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Non-linear Behavior of Turbine-Generators supporting structure under blast load using finite element analysis

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ABSTRACT: Research on the effects of blast loads on concrete structures has been conducted extensively in recent decades. This is primarily due to the increasing risk of deliberate explosive attacks, accidental explosions, and other types of explosion-related failures that structures worldwide are facing. The magnitude of blast loads generated by most explosions far exceeds the design loads considered in traditional structural design. Consequently, this heightened awareness has prompted building owners, government agencies, and design professionals to prioritize the ability of buildings to withstand blast loading and ensure the survival of structures in the face of constant global terrorist attacks.

This research paper focuses on the modeling and dynamic analysis of the foundation of a steam turbine generator, which is an important and valuable element. While there have been previous studies on the behavior of reinforced concrete (RC) structures under blast loads, this paper specifically examines the nonlinear dynamic responses and failure behaviors of the supporting structure of turbine generators subjected to blast loads using Explicit Dynamic Analysis in Ansys Workbench. The study investigates the effects of middle-rate impact loading stresses on the blast responses of RC structures. By conducting dynamic analysis using Ansys Workbench, the researchers found that the RC structure is significantly influenced by the blast load. Moreover, they observed that the effect of the blast load decreases as the distance between the TNT source and the RC structure increases.

Keywords: Steam; Turbine; Generators; Blast Load; Explosion; Finite Element Analysis; Ansys Workbench; Explicit Dynamic.

INTRODUCTION

Turbine generator machines are the most important parts of any power station. As a result, for any developed or developing nation, the capacity to supply limitless energy not only ensures steady industrial growth but also greatly improves the quality of life in the long run. The main source of this energy is clearly electricity, and this is what the turbine generator machines supply. The turbine generator machine is one of the most important and complicated systems in design, manufacturing, and testing. The weight of the turbine generator machine is very large. This weight usually ranges from 6000 KN to 17000 KN and is fixed to a large, massive concrete foundation pedestal shown in **Error! Reference source not found.**).[1]

The concept of mathematical models has been widely embraced by researchers in order to effectively capture the dynamic response of machine foundations under the influence of dynamic loading. In light of this, the American Society of Civil Engineers has published a book that specifically focuses on the design aspects of concrete turbine

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generator foundations. The book encompasses various important areas such as turbine generator equipment, turbine generator foundation layout and sizing, as well as foundation loads and load combinations. By delving into these specific topics, the book aims to provide comprehensive guidance and insights for engineers involved in the design process of turbine generator foundations. By offering a thorough understanding of these key aspects, the book ultimately aims to enhance the overall quality and effectiveness of turbine generator foundation designs.[2]

If the foundation supporting critical machines malfunctions and causes the machine to trip during operation, it can lead to significant losses for end users and industries reliant on the generated power. In severe cases, this can even have a detrimental impact on the economic growth of an entire country. Therefore, two crucial aspects are essential for the successful operation of these machines: ensuring the smooth functioning of the machine itself around the clock, and ensuring that the foundation can withstand the various loads exerted by the operating turbine (dynamic loads), as well as external factors such as earthquakes and explosions. This research aims to analyze the impact of these governing parameters on the overall response of the foundation. Additionally, the study will examine the response of the turbine generator foundation to blast loads.

In order to maintain the reliable operation of critical machines, it is imperative to address any potential issues with the foundation. The foundation serves as the base that supports the machine and absorbs the dynamic loads it generates during operation. If the foundation is unable to withstand these loads, it can result in the machine tripping, leading to disruptions and losses.

The consequences of such disruptions can be severe. End users who rely on the power generated by these machines may experience interruptions in their daily operations, resulting in financial losses. Industries that heavily depend on the consistent power supply may face production delays or even complete shutdowns, leading to significant economic repercussions. In the worst-case scenario, the impact can extend beyond individual industries and affect the overall economic growth of a country.

To prevent such undesirable outcomes, it is crucial to ensure that both the machine and its supporting foundation are functioning optimally. The machine itself should be well-maintained and undergo regular inspections to identify any potential issues or malfunctions. Additionally, the foundation should be designed and constructed to withstand the various loads exerted by the turbine during operation.

This research aims to study the factors that influence the global response of the foundation. By understanding these governing parameters, engineers and designers can develop more robust foundations that can withstand the dynamic loads imposed by the turbine. Furthermore, the study will also investigate how the foundation responds to blast loads, which can result from natural disasters or other unforeseen events.

