JAUES

Journal of Al Azhar University Engineering Sector

Vol. 13, No. 49, October, 2018, 1380-1390

BEHAVIOUR OF DIFFERENT TYPES OF FOUNDATION SUBJECTED TO DYNAMIC LOADS AND RESTED ON SAND SOIL

Kotb M. H .A.[1], Elbatal, S. A.[1], Abo-Alanwar, M. M.[1] and Zamel A. B. A.[2]
[1], Faculty of Engineering, Al – Azhar University, Cairo, Egypt
[2] Civil Engineer, National Organization for Potable Water & Sanitary Drainage Cairo, Egypt

دراسة سلوك الأساسات تحت حالات التحميل المختلفة من أهم الموضوعات التى شغلت حيزاً كبيراً من الإهتمام. ترتبط الأساسات إرتباطاً وثيقاً بالعوامل والظروف المحيطه كنوع الحمل المؤثر ونوع التربة الحامله للأساس. يعد الحمل الغير ثابت (الديناميكى) من أخطر أنواع الأحمال المؤثره على الأساسات كأحمال الزلازل والذى بدوره يعتمد بشكل كبير على وزن المبنى وال‌ذى يعتمد على عدد الأدوار وكذلك نوع التربة الحامله للأساسات. لدراسة تأثير الحمل المتغير على الأساسات تم عمل نموذج لنوعين مختلفين من الأساسات (لبشة – لبشة كمرية) ومعرضه لزلازل (El_centro) مع ثبات نوع التربة وتغيير عدد الأدوار(5 ، 10، 15). من دراسة النتائج تبين أن:

1- الاجهادات والتشكلات الناتجة من التحليل لنوعي الاساسات (لبشة – لبشة كمرية) تقريبا متساوية.
2-اللبشة الكمرية تؤدي بشكل أفضل اللبشة فى مقاومة الازاحة الافقية الناتجة عن الاحمال الديناميكية.
3-اللبشة الكمرية قد طورت النتائج للأفضل بالرغم من كونها تكافئ فقط 70% من جساءة اللبشة العادية، ولذلك يفضل استخدام اللبشة الكمرية بدلا من اللبشة العادية عند وجود أحمال ديناميكية.

ABSTRACT

Studying of foundation behaviour under different loading cases is one the most important topics that has occupied a great deal of interest. Foundation closely correlated with factors and surrounding conditions such as type of active load and type of soil bearing foundation. Non-static load (dynamic) is one of the most dangerous types of loads that affect the foundations such as earthquakes, which in turn depends heavily on the weight of the building, which depend on the number of floors, as well as the type of soil bearing foundations. To study the effect of variable load on the foundations, a model of two different types of foundations was presented (Raft – Raft with inverted beam) and exposed to El_centro earthquake with constant soil type and changing the number of floors (5, 10 and 15). From analysis results, it showed that:-

1- Raft and raft with inverted beam have almost equal stresses and deformations.
2- Raft with inverted beam is better in resisting H.Z displacement resulting of dynamic loads than raft.
3- Raft with inverted beam improved results although it is equal to 70 % of raft inertia, so that it is better to use it with dynamic loads.

KEYWORDS - Raft, Inverted Beam, (PGA) Peak Ground Acceleration, FE (Finite Element).

I. INTRODUCTION

Foundation is the name given to the interfacing element that any construction need to be stable by resting on it. The foundation is the part of an engineered system that transmits to, and into, the underlying soil or rock the loads supported by the foundation and it's self-weight. The resulting soil stresses -except at the ground surface- are in addition to those presently existing in the earth mass from its self-weight and geological history. The term superstructure is commonly used to describe the engineered part of the system bringing load to the foundation, or substructure. a numerical analysis is used to investigate any interaction between soil and foundation and the behaviour under different loads.

2. BACKGROUND

Analysis of flexible rectangular raft foundations under dynamic loading was studied by Molla, A. K. M. and Ray, P. D. (1994) [5]. The raft is assumed to be supported on a Winkler medium. Different types of foundation soils, namely sand, soft clay and peat, are considered. The subgrade modulus of these soils is determined in the laboratory. Dynamic response curves for four aluminium plates are obtained both by analytical methods and experimental investigations and the results are compared. The agreement was quite good in respect of the qualitative nature of the curves and reasonable in respect of quantitative values. Response of shallow foundations subjected to strong earthquake shaking was investigated by Gazetas ‹G. and Apostolou, M. (2004) [3]. It is observed that nonlinear soil foundation effects associated with large deformations due to base uplifting and soil failure are examined in comparison with the conventional linear approach. Analysis of soil raft structure system subjected to dynamic loads was studied by Kumar, V. (2009) [4]. The study revealed two important points. Firstly variation of Young's modulus of soil effectively influences frequency response of soil-raft-structure system whereas variations of Poisson's ratio of soil have a modest influence on the frequency of soil-raft-structure system. Secondly dynamic interactive analysis of soil-raft-structure consists of horizontal, vertical and rocking modes of vibration where as in non-interactive case horizontal mode of vibration is predominant. Seismic analysis of R.C structure in different zones and soil types considering soil structure interaction with fixed base comparing with spring base was studied by Bhutia, L. T. T. and Et al (2016) [2]. SAP2000 software is used to achieve the scope of this research. The comparison of base shear for fixed support and spring support in Different Zones of India in X and Y direction showed that there will be an increase in base shear by 70-75% from zone 2 to zone 5. The comparison of base shear for fixed support and spring support from hard to soft soil showed that there will be an increase in base shear by more than 30% and from hard to medium soil showed that there will be an increase in base shear by more than 20%. The structure with spring base showed good result when compared with fixed base in different zones of India.

3. Numerical model

Description and modelling of any engineering problem to show the actual behaviour of this system mathematically is the main purpose of a finite element analysis. In other words, the mathematical model must be represent accurately the real physical prototype. For real representation of the physical system, the mathematical model must include all components of the system such as the nodes, elements, material properties, real constants, boundary conditions, and other features. Three-dimensional analysis of the soil-structure interaction was performed using the finite element code ANSYS. ANSYS is a very large general-purpose finite element program and can be adapted to the solution of virtually any engineering problem whether it was simple or complicated. These problems include static/dynamic, structural analysis (both linear and nonlinear), heat transfer, and fluid problems, as well as acoustic and electromagnetic problems. To study foundation behaviour under dynamic loads 5, 10 and 15 floors on raft with and without inverted beam rested on sand soil were modelled with ANSYS V15.0. Different elements and material models are used in present study. SOLID65 element type was used for soil and concrete elements. SOLID65 is an 8-node brick element used for the 3-D modelling of the different layers in the soil. The element has 3 degrees of freedom at each node: translations in the nodal x, y, and z axes as shown in figure [1].

