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Dynamic Analysis of High Rise Buildings Using Conjugate Gradient Method

Malini B

India

Abstract Investment projects involving high-rise structures (tall buildings) are an indication of economic strength and a boon to the nation. Many nations have tried to advance economically by promoting the development of elaborate plans to build skyscraper investment projects as a symbol of their strength and status. The dynamic study of tall buildings is the focus of this article. Taking into account the response-influencing parameter, the dynamic analysis is performed. Parameters such as these include changes in construction systems and variations in plane dimensions. Because reinforced concrete buildings are subject to both gravitational and seismic stresses, it is necessary to conduct dynamic analyses of these structures utilizing the conjugate gradient technique. With a varied system for modeling the structure. The various solutions include a guyed frame, a central core frame, a rigid frame, and a frame with a shear wall. Verification of the "Etabs" program's core modeling methodologies and assumptions, as well as verification of the relationship between the stiffness method and the energy method in 3D modeling, are all part of the program's verification process for static and dynamic analysis. The "UBC" code is followed throughout the design process. The structural period of vibration and base shear values are indicators of the structure's efficiency. Based on decreasing the cost of the seismic force resisting parts, boosting the lateral stiffness, and limiting the structure's seismic drift, the structural solutions are recommended. A Fortran software with the goal of minimizing the structure's total potential energy by use of the conjugate gradient technique conducts the simulation [1].

Keywords: High-rise constructions, conjugate gradient approach, dynamic analysis, and the El Centroo earthquake

1. Introduction

The energy technique provides a common framework for studying non-linear and linear processes alike. Conjugate gradient minimization of the structure's total potential energy is the basis of the study [2]. All kinds of structures may benefit from this indirect way of study. Structures of tall buildings are analyzed using the energy approach. To account for massive displacements and stresses and major configuration changes caused by the structural reaction, the formulation directly incorporates both geometric and material nonlinearities. the third

No matter how many floors or how tall a building is, its height is relative and cannot be measured in absolute terms. A high-rise structure is defined by the Council on Tall Buildings and Urban Habitat as one with nine floors or more [4]. However, according to structural engineers, a tall building or multi-story structure is one that is susceptible to lateral stresses from wind, earthquakes, or both to a certain degree because of its height. Extreme strains, swaying, or tremor may result from lateral loads [5]. For this reason, the structure must be both stiff enough to resist lateral stresses and strong enough to withstand loads acting vertically. In designing tall buildings, it is necessary to take into account not only the forces of gravity but also the lateral forces caused by wind or seismic loading. Slender, tall structures are more vulnerable to wind damage [6]. It is not a simple undertaking to advance the structural systems of high-rise structures. In this case, the acceleration rate is directly proportional to the building's height since lateral stresses act with increasing significance. Wind loads and seismic loads are the two main categories of lateral forces. Designing high-rise structures using lightweight materials is crucial due to seismic stresses.

bones that make people sway too much in all directions at once.

From a financial, housing, and architectural standpoint, high-rise buildings are preferable than low-rise ones due to their superior structural systems. The idea of a high-rise or towering structure therefore emerges. Modern society relies heavily on tall buildings, which are vulnerable to dynamic stresses like earthquakes and wind because of their thin construction. A high-rise building's simplified behavior model is a vertical cantilever that extends from the ground upwards. The lateral system, core, shear walls, and

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columns all have their inertia movements computed in this model.
The members of the early buildings of the twentieth century were said to have been designed only under the pull of gravity. Modern structural design technologies have made it possible to lower building weight while increasing the slenderness ratio; as a result, while constructing high-rise structures, it is essential to consider lateral pressures like wind and seismic loads.
Buildings, especially tall ones, are vulnerable to lateral stresses caused by wind and earthquakes, thus it's important to keep their slenderness in mind. It is standard practice to choose the building's most appropriate structural system in order to withstand lateral loads. There are a variety of structural methods available today that can withstand the lateral stresses experienced by tall structures.

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]

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

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:

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

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.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]

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

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.

f 12

(3)

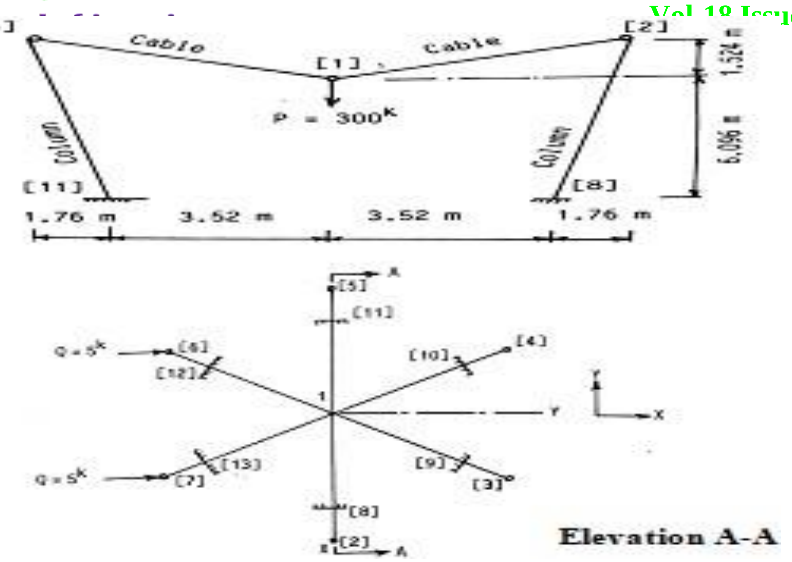

Table 1: Properties of section used

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:

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

Displacement for frame (TEZCAN) [8]

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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

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.