By gaining insights into these aspects, the research aims to contribute to the development of more reliable and resilient foundations for critical machines. This, in turn, will help ensure the uninterrupted operation of these machines, preventing potential losses for end users and industries alike. Ultimately, the findings of this research can have significant implications for the overall stability and economic growth of a country.[1]

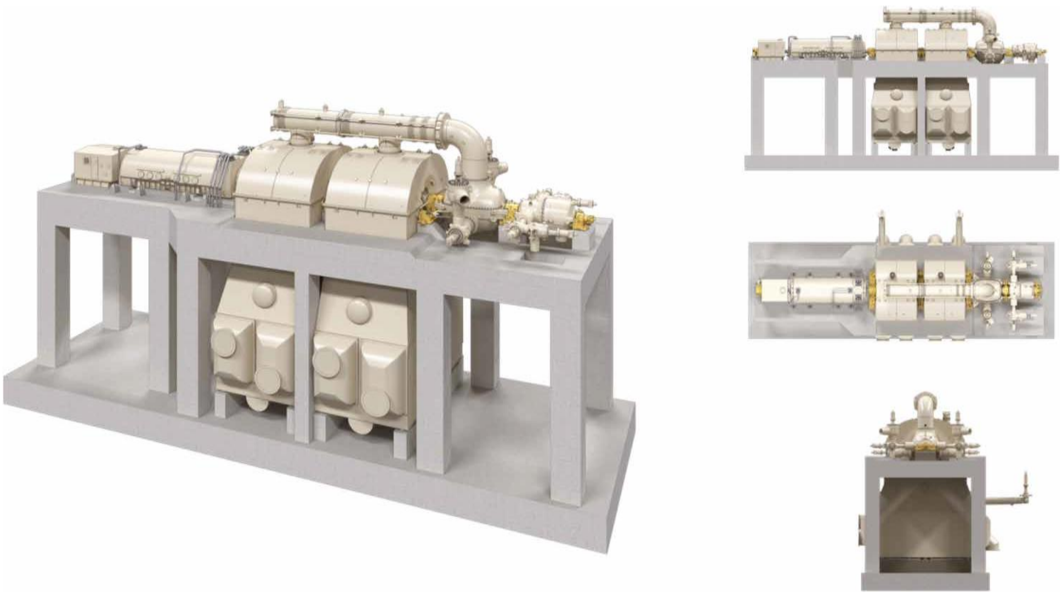

Figure (1) STG arrangement: HP-IP-LP-LP with bottom exhaust. [2]

The purpose of this book on finite element dynamic study is to explore the behavior of large-framed foundations under dynamic loading, with a specific focus on the response of a steam turbine generator foundation. The study examines various types of machine foundations, the loads they experience, and their behavior when subjected to dynamic loading.[3]

One notable example of a large-framed machine foundation is the steam turbine generator foundation, and the research presented in this book focuses on a specific case study of a Hitachi 650 MW steam turbine generator. This particular machine is the largest of its kind currently in operation in Egypt.

To accurately model such a large-framed foundation, a 3D model using tetrahedral solid elements is created using ANSYS finite element software. The main objective of this paper is to analyze the dynamic response of the turbine generator frame under the influence of blast loads, specifically the effect of a known quantity of TNT at a certain distance from the reinforced concrete structure.

It is important to note that blast loads differ from seismic loads in terms of their characteristics. Blast loading is characterized by extremely high intensity, localized effects, and short durations, typically lasting only milliseconds. In contrast, seismic loading has lower intensity, affects the entire structure, and can last from a few seconds to over a minute.

By studying the dynamic response of the large-framed foundation of a steam turbine generator to blast loads, this research aims to provide valuable insights into the behavior and performance of such foundations under extreme loading conditions. The findings of this study can contribute to the design and optimization of machine foundations, ensuring their structural integrity and reliability in various operating environments.[3]

CASE STUDY

This case study focuses on the turbine generator concrete pedestal used in the Hitachi turbine generator machine at the El Sokhna thermal power plant in Egypt. This power plant is notable for being the first thermal supercritical power plant in the country, boasting a capacity of 1300 MW. It consists of two steam turbine generator units, each with a capacity of 650 MW, resulting in a total capacity of 1300 MW. Each unit is composed of a generator, a high-pressure turbine, and two low-pressure turbines. The entire set weighs approximately 1700 tons and is supported by a large concrete pedestal.

