



**ANALYSIS OF NORTH EL-SUKHNA PORT WATCHING TOWER
UNDER EARTHQUAKE LOADING**

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SUMMARY

North El-Sukhna port is a new port that is built recently in Egypt. A unique watching tower was proposed by the architect of the project with an overhanging cantilever of about 15 meters on one side of its main shaft that is 40 meters high above ground level. Combined construction of reinforced concrete for the main shaft and structural steel for the elevated floors is considered. The coast of the Red Sea, where the structure is built, is considered of highest seismicity level in the country of Egypt. This level is equivalent to level 2A on the American scale of the uniform code of building (UBC 1997).

The analysis of this tower under the effect of different combinations of loads is described in this paper. The dynamic behavior of the tower under the estimated earthquake loading in the region is emphasized. The analyses are carried out using loads as defined in both the Egyptian code and the UBC 1997 code and using a dynamic analysis. Comparisons are held between the results of the different parameters of the study. Modified equivalent static loads are suggested to match the results from the dynamic analysis. The suggested loading values can be used for a fast evaluation of similar structures under earthquake loading.

INTRODUCTION

Egypt suffered from a few major earthquake events along its history according to Ambraseys [1]. The last recorded major earthquake event measured 7.4 on Richter scale was originated near the shoreline of the Red Sea of Sinai in 1995. It was only three years after the other big one of 5.3 level on Richter scale that hit the capital city Cairo with its epicenter in Dahshour, about 35 km southwest of Cairo. Although earthquakes are not so frequent or intensive in Egypt, their destruction effects are enormous due to a combination of some factors, mostly related to the local site effects, El-Araby [2]. The geology of the region is mostly clay and sand that amplifies the ground motion during an earthquake by a higher level than rock. The 1992 earthquake depth was quite shallow at about 10 km below the surface resulting in stronger effects than deeper earthquakes. The lack of specifications for applying provisions of earthquake resisting systems in the older versions of the building codes is another factor in amplifying the earthquake

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destruction results. The current Egyptian code for calculation of loads and forces on structures [3] that was issued in 1993, includes a chapter about the calculation of earthquake loading. It divided the country to three zones of seismic intensity. The shorelines of the Red Sea are located within the area of third and highest seismology activity level. This level is equivalent to level 2A on the American scale given in the uniform code of building, UBC 1997 [4]. The recent Egyptian code for design and construction of reinforced concrete structures [5] and that for analysis and design of metallic bridges and steel structures provide provisions for seismic resisting structures. The draft of the new code for loads and forces on structures includes more details regarding earthquake-loading calculations especially for irregular and non-building structures.

The eastern shoreline of Egypt extends for more than one thousand kilometer with only port having the facilities for berthing of third generation container vessels. The maximum depth of water is 12 m at the Port Said port at the connection of Suez Canal to the Mediterranean Sea. The development of the Red Sea coastal area and the inception to share in the international trade market using the container terminals and the new generations of vessels requested the construction of the new port of North El-Sukhna. It lies about 150 km south of Suez city with a water depth of 17 m to allow for the future generation of container vessels. An industrial area is planned to overlook the port to help in factorizing the imported raw materials and re-export the complete products. One Feature structure for this port is the control tower designed by the consultant of the project, Hamza Associates, with a hanging cantilever of about 15 m length. The cantilever part of the structure comprises the two elevated floors for the control rooms of the port. The idea of the architect is to have a boat-like structure at the entrance of the port. The height of the bottom of the lower elevated floor is about 25 m above ground level while the top of the hanging cables is at level 40 m. The analysis of this structure and its response to different combinations of loads especially the dynamic loads resulted from earthquakes is the subject of this research.

The use of the reinforced concrete for the construction of the structure under study was found to result in impractical sections and structural steel elements including trusses and frames were chosen for the cantilever parts. As steel structures are usually lighter in weight than corresponding reinforced concrete structures, it is believed that the effect of earthquake loads on them is not so critical. The structure of this case study consists of a combination of structural steel and reinforced concrete elements. The main core of the structure is made of reinforced concrete while the main elements of the floor levels built at the higher elevations of the structure are made of structural steel and covered with tiny layers of composite steel and concrete sections. The behavior of such structure under horizontal loading either from earthquake or wind effects is complicated and can not be predicted easily by hand calculations. The current Egyptian code for loads and forces on structures does not give a clear definition of loads to be used for such a structure. The use of the American code for loads (UBC 1997) was considered as a comparative international code. More details about the earthquake loading calculations for this case study are given in the following section.