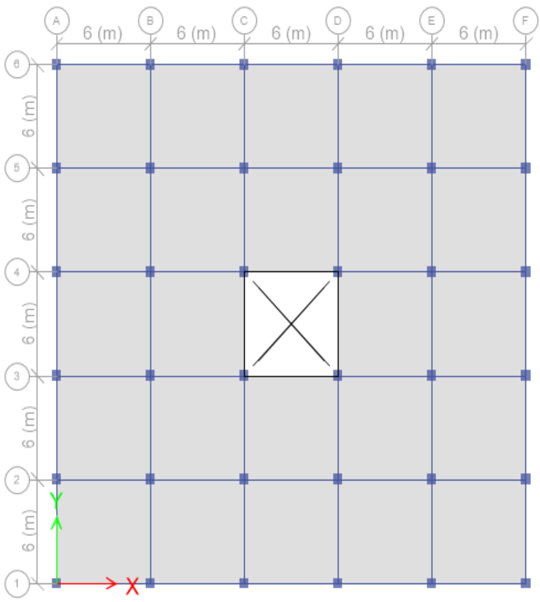

Figure 2: Ten stories reinforced concrete tower

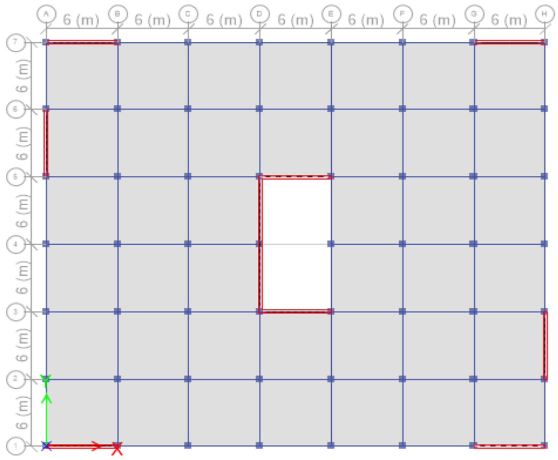
A
B
C
D
E
F
G
H
6 (m)
6 (m)
6 (m)
6 (m)
6 (m)
6 (m)
6 (m)
7
6
5
4
3
2
1

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Figure 3: Forty stories reinforced concrete tower

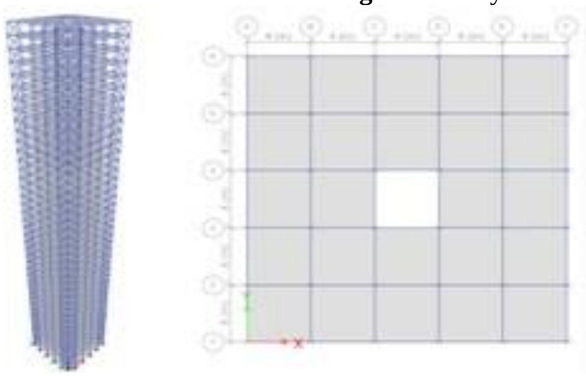

Figure 4: Forty steel structure with vertical bracing

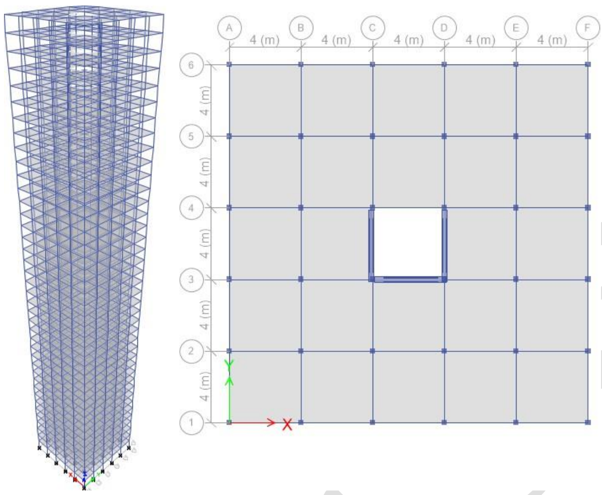

Figure 5: Forty reinforced concrete tower with central core

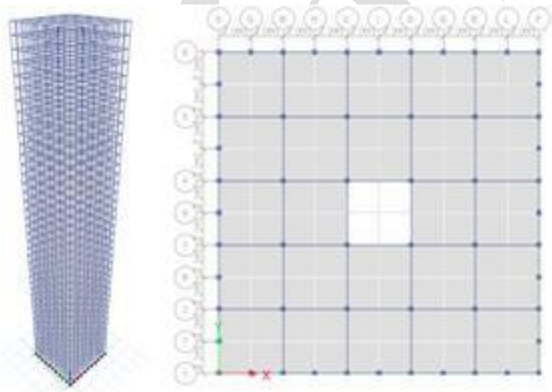

Figure 6: Forty reinforced concrete tube system

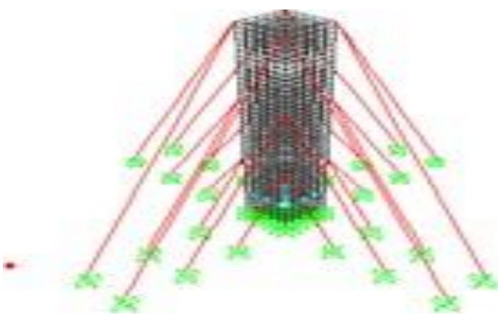

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Figure 7: Forty guyed frame steel tower

