

Figure 34: shows the lateral displacement of joints at each story level for example (8) at x=0m, y=0m

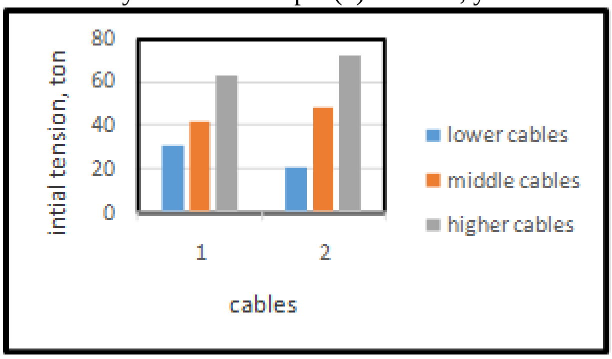

Figure 35: shows the initial tension on cables of example (7), (8) respectively.

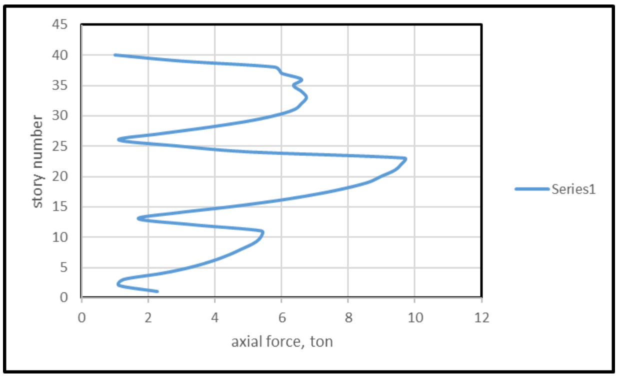

Figure 36: shows the normal force of vertical members at x=0m, y=0m in model (8)

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