BACKGROUND FOR EARTHQUAKE LOADING CALCULATIONS

The current Egyptian code for calculation of loads and forces on structures permits the use of the equivalent static method to calculate the earthquake loads. It gives the details for calculation and distribution of such loads on different elements of the structure. The main idea is to estimate the earthquake loading as a percentage of the own weight of the structure and to distribute it along its height. The value of the percentage to be taken of the weight of the structure depends mainly on the level of the seismology activity in the project site, the nature of soil conditions, the structural earthquake-resisting system and the natural frequency of the structure. One of the limitations put to the application of this

method is that the structure shall be as regular as possible in plan and elevation. As the studied structure is irregular, the provisions of the Egyptian code requested the application of dynamic analysis. However, the use of dynamic analysis is mentioned in the Egyptian code shortly with no details of the applied spectra or their parameters. The engineering practice is to apply the ground acceleration recorded during recent earthquakes in the region, especially those of years 1992 or 1995 or to apply the design spectrum suggested by the Engineering Society of Egypt.

The application of the American code of loads (UBC 1997) was considered to compare its resulted earthquake loads to those estimated using the Egyptian code for calculation of loads and forces. The UBC 1997 gives a design spectrum to be applied to structures together with the details of the parameters required to fully define it.

DESCRIPTION OF THE MAIN ELEMENTS OF THE STRUCTURE

The main elements of the cantilever parts of the structure are two identical steel trusses for the lower elevated floor and two steel frames for the upper elevated level in addition to two hanging cables that connect the edges of the upper steel frames to the main reinforced concrete shafts. The main steel elements are connected to the reinforced concrete walls using steel end plates with steel anchors that are buried deep in the reinforced concrete. The walls of the structure are 40 m high and have variable thickness ranged between 50 and 125 cm. There are two cores of reinforced concrete walls connected together along their height with reinforced concrete beams. The walls of each core are longer in the direction parallel to the cantilever part with the smaller thickness, while the perpendicular walls are shorter in length and of high thickness. The internal walls of the cores perpendicular to the cantilever part of the structures are stopped below the elevated floor levels to allow for the openings to the floors. The foundation of the structure is made of a thick reinforced concrete raft with a variable depth and extended length in the direction of the cantilever of the structure to eliminate the eccentricity on the founding soil in the normal case of vertical loads. Fig. 1 shows a view of the structure as imagined by the architect and as actually executed.

DESCRIPTION OF THE FINITE ELEMENT MODEL

A three-dimensional model is built to represent the structure using the finite element method [6]. The used software for construction of the model allows for non-linear analysis of structures in addition to dynamic analysis. The foundation of the tower structure is considered in the model using shell elements of variable thickness. The main reinforced concrete walls that carry the elevated structure are modeled using shell elements too. The members of the main two steel trusses and frames and steel beams in the floors are modeled using frame elements. The floor slabs are modeled using shell elements with much smaller thickness. The dynamic analysis of the complete model of the structure is based on the standard mode-supervision method of response analysis [7].

Fig. 2 shows a view of the three-dimensional model of the structure. The soil is represented in the model by springs with sub-grade reaction values suitable for the project site. The described model, which includes the representation of all the elements of the super and sub-structure, is denoted as model TC. Another model is considered in which the foundation elements are eliminated and the base of the main core elements and the ground floor columns and walls are fixed. The fixed base model is denoted as model TF.



Fig. 1 View of the Watching Tower of North El-Sukhna Port.

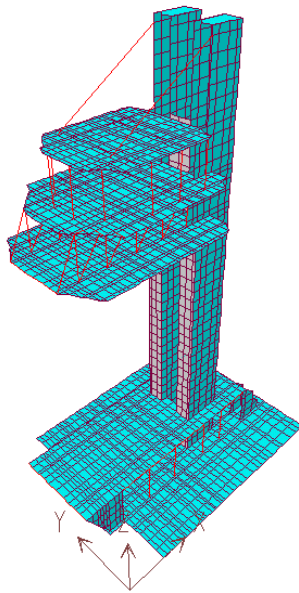


Fig. 2 View of the Three-Dimensional Finite Element Model for the Tower (Model TC).
PARAMETERS OF STUDY