The sensitivity of this machine arises from the deflection criteria set by the manufacturer for its operation. Hitachi, the supplier of the turbine generator machine for the EL SOKHNA project, specifies a maximum allowable amplitude (deflection) of 34 microns peak to peak at the bearing locations. If the machine's bearings exceed this limit, the machine will automatically shut down, causing a disruption in the electricity supply throughout Egypt. In other words, 1300 MW of power will be lost from the national grid. Due to the critical nature of this machinery, numerous studies have been conducted to ensure the stability and performance of the machine foundation.

The selection of the ANSYS package for dynamic analysis in this study is based on the understanding of the machine's sensitivity and the need for accurate and reliable results using sophisticated software. ANSYS is chosen for its advanced computational capabilities, offering speedup ratios that are five to 10 times higher than other software or previous ANSYS releases. This ensures that the analysis is conducted with the utmost precision and efficiency.[2]

METHODOLOGY

Explicit Dynamic System in ANSYS Workbench v. 19.0 is used as an analysis system to apply dynamic loads.

The materials used in this Modeling are Concrete-NL with principle strain failure properties, non-linear concrete properties, a density of 2314 kg/m^3, Structural Steel-NL as a high tensile reinforcement steel with a density of 7850 kg/m^3, Young's modulus of 200E05 MPA, Poisson's ratio of 0.3, and TNT material as a blast loading source with a density of 1630 kg/m^3.

The Loads in this modeling are Foundation Self-weight and Equipment Loads, including machine weights, normal operation loads, emergency operation loads, and catastrophic equipment loads. Environmental Loads include seismic, wind, and snow loads; installation and maintenance loads include equipment laydown and rotor removal loads, as well as live loads on the tabletop and basemat. Blast pressure can create loads on buildings that are many times greater than normal design loads, So Operation loads will be neglected.[5] the concrete damage plasticity model was used for the concrete material. The stress-strain curves used for the damaged concrete plasticity model are obtained. The stress-strain curves are based on the material properties of Chopra and Chakrabarti, which are designed to model the behavior of concrete structures under blast loads.[4]

VERIFICATION

A 100-kg ANFO explosion occurred on an RC Column with fixed-fixed supports. The blast wave reached the bottom-front gauge, resulting in a peak pressure of 1378.64 MPa. The finite element analysis conducted using the program yielded a result of 1390.82 Mpa. After analyzing the practical experience and analytical program in the four designated locations depicted in the diagram, it is evident that the average match percentage is as high as 97% Shown in Figure (2).[5]

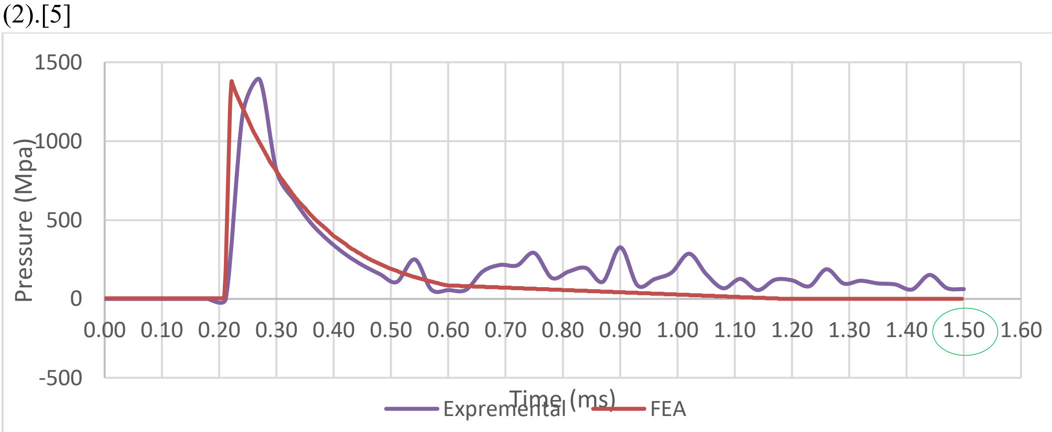

Figure (2) Verification of Blast Pressure.

RESULTS

Explicit Dynamic Analysis is performed to determine the impact of blast load and vertical displacement caused by 1000 Kg of TNT at distances of 2.5, 5, and 10 meters in the short and long directions of the frame. The location of the TNT at the top and bottom is illustrated in Figure (3) and Figure (4).