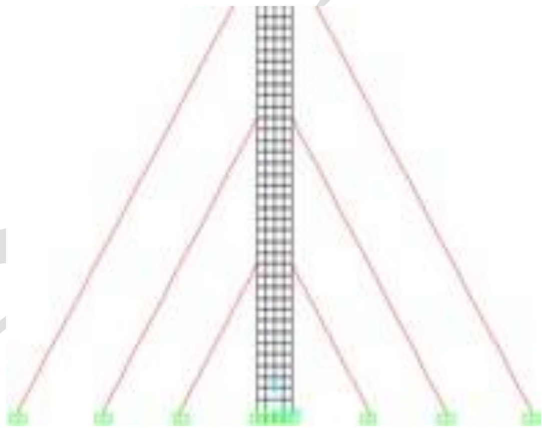

Figure 8: Forty guyed frame steel tower 10*10m

2.5 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).

2.6 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, baseshear, 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.

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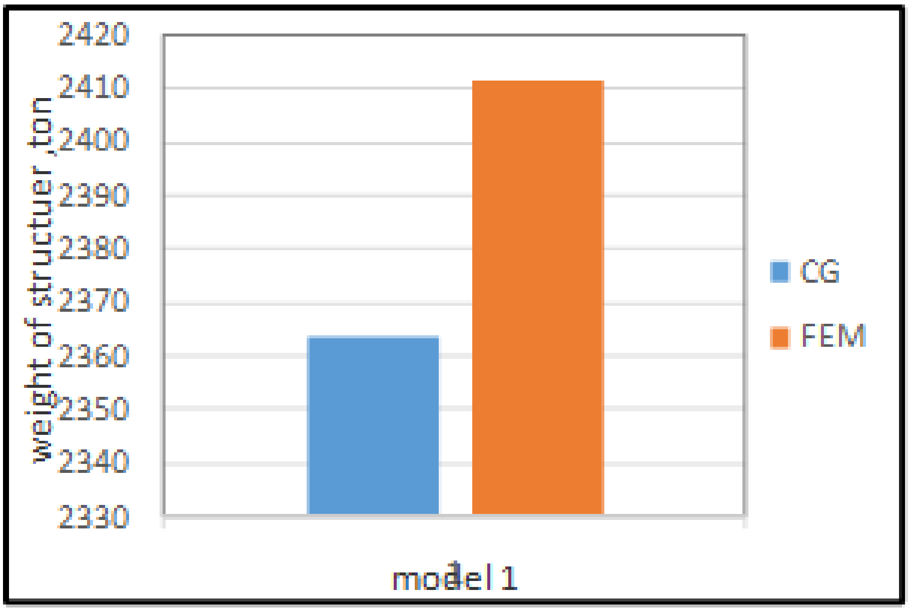

Figure 9: shows the base reaction (example 2)