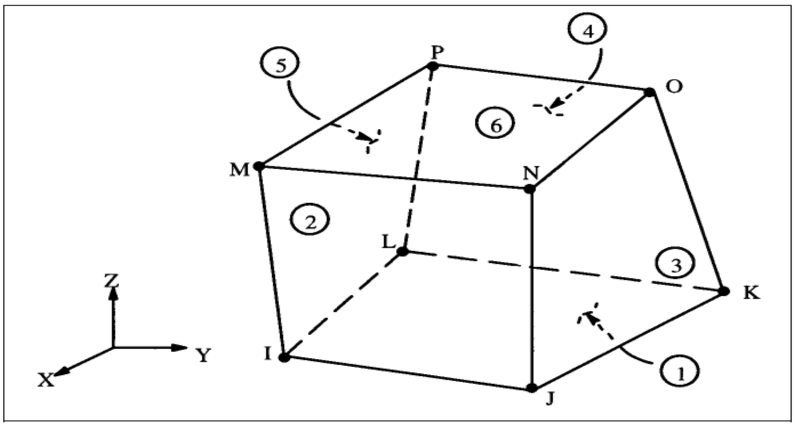

Fig. 1. Solid65 – 3-D reinforced concrete solid [ANSYS (1998)].

Additionally, the element is capable of representing orthotropic material properties, and has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities. Two material models are used for simulating soil in linear and nonlinear behaviour. The two models are linear elastic and Drucker-Prager. The elastic model uses Hooke's law of isotropic linear elasticity. This model uses two elastic stiffness parameters, namely Young's modulus (E), and Poisson's ratio (ν). The Drucker-Prager uses three parameters, namely the cohesion (c), the friction angle (φ), and the dilatancy (flow) angle (ψ). The soil properties are presented in Table [1].

Table [1]. Soil material table.

Layer ID	γ_{dry} (Kn/m3)	C (MPA)	φ	E (MPA)	□	▱
Sand	19.5	0.07	35 °	60	0.35	5 °

A small value for cohesion (0.07 MPA) is used to improve the numerical conversion and does not affect the overall predictions of the model Akl, S. A., and K. G. Metwally (2017) [1].From another side the concrete is capable of cracking (in three orthogonal directions), crushing, plastic deformation, and creep. The rebar are capable of tension and compression, but not shear. They are also capable of plastic deformation and creep. The properties of Concrete materials taken for deformation prediction are presented in Table [2].

Table [2]. Structural (Concrete) material table.

Layer ID	γ_c (Kn/m3)	E (MPA)	□
Concrete	25.0	23.025 X 10^3	0.30

Raft foundation with square shape is suggested for analysis operation and with dimensions (17.0 X 17.0 X 1.50) m. Also raft with inverted beams foundation with 70 % of raft inertia and with the same previous dimensions, but raft thickness (1.00) m and with inverted beam at columns positions with thickness (1.00) m is suggested as the second parametric study in our research. Superstructure that is resting on raft foundation consists of flat slab with dimensions (17.0 X 17.0 X 0.20) m supported by columns with dimensions (0.50 X 0.50) m and the height of floor is (3.0) m. To be able to convert any solid model to FE model can be solved it must be meshed. Meshing is the step which model components are divided to small parts to make its results more accurate. Soil media is divided to small parts with dimensions (2.0 m X 2.0 m X 2.0 m), Raft is divided (0.50 m X 0.50 m X 0.50 m), Slabs are divided to (0.20 m X 0.50 m X 0.50 m), Columns are divided to (1.00 m X 0.50 m X 0.50 m) and beams are divided to (0.50 m X 0.50 m X 0.50 m). Meshing is a very important step to convert any model from solid model to finite element model can be solved as shown in figures [2].

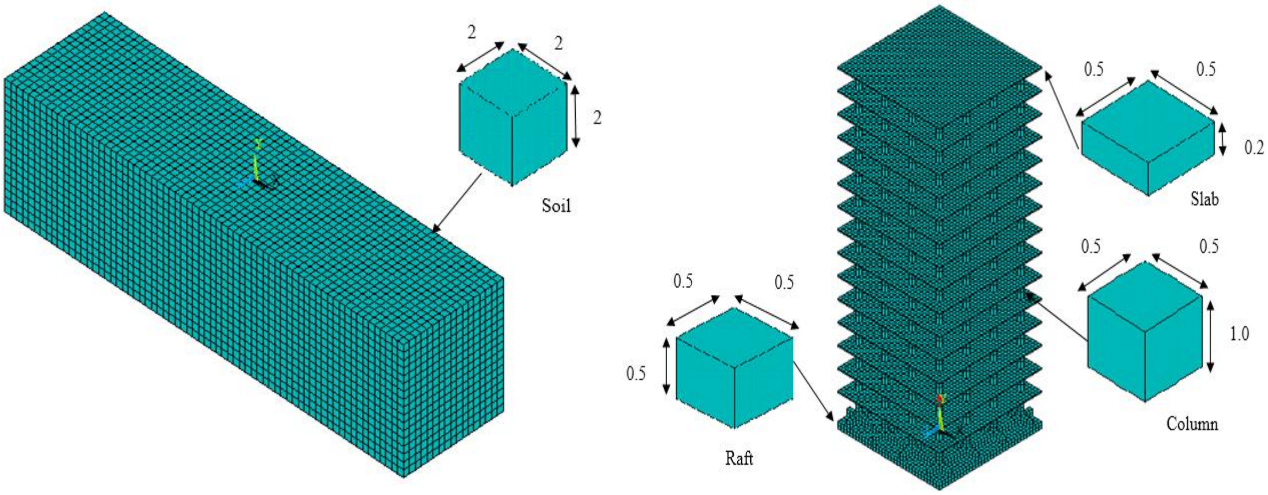

Fig. [2]. 3-D finite element mesh for model components.

For connecting two materials and finding interaction between two materials, contact element must be used. ANSYS provides several elements that can be utilized to model the interface between two elements that are in contact. Contact between two surfaces can conveniently be modelled in ANSYS by utilizing the surface-to-surface contact elements TARGE170 and CONTA173. Each of these "contact pairs" is capable of representing contact and sliding between two 3-D surfaces, with the "target" elements (TARGE170) defining the stiffer surface, and "contact" elements (CONTA173) defining the deformable surface as shown in Figure [3].

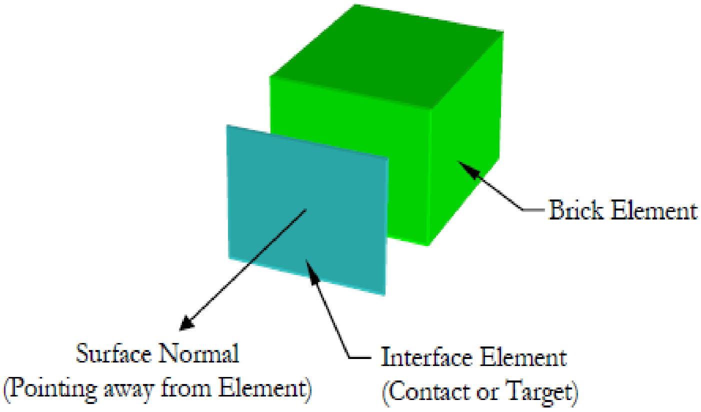

Figure [3]. Orientation of interface element.