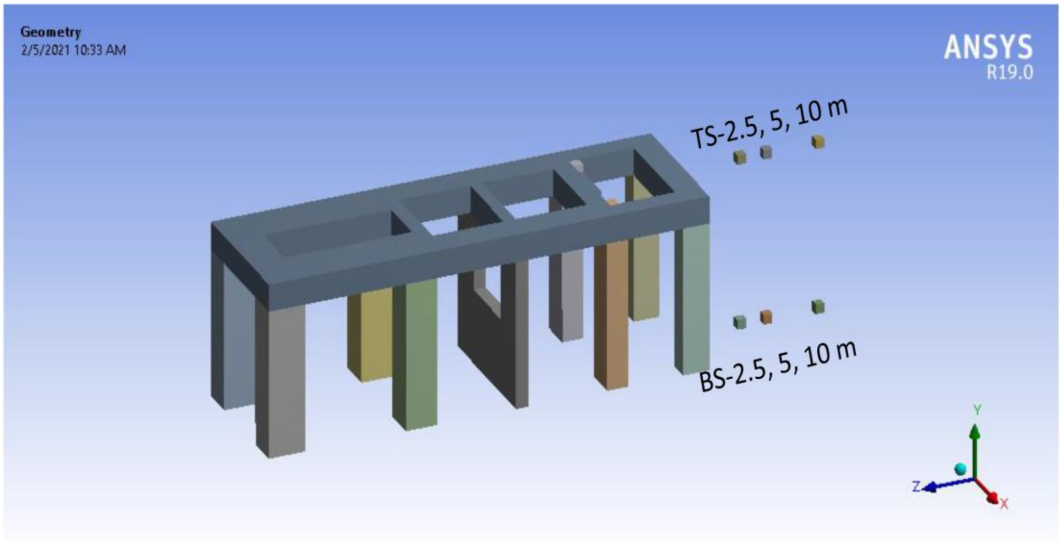

Figure (3) T Figure (4) Top/Bottom Location of TNT at the Long Direction of the Frame

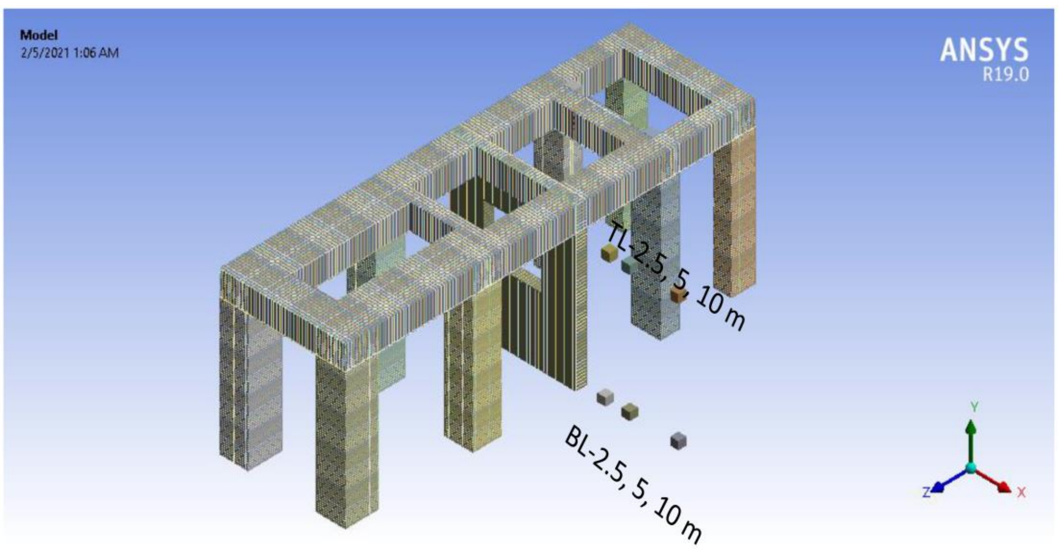

Fig. 4 Top/Bottom Location of TNT at the Short Direction of the Frame

- **Pressure in Short Direction Bottom / Top of TNT:**

The pressure values were not present within a 5-meter range, but they varied at a distance of 10 meters for all points. Point B had the highest value, reaching 4.6 MPA, which is a 4.5 meter increase from the bottom (the location of the explosion). This is illustrated in Figure (5).