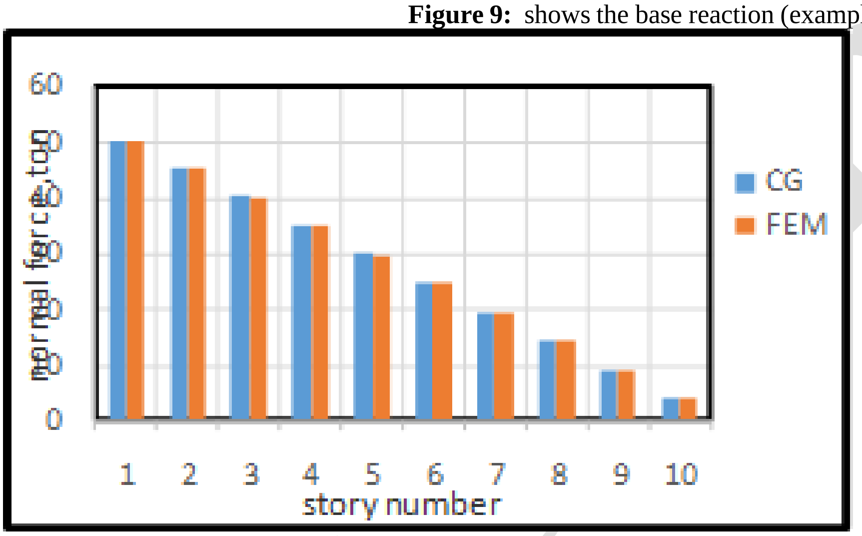

Figure 10: shows the normal force on col at x=0m, y=0m example 2

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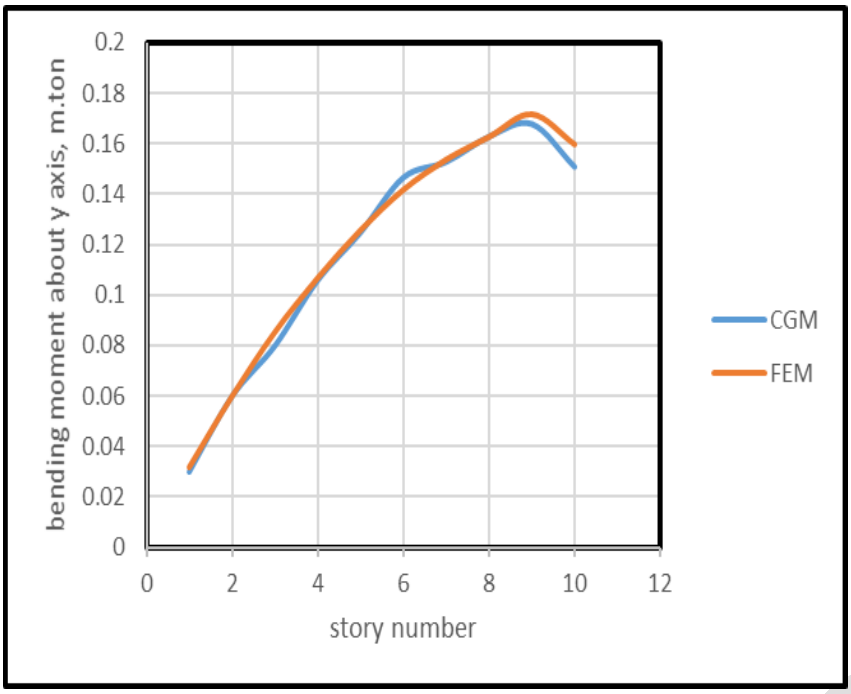


Figure 11: shows the member moment at x=0m, y=0m example 2

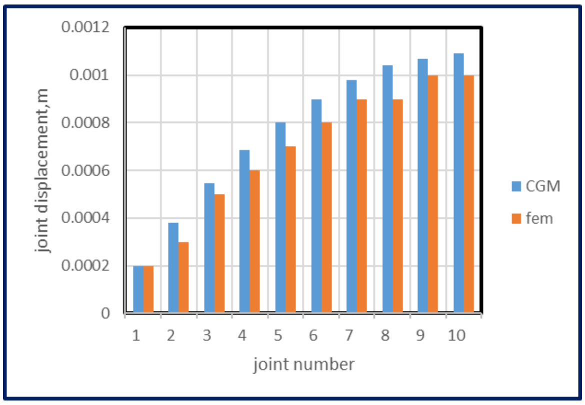


Figure 12: shows the joint displacement at x=0m, y=6m example 2

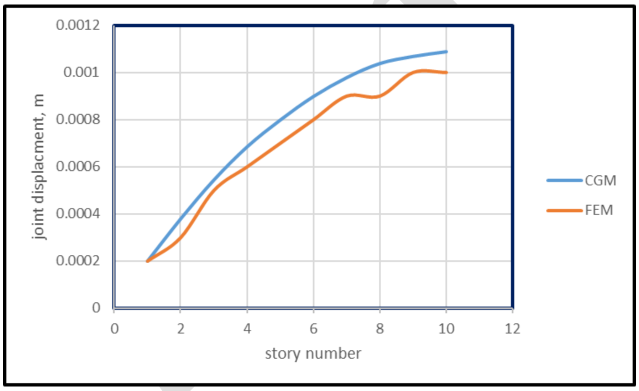


Figure 13: shows the joint displacement at x=6m, x=0m example 2

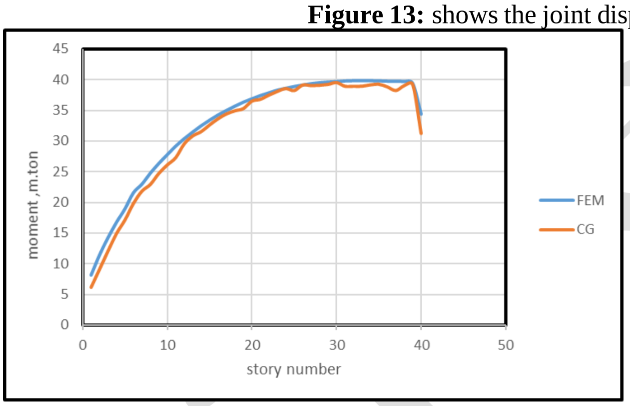
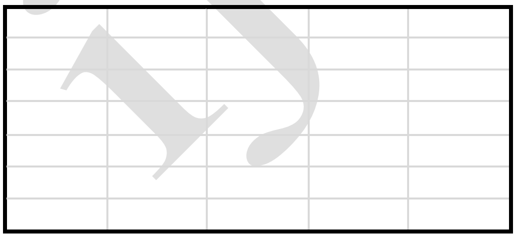


Figure 14: shows the moment of the horizontal members at x=0m, y=0m at each floor level example 3