There are different types of loads that we will use in our study. These types can be explained as the following:-

- Dead loads: - own weight of model elements.
- Live loads: - all loads of non-static elements, it is taken 3.0 KN/m2.
- Wall loads: - all loads of static walls, it is taken 5.0 KN/m2.
- Dynamic loads: - El_centro earthquake loads will be represented by time history method as shown in figure [4] and model is exposed to earthquake excitation to time 2.20 second.

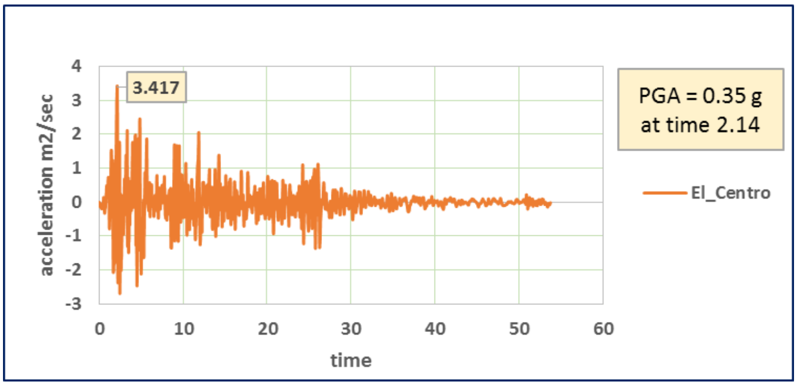

Figure [4]. El_centro earthquake.

To be able to solve any FE model we must assign boundary conditions. Boundary conditions, also called support conditions, have great influence on the computed results. Boundary conditions can be defined by two types: displacement or force (also called stress or traction). Fixation is considered in Y-direction, Z-direction and to represent infinity length of soil in earthquake direction (X-direction), elastic part with linear material and fixed final points in x-direction is suggested in the start and the end of soil model, Nguyen, V. Q. And Et al (2016) [6].

4. RESULTS

In this section, results of 3D model as contact pressure between foundation and soil, deformation and stresses of soil and foundation, acceleration response with time and relative H.Z displacement with time, some results for raft model supporting 15.0 floors without basement are shown in figures [5] to [14] and these results are discussed. Some points are selected for showing results and comparison between different parameters as shown in figures [9] to [62]. For soil under foundation points (1 and 3) are selected in center and corner respectively. For raft points (1* and 3*) are selected in center and corner respectively. For superstructure point (4) is selected in center.

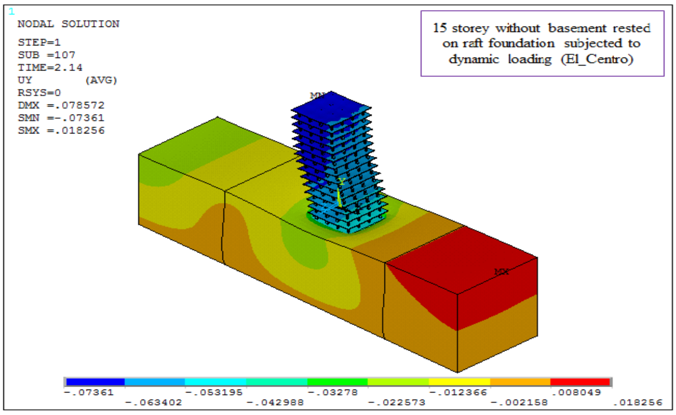

Figure [5]. Vertical displacement for 3D model.

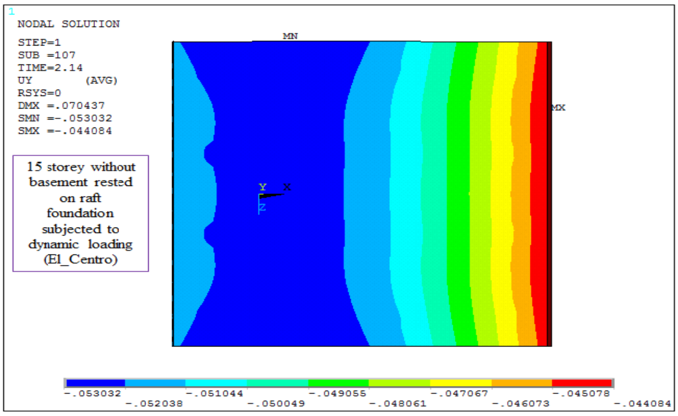

Figure [6]. Vertical displacement for raft.

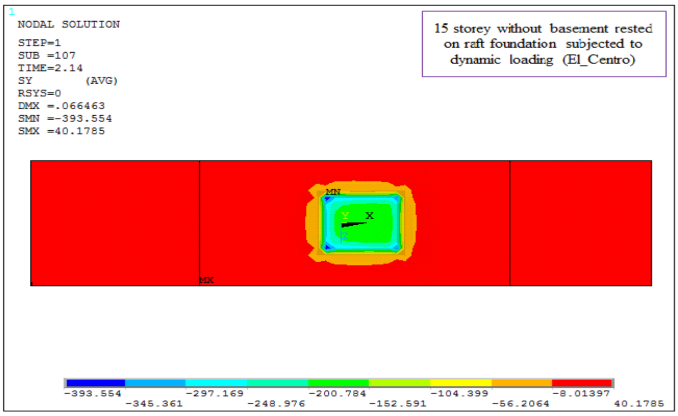

Figure [7]. Vertical stress for plan.

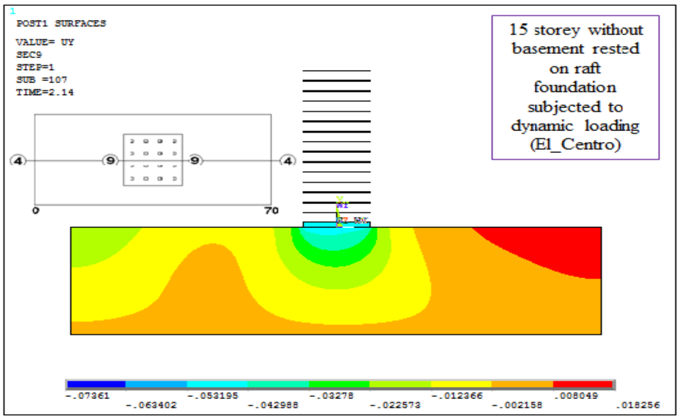

Figure [11]. Vertical displacement at center.