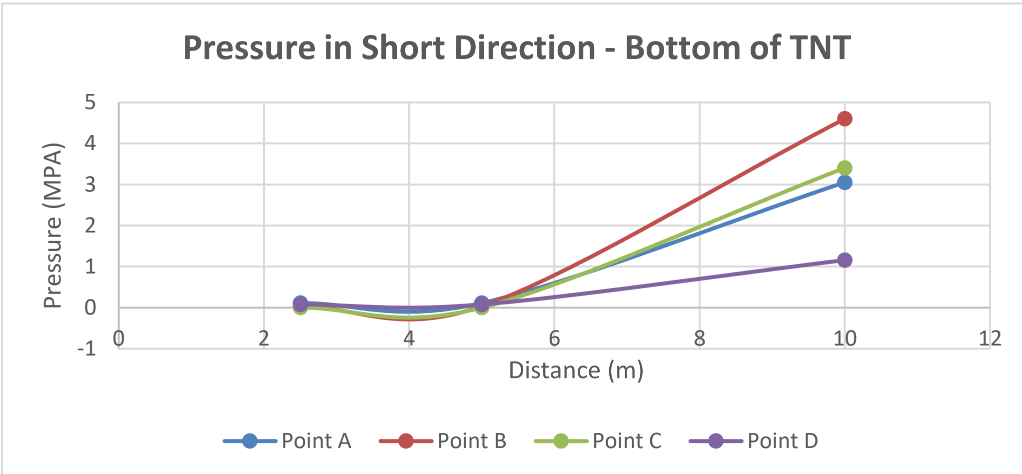

Figure (5) Pressure in Short Direction Bottom of TNT

If the explosive source is also at the top, the pressure effect diminishes as the distance gets closer, up to 5 meters. However, at a distance of 10 meters, particularly at point D, the pressure value reaches its maximum of 44.125 MPA, as depicted in Figure (6).

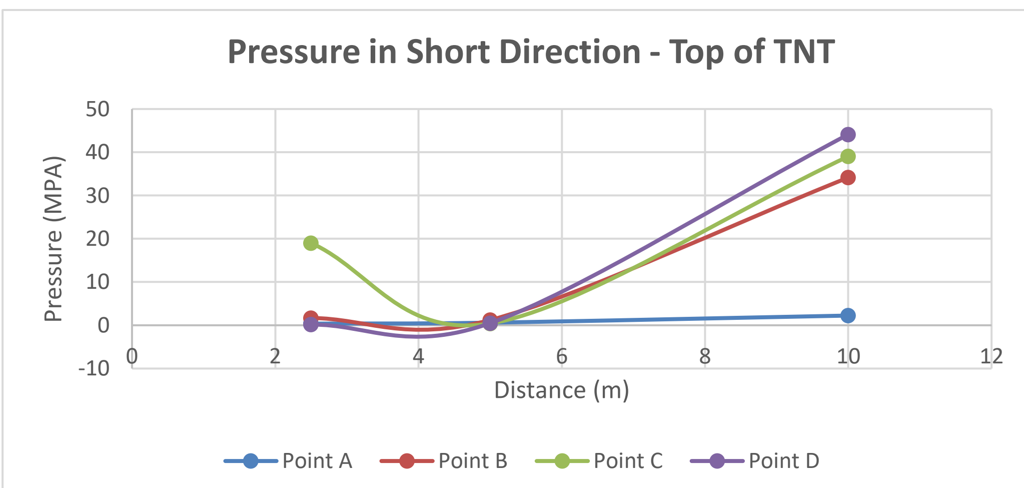

Figure (6) Pressure in Short Direction Top of TNT

- **Pressure in Long Direction Bottom / Top of TNT:**

The pressure resulting from the detonation changed longitudinally, with the highest value observed at a distance of 5 meters. At distances of 2.5 meters and 10 meters, the pressure was almost non-existent.

The pressure effect from the explosion disappears at point D due to the distance between the explosion source and that point, as shown in Figure (7).

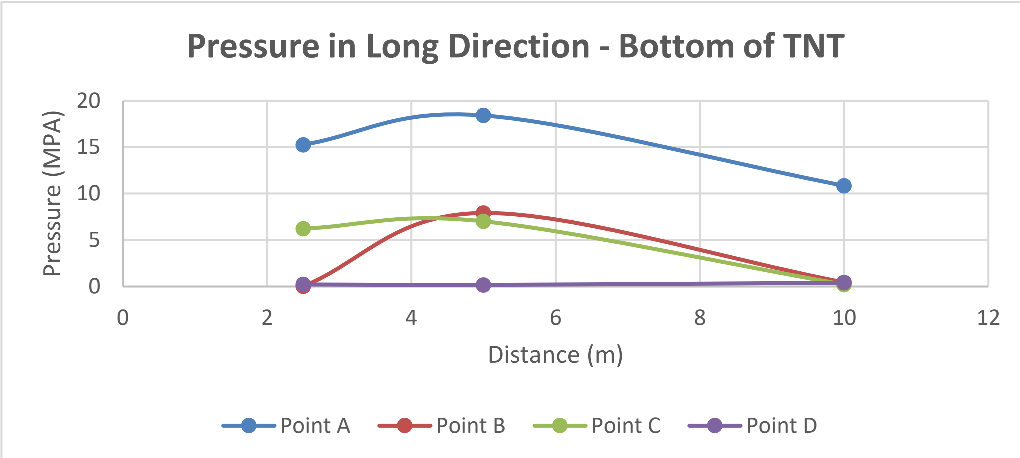

Figure (7) Pressure in Long Direction Bottom of TNT

The pressure effect from the explosion disappears at point D in Figure (8) because the explosion source is far from that point.