As mentioned above, two main models are used in the analyses of this structure; one having the foundation element included and denoted TC model and the other without the foundation elements, called TF model. Each model is studied under the same combinations of loads. The main applied parameters for the earthquake loading were the used code of practice to estimate the loads, the method to analyze the model and the values of the sub-grade reaction of soil for TC model. Both Egyptian and American codes of practice were used in the calculation of the earthquake loading. The dynamic method of response spectrum is used in applying the earthquake loads. The values of the sub-grade reactions were considered on three levels, one considering the values that exactly match the carried out geotechnical studies in the project area and the other two considering a much weaker and stronger soil than that of the actual case. The effect of the soil sub-grade reaction was considered to assess the change in the resulting straining actions in different elements of the structure with the change of the soil. The values of the stronger soil sub-grade reaction were taken equal to three times those of the actual values in a model denoted as TC-3S. For the weaker soil, the sub-grade reaction values were taken as one-third those of the actual values and the corresponding model was denoted TC-S/3. 15 mode shapes were taken in the analysis of the complete model TC and found to be sufficient to activate participation factors higher than 90% in both horizontal directions of earthquake loading cases (EX parallel to the cantilever of the structure and EY perpendicular to the cantilever). The same number of mode shapes was considered first for the fixed base model TF and resulted in only 72 and 83% participation factors in the cantilever direction and the perpendicular direction respectively. The number of mode shapes for the fixed base model was doubled to try to reach suitable participation factors. The effect of the coupling beams that connect the two reinforced concrete cores was separated from other parameters by eliminating them from the models and introducing them in their actual positions in a separate model called TC-B. Suggested equivalent static loads were estimated on the structure following the requirements of the Egyptian code for regular structures and increased by increments to reach the values that results in a comparable response to that resulted from the dynamic analysis.

RESULTS AND DISCUSSION

The results of the different carried out analyses are briefly described and discussed in this section. The mode shapes of the structure resulting from the modal analysis are mentioned. The effects of the base fixation, the sub-grade reaction values, the introduction of the coupling beams are given. The effects of using loads as defined in either the Egyptian code or the UBC code are compared. The application of suggested distributed equivalent static loads is studied.

The dead and live load combination is denoted as load combination DL. The load combination due to dead, live and earthquake loads in the cantilever direction of the structure is denoted as DLEX. The corresponding load combination with the earthquake loads in the direction perpendicular to the cantilever direction is denoted as DLEY. Comparison between the resulting stresses due to the above-described three load combinations are given in Fig. 3 and 4. Fig. 3 represents the highest vertical compression stresses along the height of the internal thick shear wall, which is perpendicular to the cantilever of the structure. Fig. 4 shows the highest vertical compression stresses along the lower part of the external wall, which supports the cantilever steel structure. All the shown results are according to the reference model, TC, of the complete structure including the raft and the actual values for sub-grade reactions. The effects of the other parameters on the results are discussed in the following sub-sections. The increase in

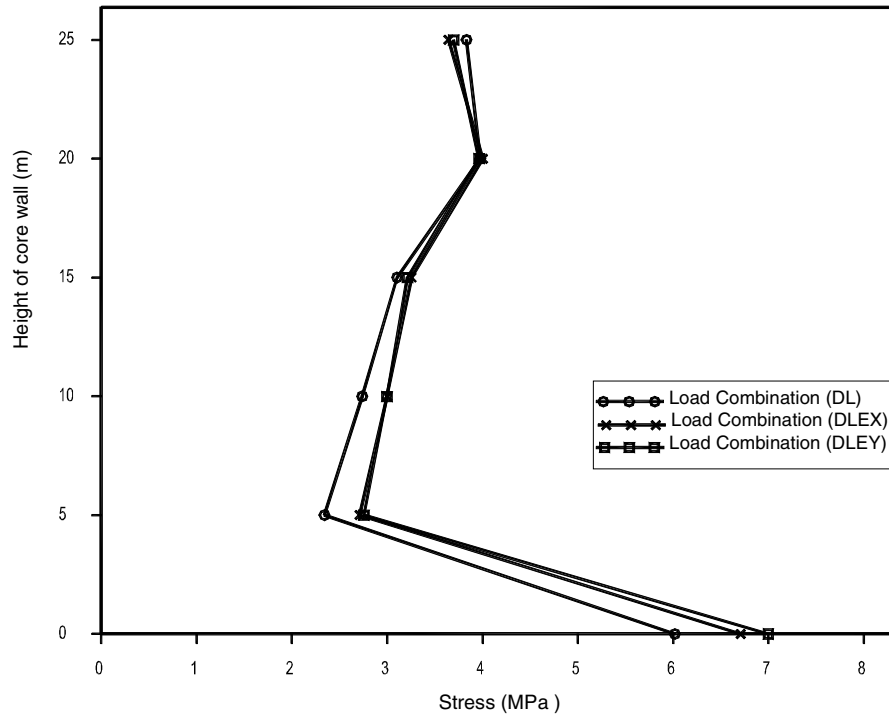


Fig. 3 Effect of Earthquake Loads on Critical Compressive Stresses in the Internal Wall Parallel to Y-Direction.