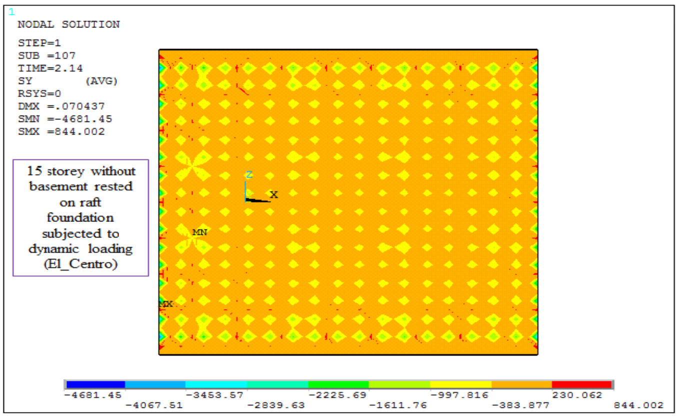

Figure [8]. Vertical stress for raft.

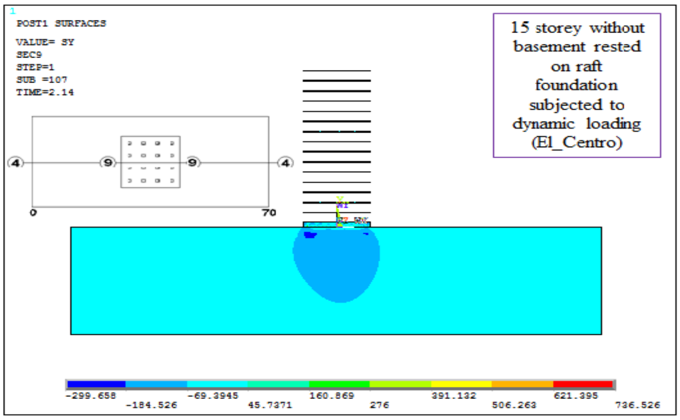

Figure [12]. Vertical stress at center (5.0 floors).

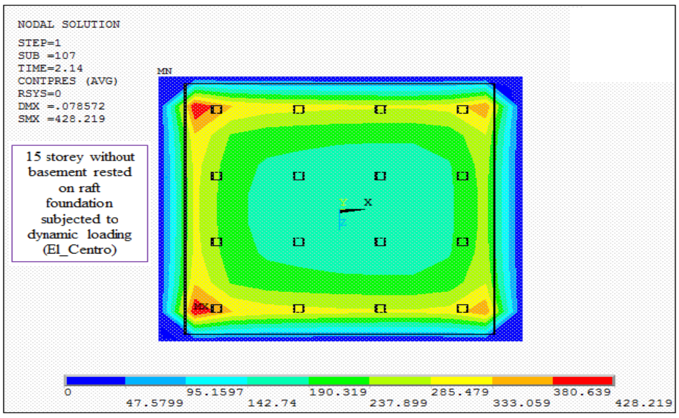

Figure [9]. Contact pressure.

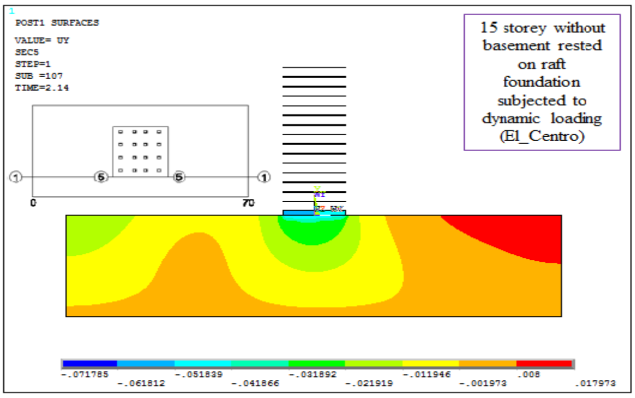

Figure [13]. Vertical displacement at edge (5.0 floors).

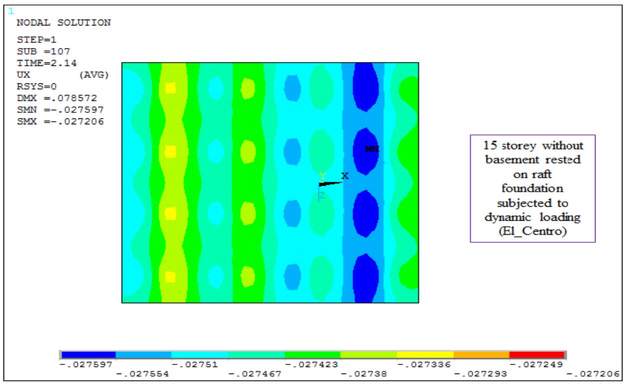

Figure [10]. Relative horizontal displacement for final slab.

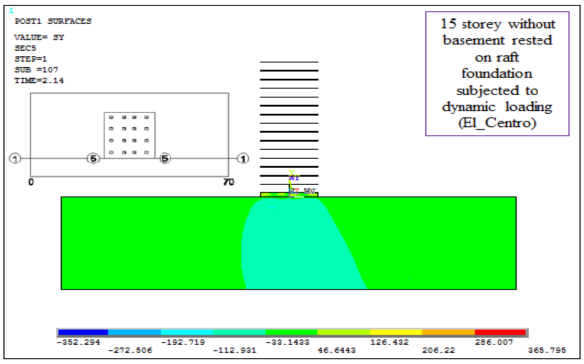

Figure [14]. Vertical stress at edge (5.0 floors).

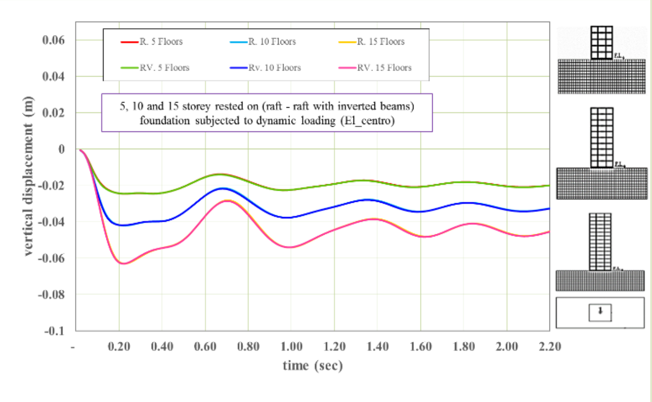

Figure [15]. Vertical displacement at point (1).

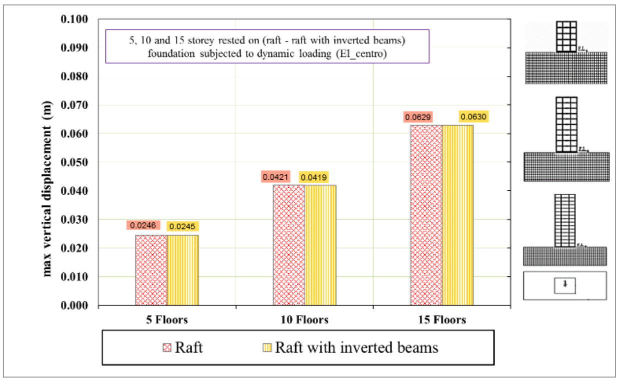

Figure [16]. Comparison vertical displacement at point (1).