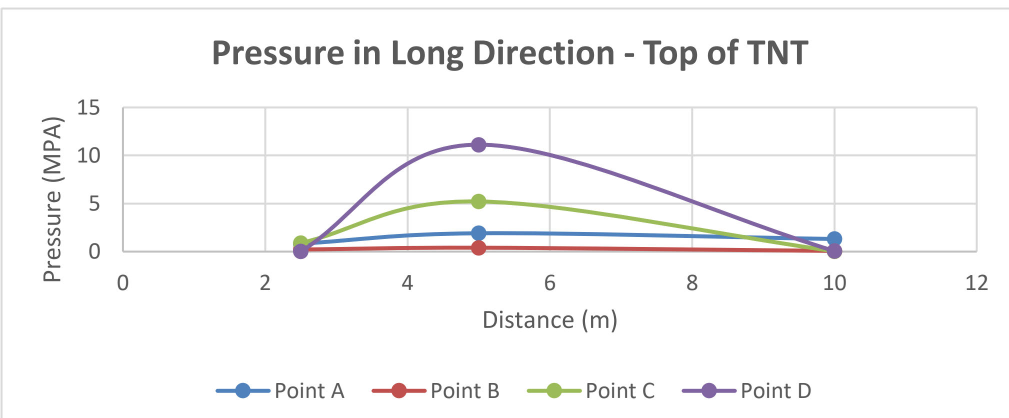

Figure (8) Pressure in Long Direction Top of TNT

- **Vertical Displacement in Short Direction Bottom / Top of TNT:**

The explosion affected most of the eight points, causing the turbine generators to stop because of the vertical displacement for all points were greater than 34 micron. However, the impact varied depending on the distance between the explosion source and the points, as illustrated in Figure (9), Figure (10), and Figure (11).