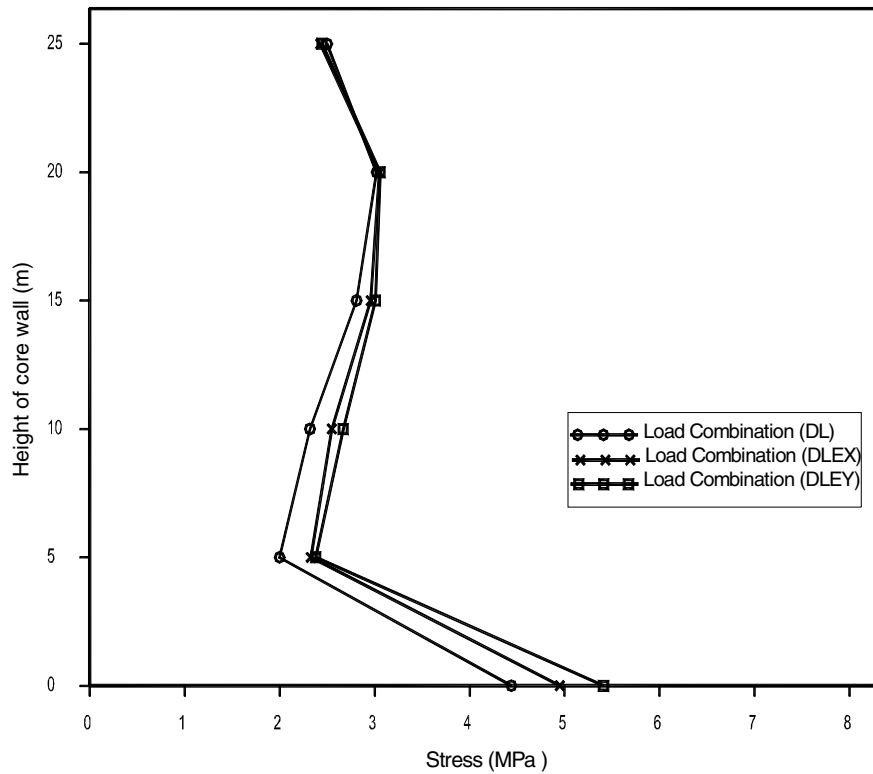


Fig. 4 Effect of Earthquake Loads on Critical Compressive Stresses in the External Wall Parallel to X-Direction.

the stresses due to the inclusion of earthquake loads are found to be in the range of 10% to 15% for the combination including earthquake loads in X-direction while it reached up to 22% for the load combination including earthquake in Y-direction. The increase in stresses due to earthquake loads is more pronounced at the base of the walls and decrease with the height until it reaches a negative small value at the lower level of the elevated floors.

The maximum tensile and compressive forces resulted in the main steel elements of the cantilever part under earthquake load combinations are found to be very close to those resulted from dead and live load combination.

The forces in the cross girders connecting the two main trusses and representing the elevated floor main beams suffered from limited additional normal forces under the earthquake load combinations. The additional normal stresses are so small that the overall increase in stresses in the floor beams is limited to less than 10% of the original primary stresses.

The deflection of the elevated floors of the structure and the horizontal movements in X-direction parallel to the cantilever is almost the same under primary and secondary load combinations. Fig. 5 shows the resulting vertical deflections of the bottom chord of the main truss under different load combinations. It can be seen that the deflections are even less during the load combination DLEY than those for primary load combination DL. The earthquake load combinations resulted in small transversal movements in Y-direction that was originally zero for the dead and live load combination, see Fig. 6.