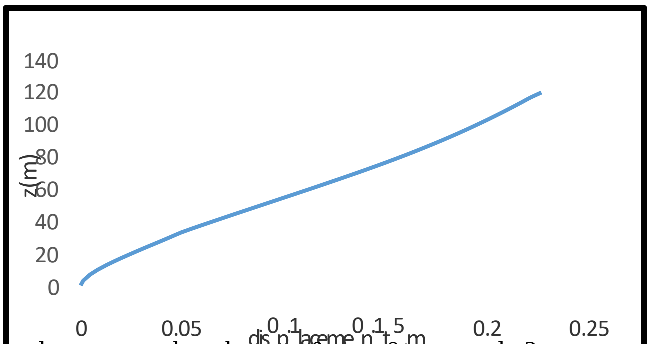


Figure 15: shows the maximum story displacement due to elcentroo earthquake at x=0m, y=0m example 3

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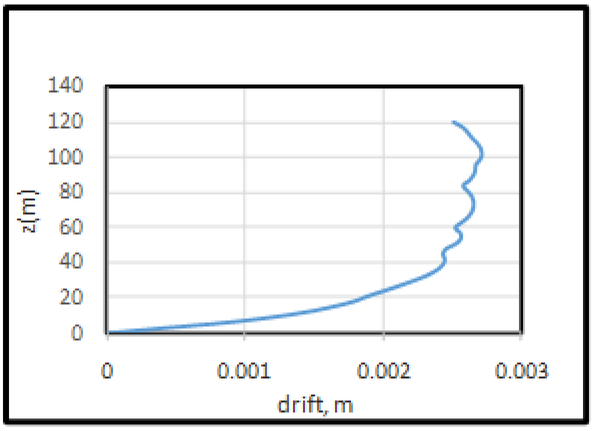

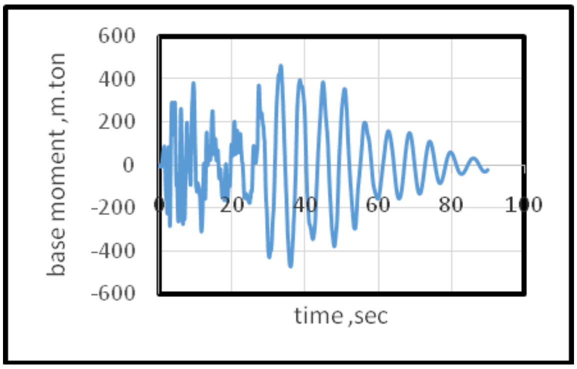

Figure 16: shows the inter story drift at each floor due to elcentro earthquake for example 3At x=0m, y=0m

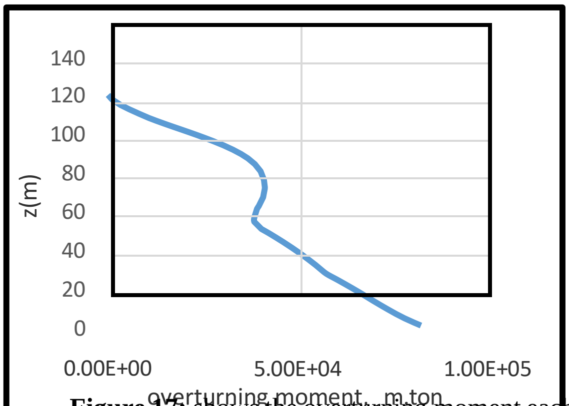

Figure 17: shows the overturning moment each floor due to elcentro earthquake example 3 at x=0m, y=0m

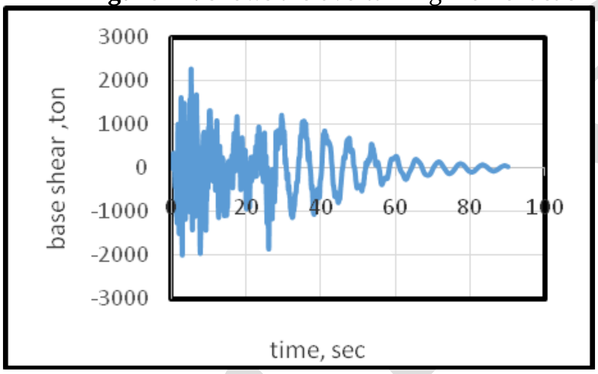

Figure18: shows the base shear due to elcentroo zearthquake example 3

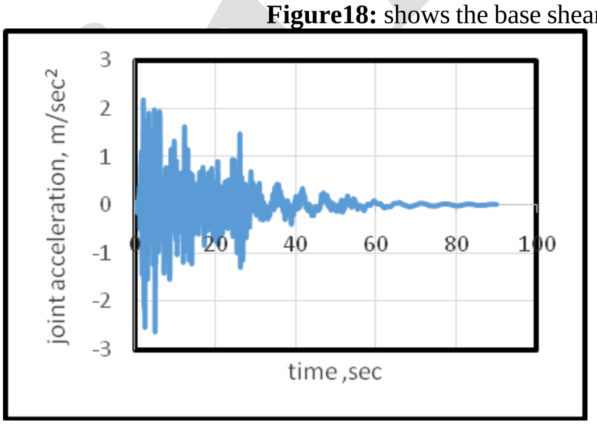

Figure 19: shows the joint acceleration at each time step due to elcentro earthquake of example 3 at x=0m, y=0m, z=120m