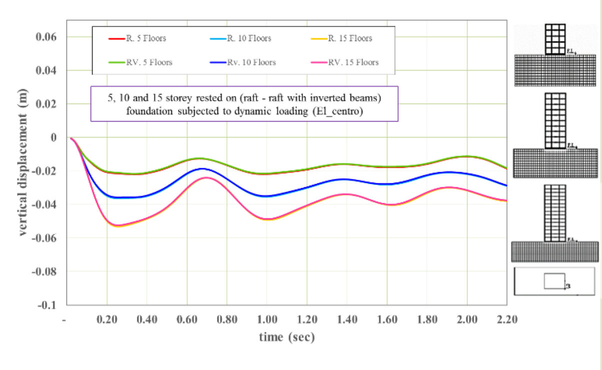

Figure [17]. Vertical displacement at point (3).

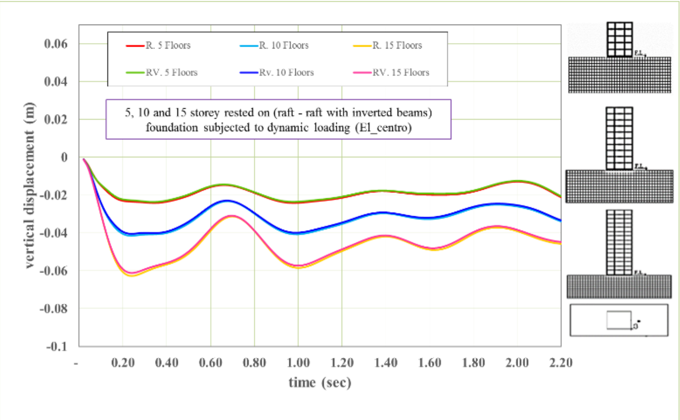

Figure [21]. Vertical displacement at point (3*).

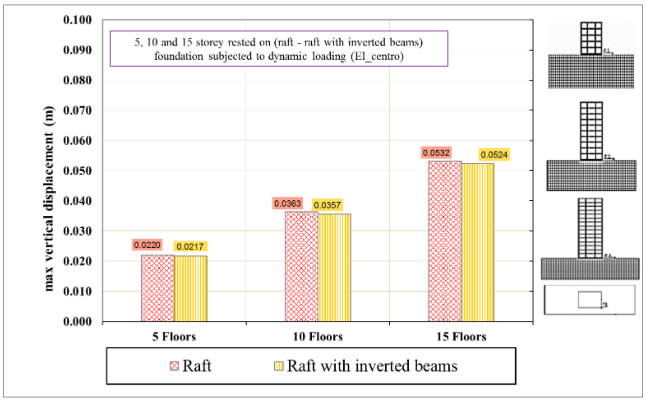

Figure [18]. Comparison vertical displacement at point (3).

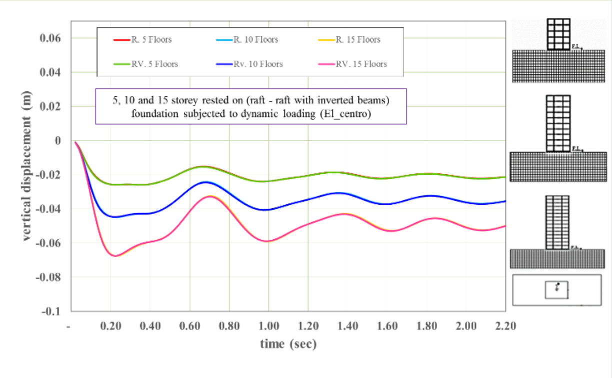

Figure [19]. Vertical displacement at point (1*).

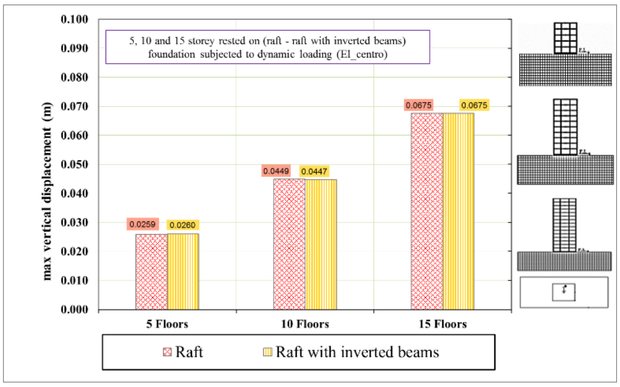

Figure [20]. Comparison vertical displacement at point (1*)

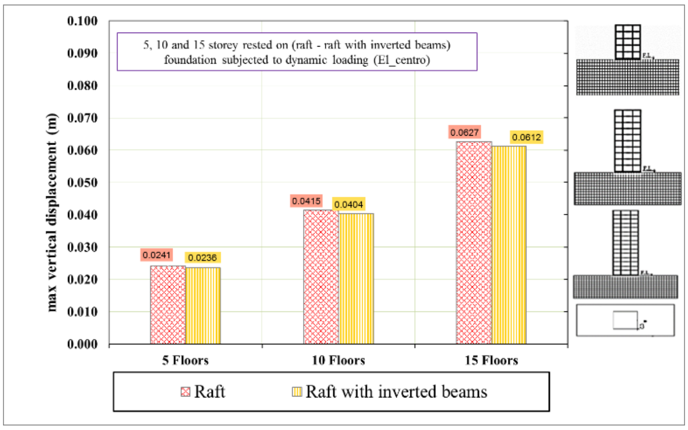

Figure [22]. Comparison vertical displacement at point (3*)

From previous results it is clear that vertical displacement increase with increasing number of floors and two types of foundation almost have nearby values. For soil central point is more critical, but for foundations two points sufficient have nearby values.

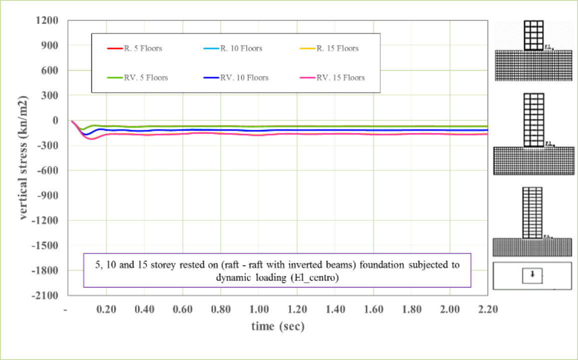

Figure [23]. Vertical stress at point (1).

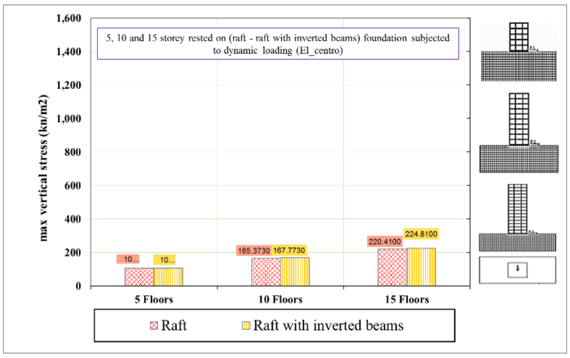

Figure [24]. Comparison vertical stress at point (1).