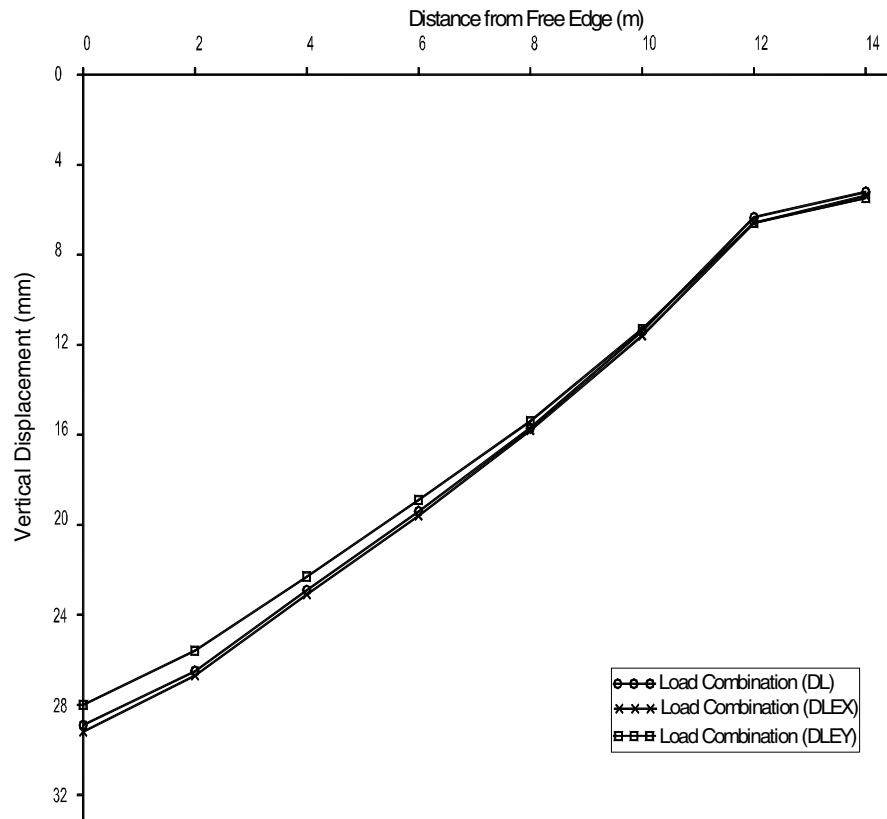


Fig. 5 Vertical Displacement of the Elevated Floor under Different Load Combinations.

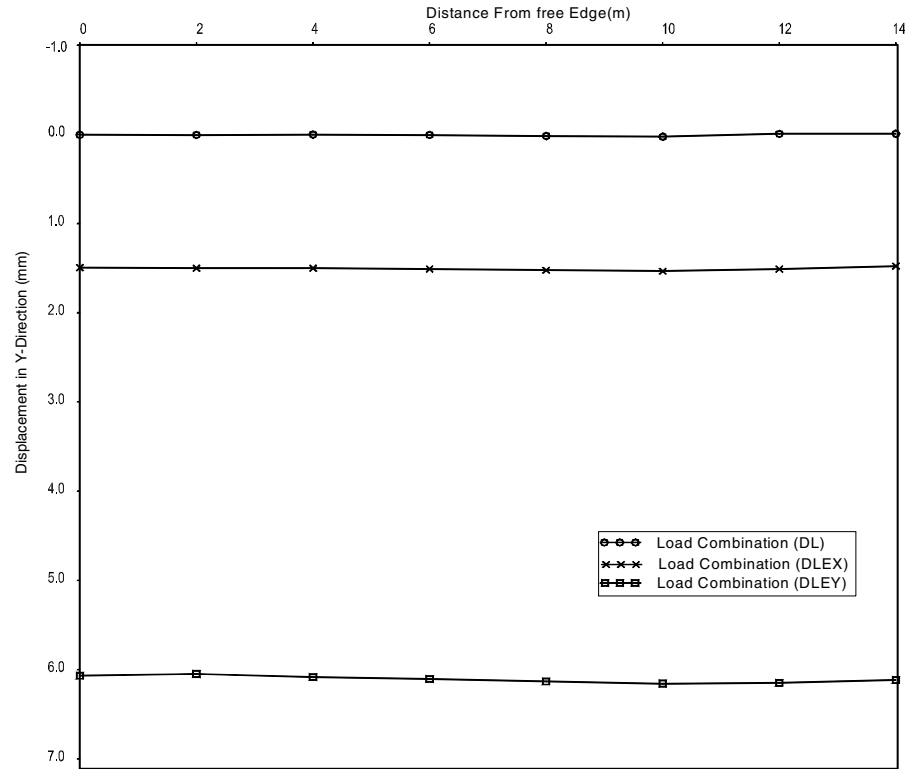


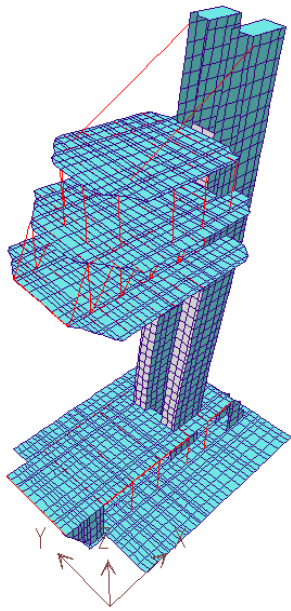
Fig. 6 Horizontal Displacement in Y- Direction due to Different Load Combinations.