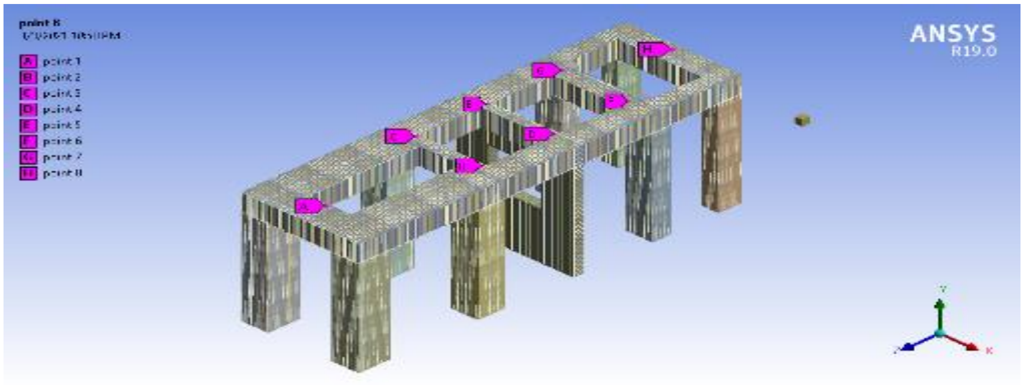

Figure (9) Vertical Displacement in Short Direction Bottom/Top TNT

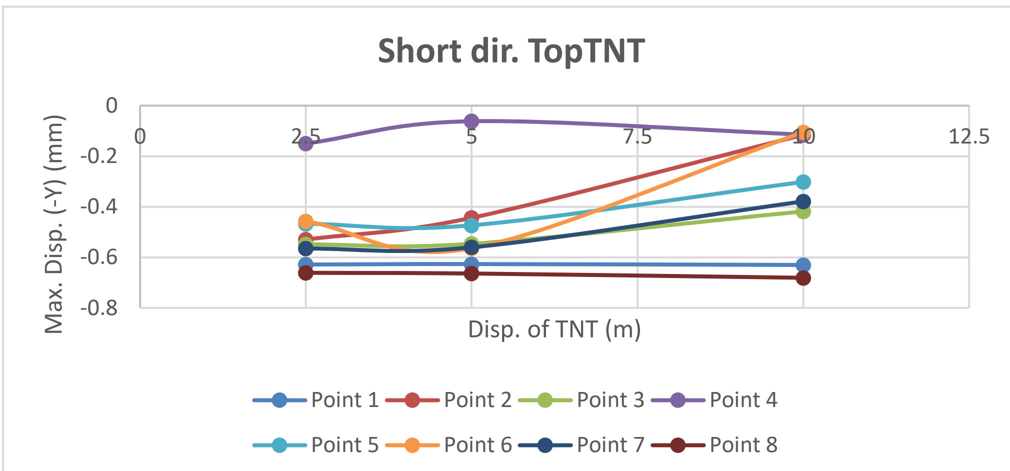

Figure (10) Vertical Displacement in Short Direction Bottom TNT

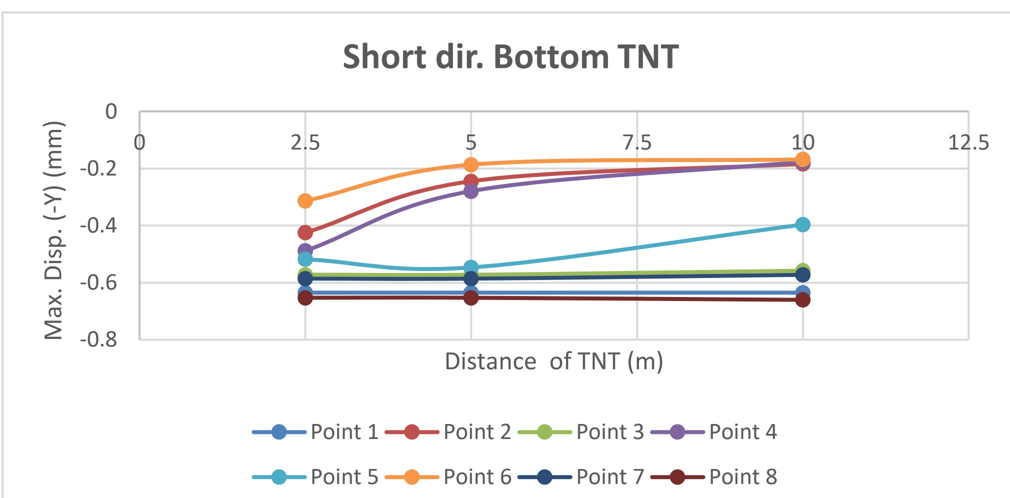

Figure (11) Vertical Displacement in Short Direction Top TNT

- **Vertical Displacement in Long Direction Bottom / Top of TNT:**

The explosion affected most of the eight points, causing the turbine generators to stop because of the vertical displacement for all points were greater than 34 micron. However, the impact varied depending on the distance between the explosion source and the points, as illustrated in Figure (12), Figure (13), and Figure (14).

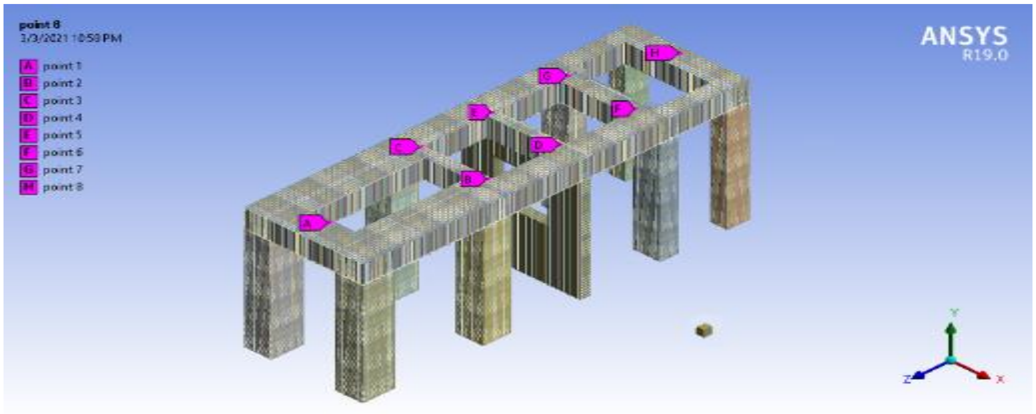

Figure (12) Vertical Displacement in Short Direction Bottom/Top TNT.