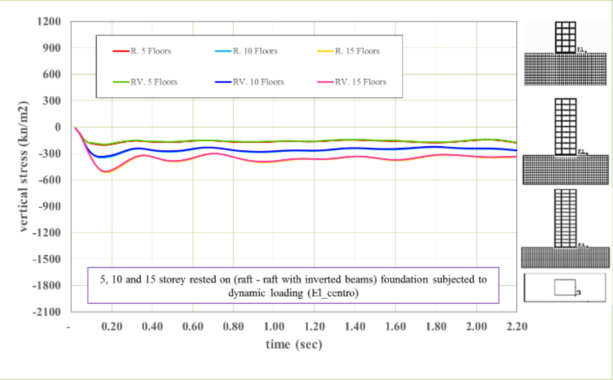

Figure [25]. Vertical stress at point (3).

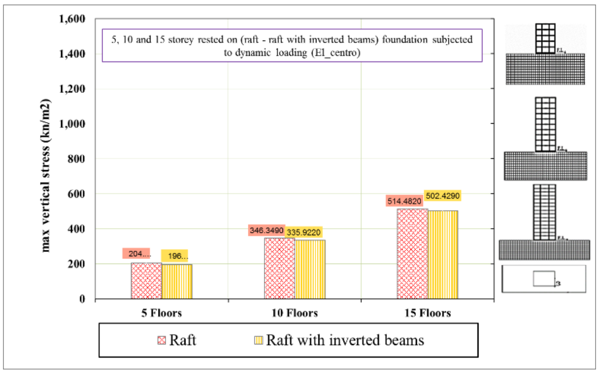

Figure [26]. Comparison vertical stress at point (3).

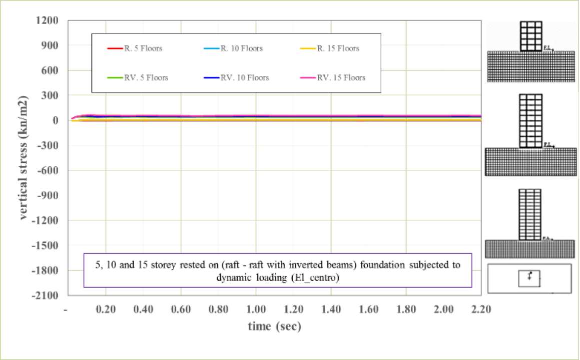

Figure [27]. Vertical stress at point (1*).

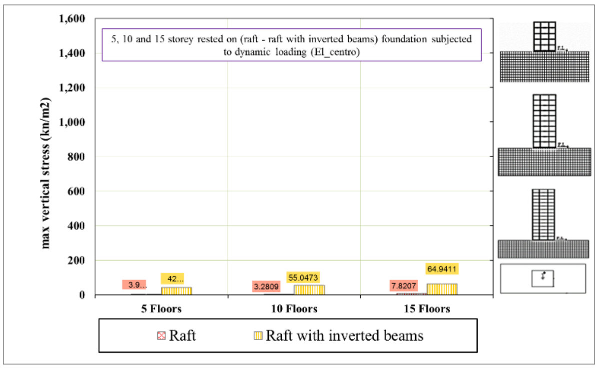

Figure [28]. Comparison vertical stress at point (1*).

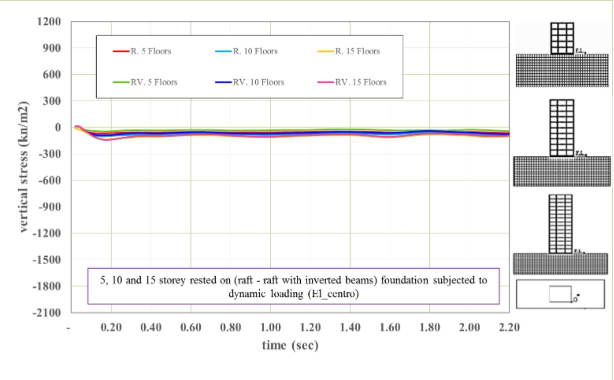

Figure [29]. Vertical stress at point (3*).

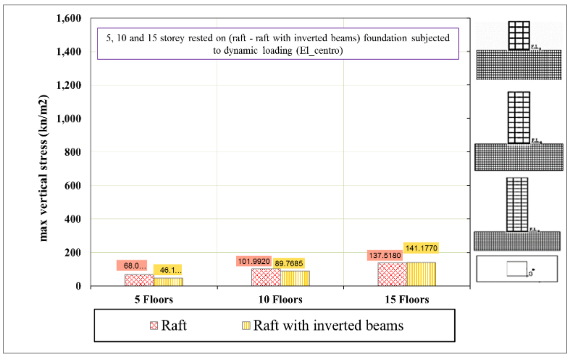

Figure [30]. Comparison vertical stress at point (3*).

From previous results it is clear that vertical stress increase with increasing number of floors and two types of foundation almost have nearby values for corner, but raft with inverted beam has large values for central point. For soil corner point is more critical, also for foundations corner point is more critical.

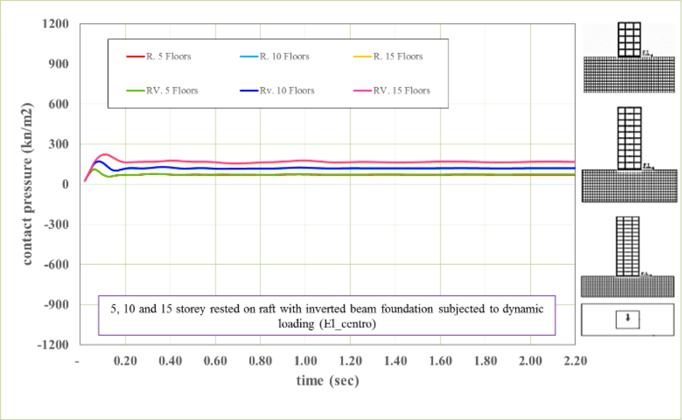

Figure [31]. Contact pressure at point (1).

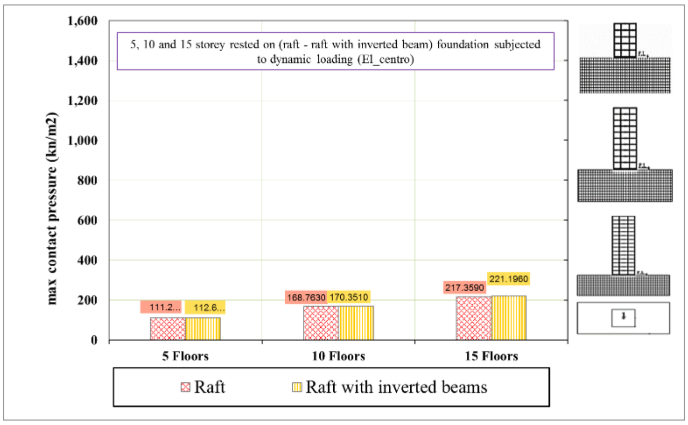

Figure [32]. Comparison contact pressure at point (1).