Mode Shapes

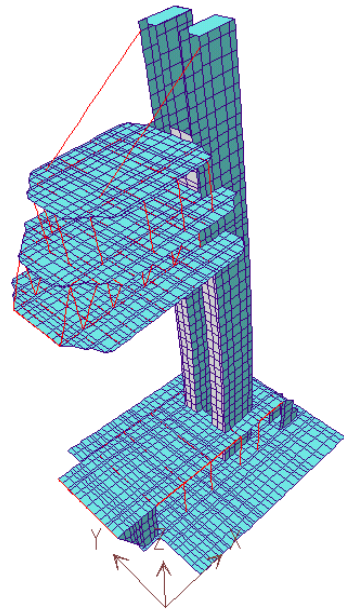
Fig. 7 shows four mode shapes of the complete model of the structure. The chosen modes are those participating most for the earthquake loads in either X-direction or in Y-direction. Mode 1 has a period of 0.87 second and it represents the translation of the building in Y-direction. It shares by about 38% of the loads for the load combinations DLEY. Mode No. 4 represents the rotational mode shape around the vertical plane parallel to X-direction with a participation factor to the load combination DLEY of 44%. Modes 2 and 5 are the corresponding modes to 1 and 4 for the load combination DLEX with participation factors of 36 and 57 % respectively.

Effect of Base Fixation

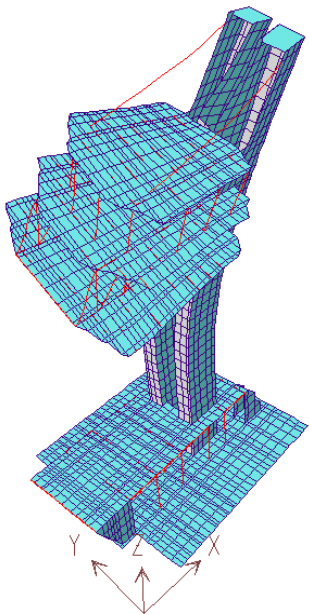
Base fixation of the core walls, as described in model TF above, resulted in lower stresses at the base of shear walls for the load combinations of earthquakes in both X and Y directions. The thicker walls, that is parallel to Y direction, experienced much reduction in the stresses at the their bases. Fig. 8 Represents the variation in stresses in the most critical elements along the height of the internal wall, parallel to Y-direction, under the load combination of dead, live and earthquake loads in Y-direction for both fixed base model and the complete model having the actual sub-grade reaction values. The fixation of the base increased the stresses along the rest of the wall height. The base fixation had minor effect on the deflections and horizontal movements of the cantilever edges of the elevated floors. The reduction in deflections and displacements in the X-direction in the fixed base model was about 10%, while an increase of more than 50% in the displacements in Y-directions was observed. The fixation of the base of the core walls had almost no effect on the resulting forces in the main steel elements.



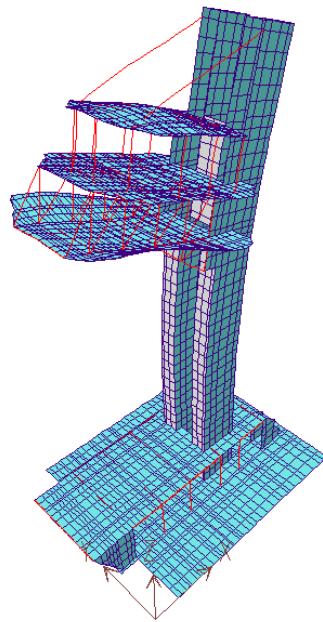
Mode(1)



Mode (2)



Mode (4)



Mode (5)

Fig. 7 Basic Mode Shapes of the Structure.