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

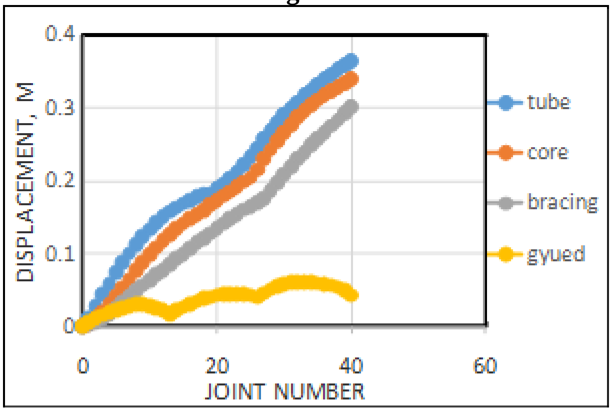

Figure 21: shows the comparison of joint displacement of examples (4, 5, 6, 7)

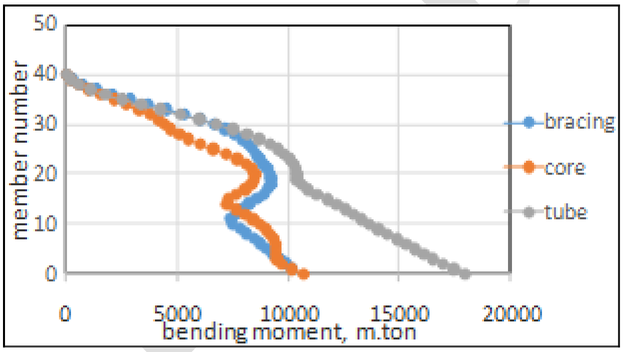

Figure 22: shows the overturning moment in examples (4, 5, 6)

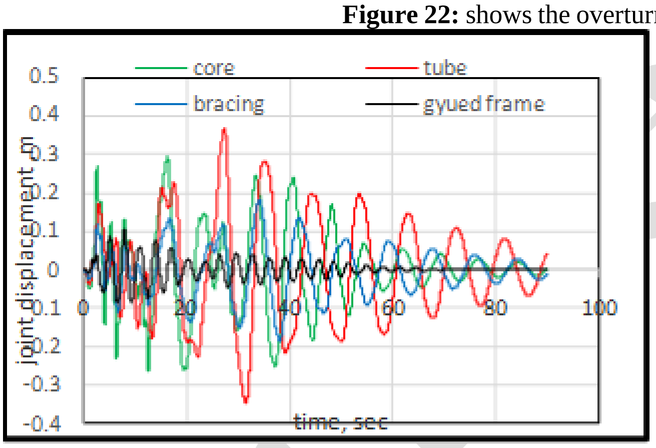

Figure 23: shows the joint displacement at x=0m, y=0m, z=120m for examples from (4, 5, 6, 7)

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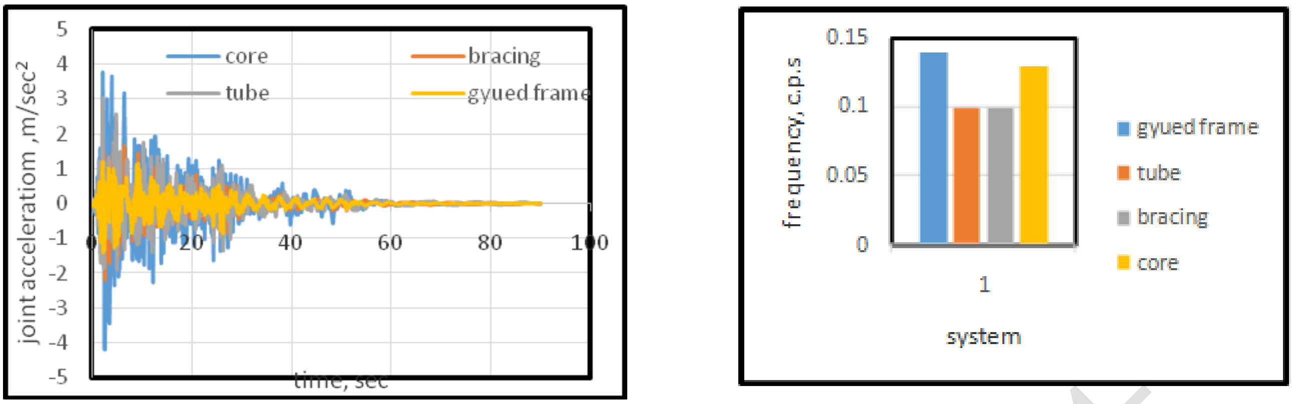

Figure 24: shows the joint acceleration for examples (4, 5, 6, 7) at x =0m, y=0m, z=120m

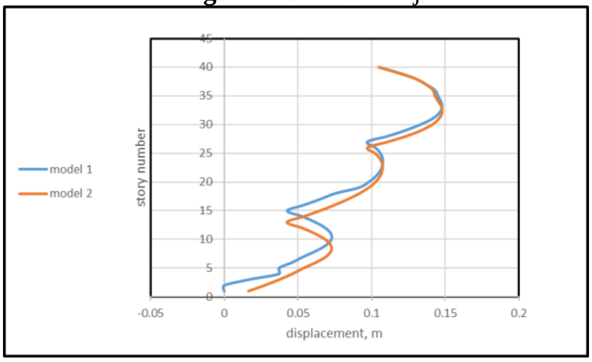

Figure 25: shows the lateral displacement for guyed frame example (7) with varying the initial tension of lower cable