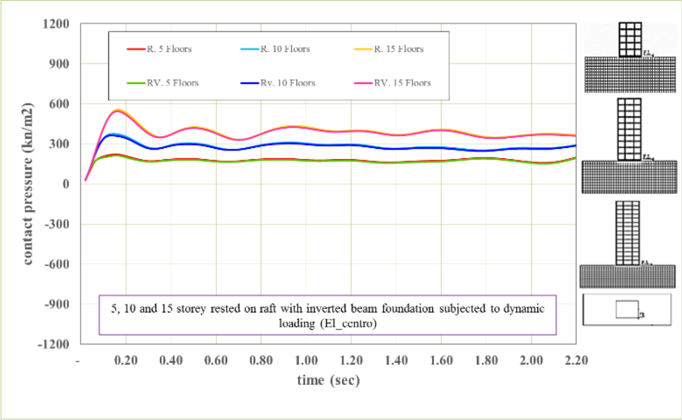

Figure [33]. Contact pressure at point (3).

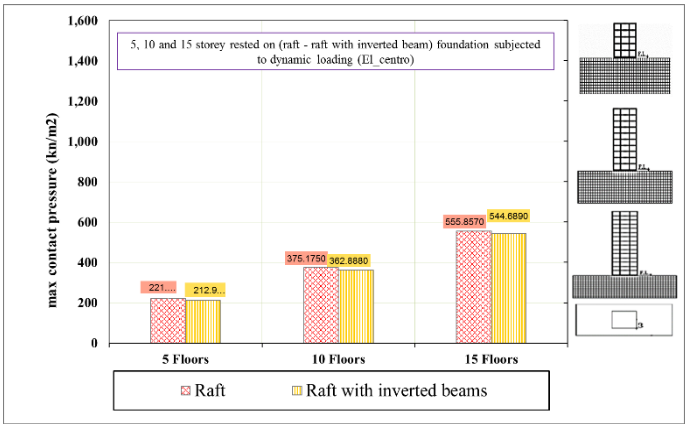

Figure [34]. Comparison contact pressure at point (3).

From previous results it is clear that contact pressure increase with increasing number of floors and two types of foundation almost have nearby values. For contact pressure, corner point is bigger than central point.

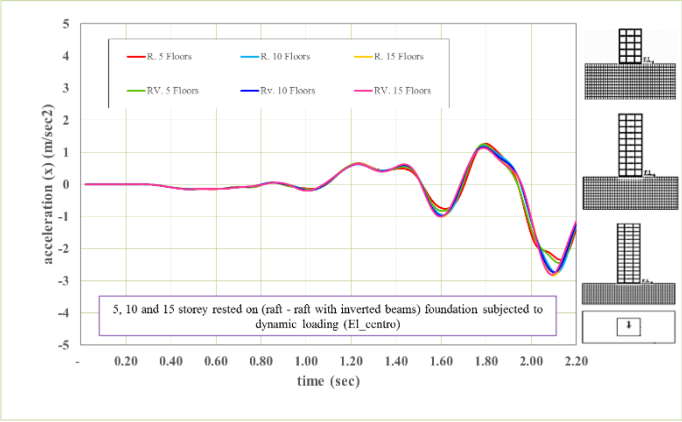

Figure [35]. Acceleration (x) at point (1).

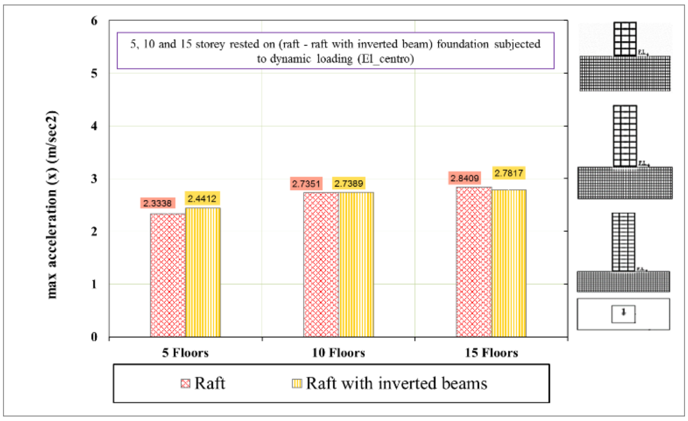

Figure [36]. Comparison acceleration (x) at point (1).

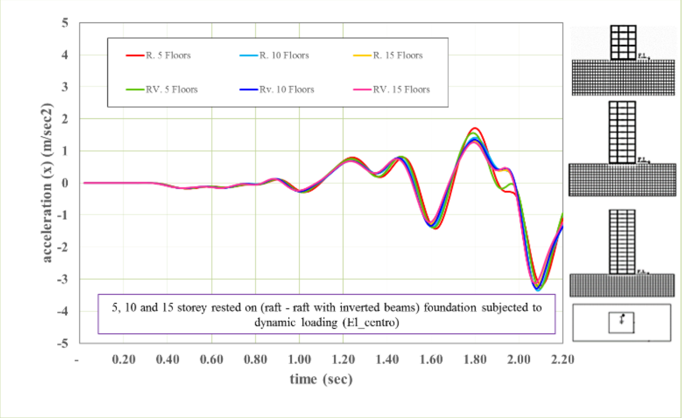

Figure [37]. Acceleration (x) at point (1*).

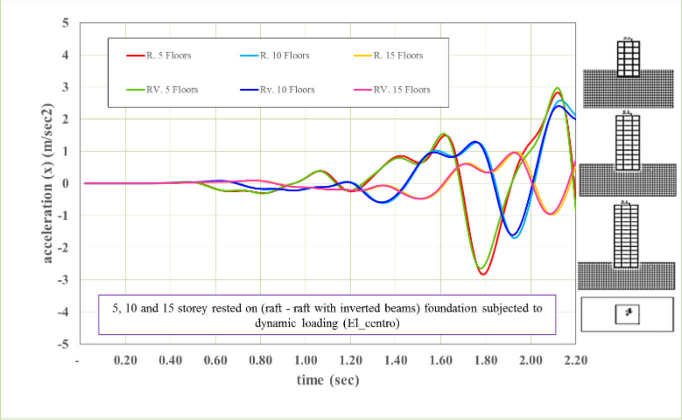

Figure [39]. Acceleration (x) at point (4).

