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Stability Analysis on Tower Crane Foundation Using Finite Element Method

(Analisis Kestabilan Asas Bagi Kren Menara Menggunakan Kaedah Unsur Terhingga)

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ABSTRACT

Currently, the construction of high-rise buildings is increasing as the modernization of the city. Especially in the heart of Kuala Lumpur City, construction is more focused on the construction of high-rise buildings due to over-crowded areas. To meet demand due to the activity, the number of tower cranes brought into Malaysia has increased. The tower crane is used to lift construction items and requires a solid base to ensure tower crane stability. Analysis obtained from the Department of Occupational Safety and Health (DOSH), the rate of accidents involving in particular the use of cranes tower cranes occurred due to the failure of the crane foundation. The main objective in carrying out this project is to ensure the stability of the foundations for ensuring the safe use of tower cranes in reducing accident site, determine the calculation of the basic design of the site and the last one is to analyze the stability of the soil through the interaction between the soil and the basic structure of the site. Design calculations from qualified engineers as well as engineering software for analysis tests are an important element in the success of this research project. Among the parameters required are ground properties information for the installed tower cranes, engineering drawings for tower crane structure and Plaxis 3D computer software for analysis purposes. The implication of this project is to achieve the department's quality policy in providing and maintaining a quality, safe and healthy work and system without any harm and risk.

Keywords: Departmental of Occupational Safety and Health (DOSH); tower crane foundation, micropile, deflection, settlement

ABSTRAK

Ketika ini, pembinaan bangunan-bangunan tinggi semakin bertambah seiring dengan pemodenan bandar. Khususnya di tengah-tengah Bandaraya Kuala Lumpur, pembinaan lebih fokus kepada pembinaan bangunan-bangunan tinggi disebabkan kawasan yang terlalu padat. Bagi memenuhi permintaan disebabkan aktiviti tersebut, bilangan kren menara yang dibawa masuk ke Malaysia semakin bertambah. Kren tersebut digunakan untuk mengangkat barang-barang pembinaan dan memerlukan asas tapak kukuh bagi menjamin kestabilan kren. Analisa yang diperolehi daripada Jabatan Keselamatan Dan Kesihatan Pekerjaan (JKKP), kadar kemalangan yang berlaku melibatkan penggunaan kren khususnya kren menara terjadi disebabkan kegagalan asas tapak kren tersebut. Objektif utama dalam menjalankan projek ini adalah untuk memastikan kestabilan asas tapak bagi menjamin keselamatan penggunaan kren menara di dalam menurunkan kadar kemalangan tapak bina, menentukan pengiraan rekabentuk asas tapak dan yang terakhir sekali adalah untuk menganalisa kestabilan tanah melalui interaksi antara tanah dan struktur asas tapak tersebut. Pengiraan rekabentuk daripada jurutera bertauliah selain perisian kejuruteraan untuk ujian analisa dijalankan merupakan elemen penting dalam menjayakan projek kajian ini. Antara parameter-parameter yang diperlukan adalah maklumat sifat-sifat tanah bagi lokasi kren yang dipasang, lukisan kejuruteraan bagi struktur tapak kren menara dan perisian komputer Plaxis 3D bagi tujuan analisa. Implikasi projek ini adalah untuk mencapai polisi kualiti jabatan dalam menyediakan dan menyelenggara tempat kerja dan sistem yang berkualiti, selamat dan sihat tanpa sebarang bahaya dan risiko.

Kata kunci: Jabatan Keselamatan dan Kesihatan Pekerjaan (JKKP); asas tapak kren Menara; cerucuk mikro; pesongan; enapan

INTRODUCTION

Mostly construction industry in Malaysia will use the tower crane for mechanical loading transport appropriate to the situation of construction activities. The optimum location and choice of crane on a site is seen as one of the most important parts of construction planning (Furusaka & Gray 1984). A tower crane is a common piece of mechanical equipment in a modern construction site, especially in construction of tall buildings, and often provides the best combination of height and lifting capacity as mentioned by Kodikara & Samararatne (2014). For optimum design for tower crane foundation, Kim et al. (2011) find that the stability of a tower crane basically depends on the choice of the model, which is based on its lifting load, and the construction site conditions, more specifically the length of the jib, its self-standing height, the lateral supports, the foundations, etc. Therefore, to ensure the stability of the tower cranes during the construction period, the tower crane foundation shall be safely designed securely by taking the factors of soil strength where the tower crane location is installed. In conclusion as summarized by Skinner et al. (2006) in Contractor Final Report 2005, no excavation was allowed adjacent to the foundations of the tower crane. It is proved by mechanical analysis referred to Figure 1(a); how the foundation was designed to displace when subjected to the mechanical moment applied by eccentric vertical load in the arm and Figure 1(b); after removing the ground around the pile cap, the cap was no longer laterally restricted. As piles lost skin friction, the four piles did not act as cluster. Bending loads sustained by individual piles increased because of the modification of boundary conditions (Marquez et al. 2014).