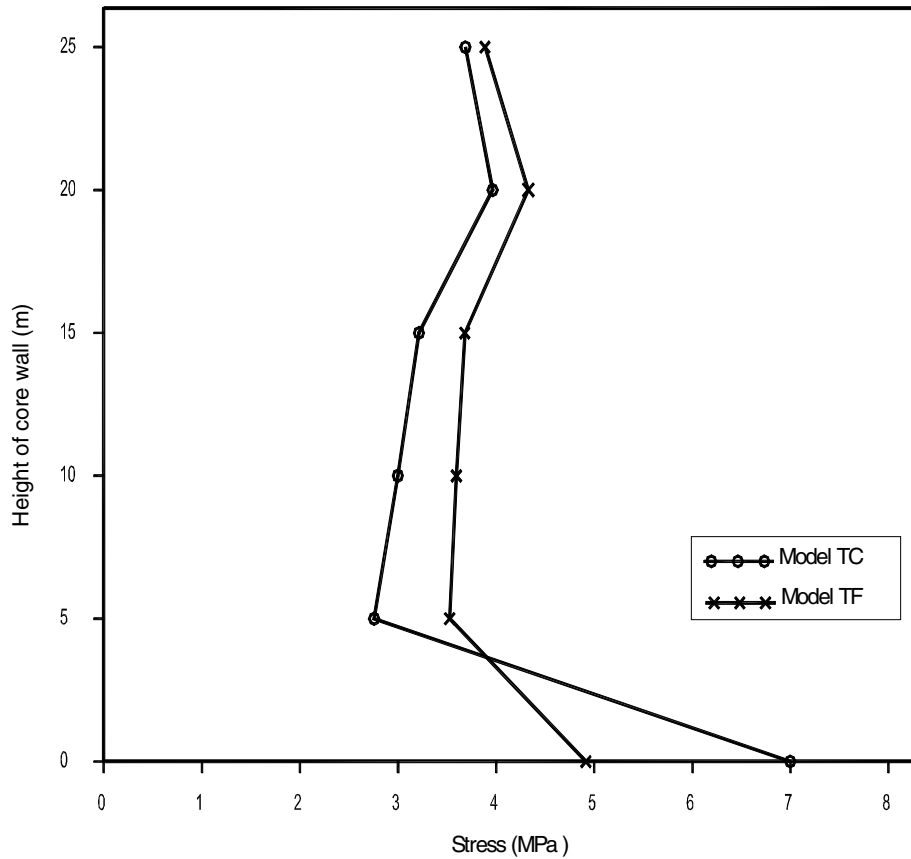


Fig. 8 Comparison between Critical Stresses in Internal Wall for Full and Fixed Base Models.

Effect of Soil Sub-grade Reaction

The increase of the sub-grade reaction values to three times their actual values gave a similar trend of results to those resulting in the fixed base model. However, the change in stresses is much less than that occurring in a fully fixed base model. On the other hand, reducing the sub-grade reaction values to one third of their original values resulted in higher stresses at the base of the shear walls, Fig. 9. The effect of the change of sub-grade reaction values was more pronounced on the critical stresses in the raft of the structure. The effect of changing the sub-grade reaction values was more pronounced on the stresses in the foundation. The maximum stresses in the raft elements were almost 20% higher for the low values of the sub-grade reactions and 30% lower for the high values of the sub-grade reaction values.

Effect of Coupling Beams

The existence of the coupling reinforced concrete beams, which connect the two cores of the structure, enhanced the overall behavior of the structure under the earthquake load combinations especially for the case of earthquake loads in Y-direction. The provision of the coupling beams reduced the change in the stresses in the walls of the core due to earthquake loads combinations as it helped the structure to act as one unit. In the same time, the horizontal displacements in the Y-direction are reasonably reduced. This in turn reduced the additional stresses in the cross girders connecting the two main truss elements.

Effect of Application of the Egyptian Code and UBC Code

The resulting critical stresses along the internal wall of the core as well as in the other members of the structure were found to be identical when applying the earthquake loads calculated according to the Egyptian code requirements and UBC provisions. Although, the overall base shear according to the Egyptian code requirement is lower by about 20% than the corresponding value according to the UBC requirements for the same-modeled structure, the resulting stresses under the load combinations including the earthquake loads were almost the same. This is attributed to the fact that the each code defines different factors for the load combinations. The UBC code permits lower ratio of the earthquake loads to be combined to the dead and live loads, thus compensating the high value of the calculated base shear.