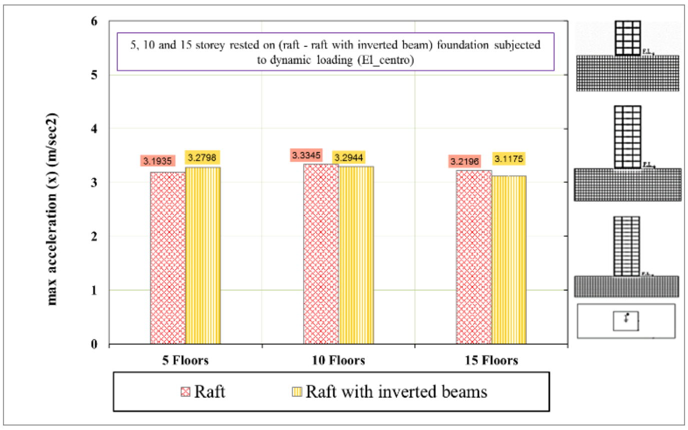

Figure [38]. Comparison acceleration (x) at point (1*).

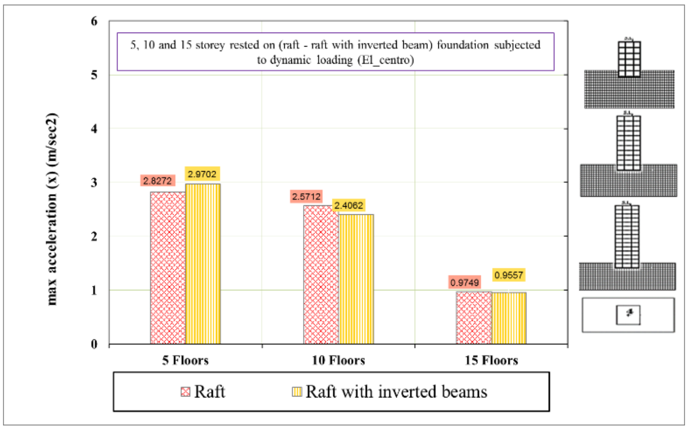

Figure [40]. Comparison acceleration (x) at point (4).

From previous results it is clear that acceleration is almost nearby for soil and foundation, but for last floor it decreases with increasing number of floors and two types of foundation almost have nearby values. For acceleration points closer to ground is bigger than others.

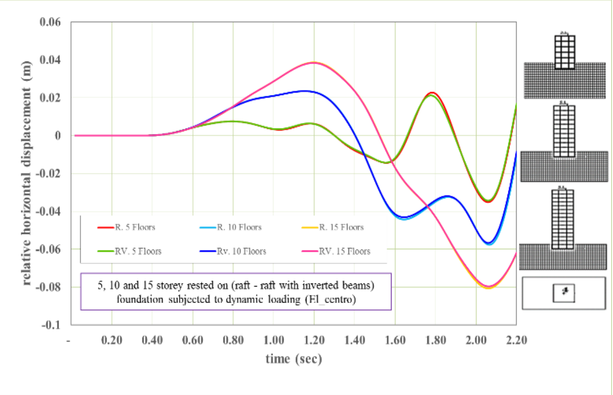

Figure [41]. Relative horizontal displacement at point (4).

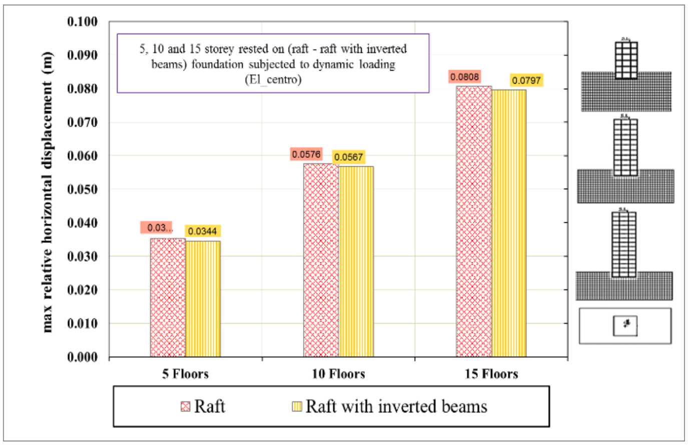

Figure [42].Comparison relative horizontal displacement at point (4).

From previous results it is clear that relative H.Z displacement increase with increasing number of floors and two types of foundation almost have nearby values, although raft with inverted beam has small value of H.Z displacement.

5. CONCLUSION

From the finite element results it can be concluded the following points:

1- Vertical displacement in soil is near to be equal for two foundations types, also for raft. Vertical displacement increases with increasing number of floors.
2- Vertical stress of soil is near to be equal for two foundations types but for raft in case of raft with inverted beam at center is bigger than case of raft. Vertical stress increases with increasing number of floors.
3- Contact pressure between soil and foundation is near to be equal for two foundations types at center and corner. Contact pressure increases with increasing number of floors.
4- Acceleration in x-direction for raft is smaller than raft with inverted beam at center of soil, raft and final slab for 5.0 floors, but it is equal in case of 10.0 floors except at final slab it is bigger for raft and it is smaller in case of 15.0 floors in all cases. Acceleration in x-direction almost equal at center of soil and raft, but it decreases at center of final slab with increasing number of floors.
5- Relative horizontal displacement in x-direction for raft is bigger than raft with inverted beam at center of final slab. Relative horizontal displacement in x-direction increases with increasing number of floors at center of final slab.

All previous points strongly prove that raft with inverted beam behaves better and improved results as relative horizontal displacement, also it is cheaper than raft, although it is equal to 70 % of raft inertia. So that in dynamic it is better to use raft with inverted beam than raft foundation because it is expected to resist dynamic loads better.

REFERENCES

1- Akl, S. A., and K. G. Metwally. "Optimizing Arching Creation for Abou Muharik Tunnel in Egypt Using Numerical Analysis." KSCE Journal of Civil Engineering 21.1 (2017).
2- ANSYS. (1998), " ANSYS User's Manual Revision 5.5 ", ANSYS, Inc., Canonsburg, Pennsylvania.
3- Bhutia, L. T. T. and Et al (2016), " Comparative study on seismic analysis of r.c structure with fixed and spring base in different zones and soil types considering soil structure interaction ", International Journal on Recent and Innovation Trends in Computing and Communication, vol. 8, No. 2, pp. 286 – 292, ISSN: 2321-8169.
4- Gazetas , G. and Marios Apostolou, M. (2004), " Nonlinear Soil–Structure Interaction: Foundation Uplifting and Soil Yielding " , Proceedings of third joint United States–Japan workshop on soil–structure interaction, California.
5- Kumar, V. (2009), " Dynamic analysis of soil raft structure system " , Lecturer, Department of Civil Engineering, Motilal Nehru National Institute of Technology, Allahabad–211 004, IGC, Guntur, INDIA.
6- Molla, A. K. M. and Ray, P. D. (1994), " Analysis of flexible rectangular raft foundations Under dynamic loading ", Computers & structures, Vol.52, No.5, PP. 1079-1091.
7- Nguyen, V. Q. And Et al (2016), " The effects of foundation size on the seismic performance of buildings considering the soil-foundation-structure interaction ", Structural Engineering and Mechanics, Vol. 58, No. 6, pp. 1045-1075