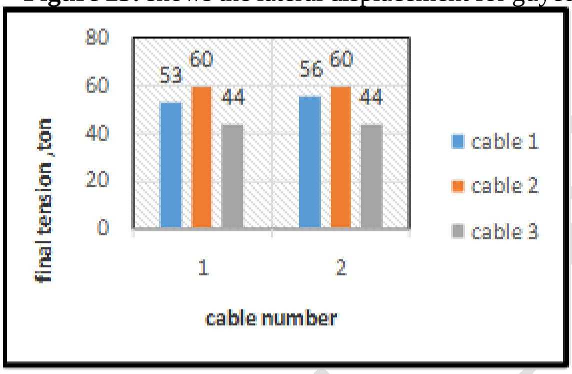

Figure 26: shows the final tension in cables in example 7 with increasing initial tension of lower cables

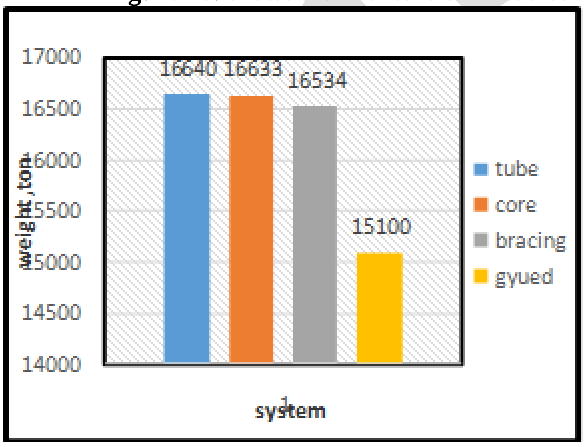

Figure 27: shows the weight of structure of system in example (4, 5, 6, 7)

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

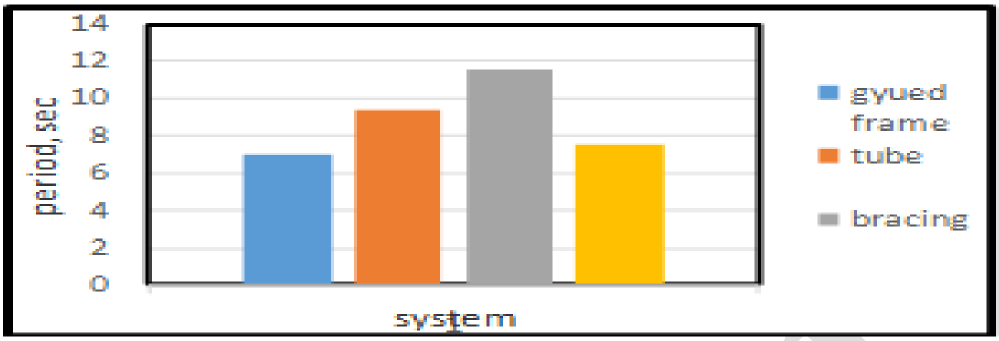


Figure 29: shows the structure period of system in example (4, 5, 6, 7)

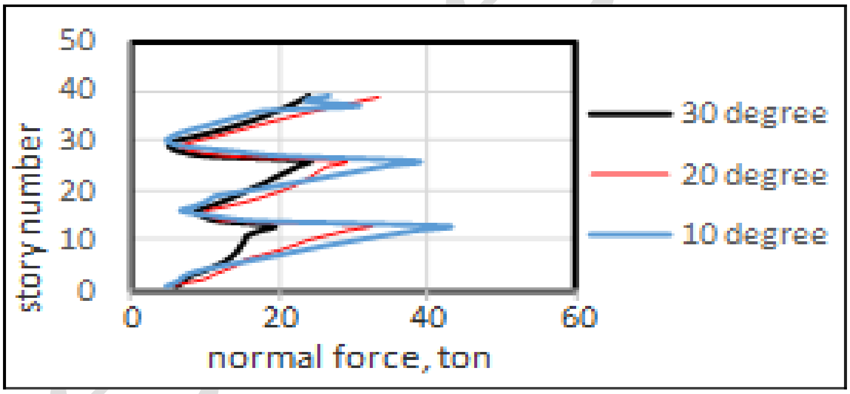


Figure 30: shows the normal force of vertical members at x=0m, y=0m in example (7)