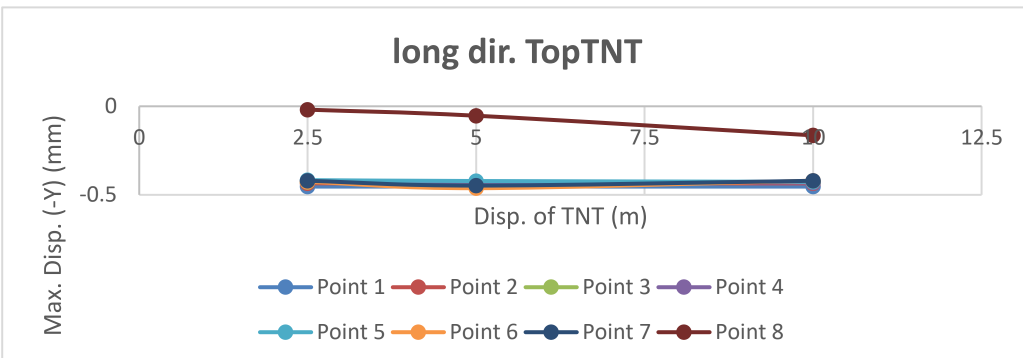

Figure (13) Vertical Displacement in Long Direction Bottom of TNT.

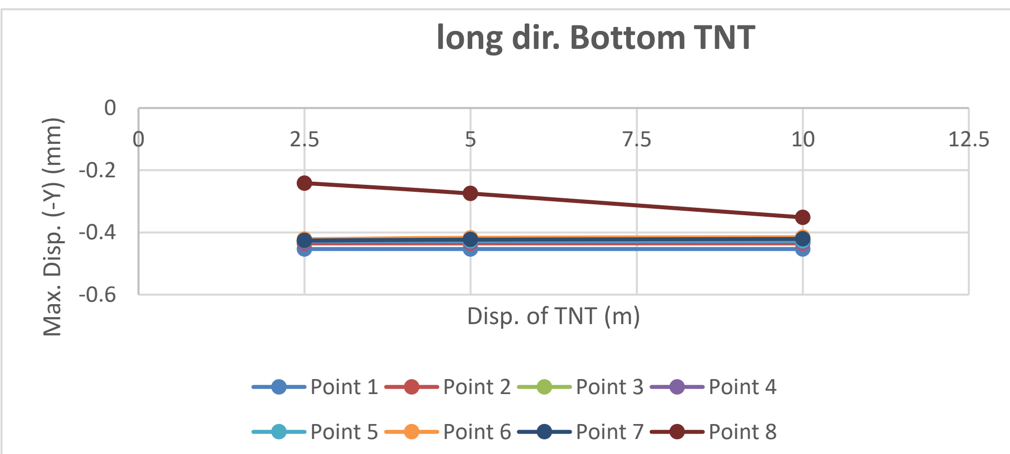

Figure (14) Vertical Displacement in Long Direction Top of TNT.

CONCLUSIONS

The purpose of this thesis is to highlight on the machine foundations types, applied loads and behavior under dynamic loading in general and to study the response of large framed foundation in particular. The famous example of the large framed machine foundation is the steam turbine generator foundation. The case study introduced in this thesis is a HITACHI 650 MW steam turbine generator, this machine is the largest machine operated in Egypt until now. To model such large framed foundation an ANSYS Workbench finite element 3D model is build using multi zone method mesh elements. The analyses performed is Explicit Dynamics analysis.

The main aim of this thesis is to study the effect of Blast load by changing the distance of TNT source (2.5 meters, 5 meters, and 10 meters), location of TNT and the frame (Top and Bottom). Also, a damage check is performed to determine the foundation response to application of blast loads using two approaches: (1) by applying the blast load in the longitudinal direction, (2) by applying the blast load in the latitudinal direction.

A case study of a simple structure subjected to blast load was analyzed, and the results were recorded. A study of the effect of strengthening concrete on the behavior of a structure subjected to blast loads was conducted. And the effect of changing the blast location was studied.

1. The concrete body is an excellent barrier against blasting damage.
2. The maximum impact of the explosion is at an angle of 22.5 to 45 degrees.
3. All the studied cases led to the turbine generator stopping working while preserving the integrity of the concrete structure.
4. The enormity of the concrete origin is a reason for resisting the effects of blasting.

FUTURE WORK

1. The effect of dampers can be used.
2. Concrete fenders can be used to block the explosive waves.
3. Steel sections can be used to protect the concrete body.
4. Different types and quantities of explosions can be used at distances greater than 10 meters.

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