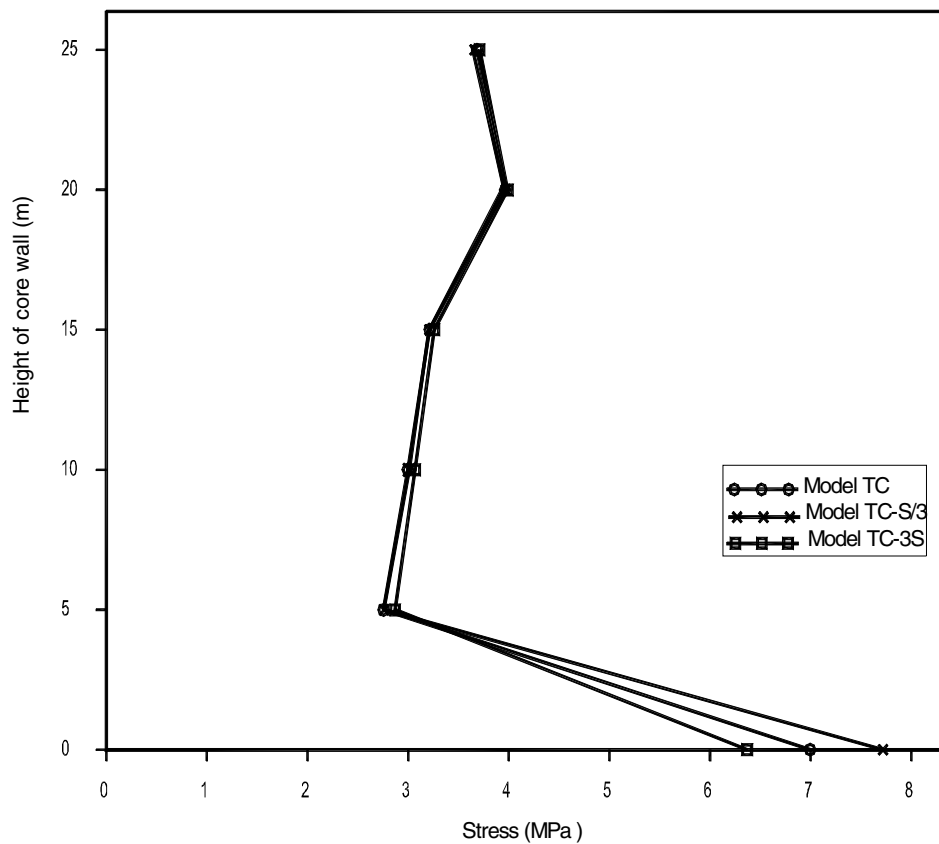


Fig. 9 Comparison between Critical Compressive Stresses for Different Sub-Grade Reaction Values.

Effect of Applying Equivalent Static Loads to Represent the Earthquake Loads

An iterative study was carried out on the reference model TC, to check the possibility to get the same resulting response using equivalent static analysis rather than the dynamic analyses represented above. As the main effect of earthquake loads was on the resulting stresses at and close to the base of the shear walls, the study focused on the equivalent static loads that result in the same stresses in the most critical elements of the shear walls. Table 1 shows in a normalized manner the ratio between the resulting critical stresses using the static analysis to the resulting values from the dynamic analysis when applying different ratios of the base shear to the weight of the structure. The first line in Table 1 represents the case of the

base shear calculated according to the requirements of the Egyptian code and applied statically on the structure.

Table 1 Calculation of the Equivalent Static Load to Match the Results of Dynamic Analysis

Ratio of base shear to weight of structure		Ratio of critical stresses in static analysis to those in dynamic analysis in internal walls		Ratio of critical stresses in static analysis to those in dynamic analysis in external walls	
In X-direction	In Y-direction	Load Combination DLEX	Load Combination DLEY	Load Combination DLEX	Load Combination DLEY
0.06	0.06	0.61	0.72	0.62	0.74
0.13	0.10	0.78	0.79	0.79	0.94
0.20	0.12	0.97	0.98	0.97	1.02

CONCLUSIONS

The current Egyptian code of loads does not include details for the application of dynamic analysis to irregular structures. However, the draft of the new code had overcome this lack. The practice of using the design response spectra suggested by the Egyptian Engineering Society resulted in very comparable results to those resulting when using the provisions of the UBC 1997 code.

The Modeling of the structure with fixed base approximation resulted in under estimation for the straining actions in the most critical positions. Therefore, a simplified fixed base model is not recommended for similar structures.

The application of the accurate values of sub-grade reactions in the modeling of soil is recommended to avoid getting misleading results. Smaller values are recommended if the accurate ones are not well defined to be in the conservative side.

The existence of coupling beams between the two cores of the structure enhanced the behavior of the structure under the earthquake loading especially in the transversal direction.

It is possible to apply equivalent static loads to such irregular structures as first and fast evaluation of the effect of earthquake loading. However, an increase of the calculated base shear according to the Egyptian code by at least 100% is recommended to get similar results to that obtained from the detailed dynamic analysis of the complete model.

ACKNOWLEDGMENT

The author would like to express his gratitude to his colleagues in Hamza Associates; Engineer Abeer Ahmed and Engineer Naglaa Abdel-Aal for their efforts in producing the manuscript of this paper.

REFERENCES

1. Ambraseys, N. N., Melville, C. P. & Adams, R. D., “ The Seismicity of Egypt, Arabia and the Red Sea, a historical review”, Cambridge Press, 1994.
2. El- Araby, H., and Sultan, M., “Integrated seismic risk map of Egypt”, Seismological Research Letters, 2000, Vol. 71, p. 52-65.
3. Ministry of Housing Utilities and New Communities, “Egyptian code for the calculation of loads and forces in structural and building works” Ministerial Decree No. 45,1993.
4. International Conference of Building Officials, “1997 Uniform Building Code, Volume 2, Structural engineering design provisions”, USA, April 1997.
5. Ministry of Housing Utilities and New Communities, “Egyptian code for the design and construction of reinforced concrete structures”, Ministerial Decree No. 98, 2001.
6. Weaver, W.Jr. And Johnston, P.R., “Finite element for structural analysis”, Prentice-Hall, New Jersey, USA, 1984.
7. Clough, R.W. and Penzien, J., “Dynamics of structures”, McGraw-Hill, New York, USA, 1975.