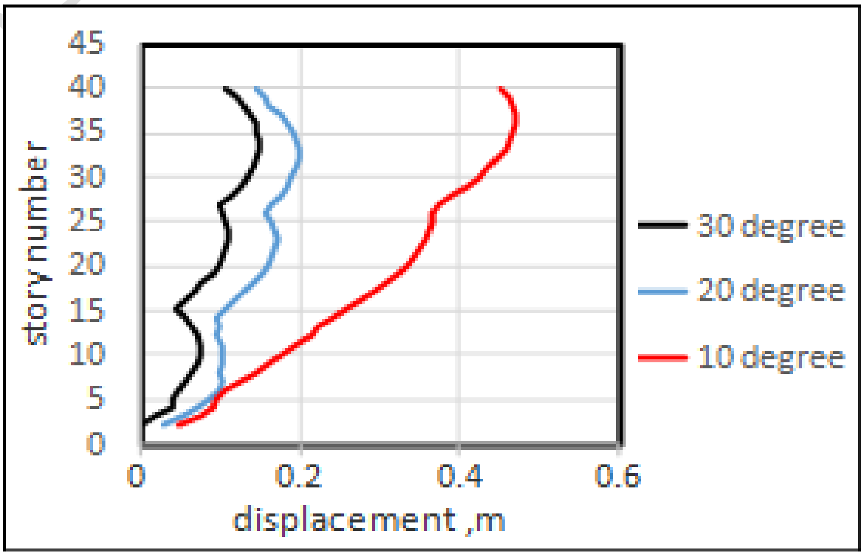


Figure 31: shows the lateral displacement of guyed frame for example (7) at x=0m, y=0m

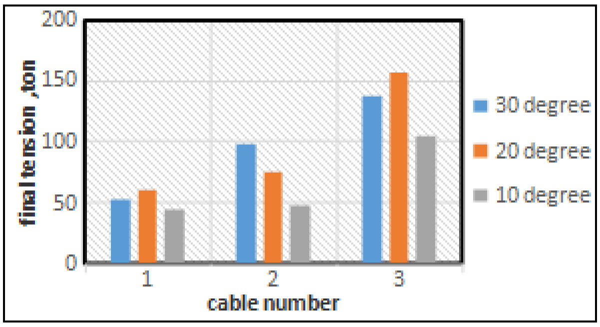


Figure 32: shows the final tension in cables between for example (7)

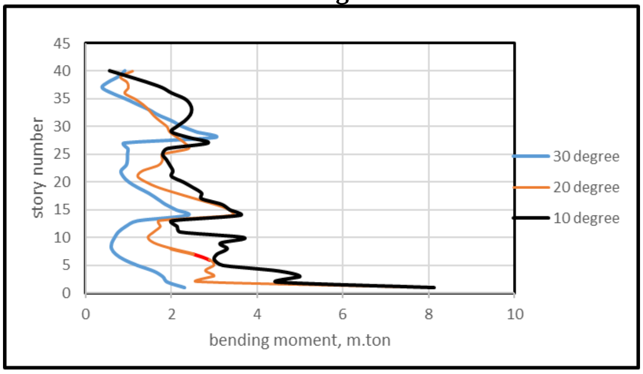
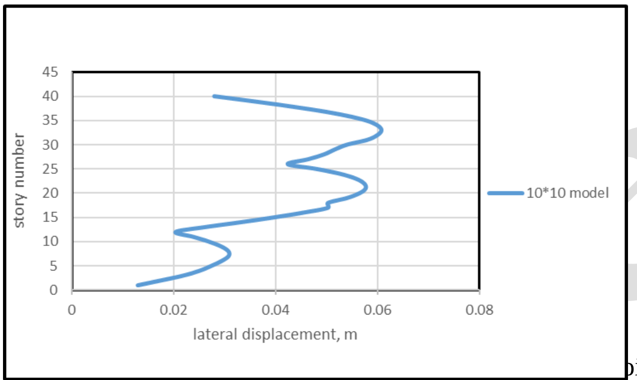


Figure 33: shows the bending moment of vertical members at x=0m, y=0m in guyed frame example (7)



oints at each story level for example (8) at x=0m, y=0m

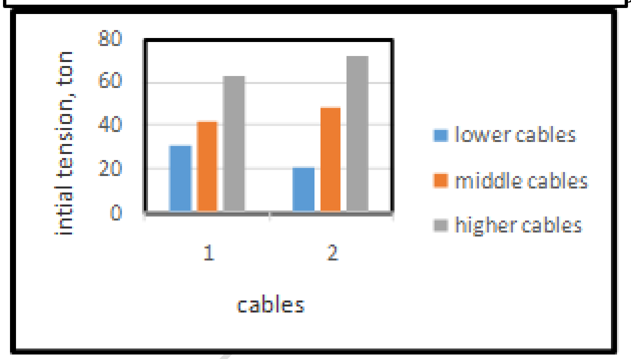


Figure 35: shows the initial tension on cables of example (7), (8) respectively.

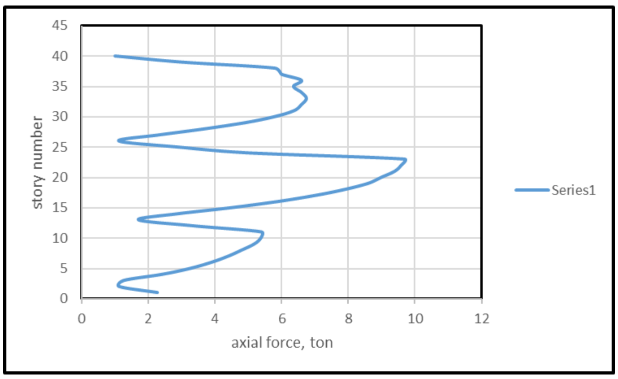


Figure 36: shows the normal force of vertical members at x=0m, y=0m in model (8)

References

[1] Naguib, M. "Buckling strength and dynamic response of guyed towers" (Ph.D. thesis), Struct. Eng. Department, Mansoura University, Mansours, Egypt, 1989.
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