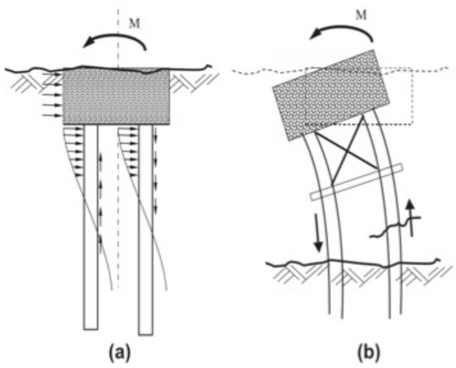

FIGURE 1. Simple mechanical model of foundation (a) As designed, (b) Bending loads by individual piles after loss of ground support.

In the analysis and design of geotechnical engineering, there are many things that professional engineers are not sure should be considered include:

1. Insufficient knowledge of underground layers.
2. Determination of the nature of land inaccuracies.
3. Relative interaction between structure and soil.

The finite element method known as FEM is one of the latest computing methods in solving engineering problems. For this research, Plaxis 3D was the chosen FEM method programme to analyse the foundation of tower crane.

METHODOLOGY

Site selection was carried out by searching for construction sites around the Klang Valley which used tower crane as lifting construction medium. The study commenced by the process of data collection which was done through two methods; site visits and documents reviews. Once the required data was obtained, document review was done before modeling using Plaxis 3D software made for both tower crane at sites. The results obtained were then compared and confirmed by the analysis.

In this study, two different tower crane models were built in two different boreholes. The maximum load borne by a tower crane base, TC1 and TC2 are shown in Table 1. Safety factors used for the calculation of the design is 1.5.

TABLE 1. Details information of tower crane foundation built

	TC 1	TC 2
TOWER CRANE MODEL	TOP SKY TL225	SANJ/CSC D5020
FOUNDATION SIZE (mm X mm)	5750 X 5750	5500 x 5500
	CRITICAL LOAD	
AXIAL LOAD, P (kN)	1107.00	1038.00
MOMENT, M_V (kNm)	4516.50	3663.00
LATERAL LOAD, H (kN)	222.00	175.50
MICRO PILES SIZE (mm)	300	300
CAPACITY LOAD (kN/piles)	550	450
BUCKLING LENGTH (m)	9.4	10.4

Design of this tower crane site covers the basic design of tower crane foundation as well as the basics in reference to BS 8110 Part 1: 1985 "The Structural Use of Concrete" and BS 8004: 1986 "Design of Foundation". This design depends on the design of the structure that is the foundation structure of the tower crane foundation base with the three micro piles at every edge foundation as deep foundation structure as shown as Figure 2(a) and 2(b). The grade of concrete used for the tower crane foundation is G25.

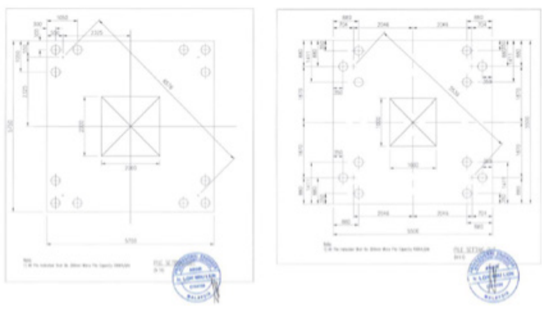

FIGURE 2. (a) TC1 Layout (b) TC2 Layout

In the process of designing the base of the tower crane, these assumptions were made:

1. Design calculations based on the load, reaction and the moment provided by the tower crane maker and can be referenced in the Operations Manual
2. The maximum number of poles installed for the stand tower crane is no more than 10 columns;
3. The safety factor used for this design calculation is 1.5; and
4. There shall be no machinery in operation or goods placed on the base of the tower crane.

The strength of the micro pile structure is calculated from the relative strength of the bond length at each possible types of soil at construction sites. The design will fail if the length of the micro pile exceeds the buckling length, *Lc* allowed and at a specified amount of load. To realize the design using finite element method, two essential elements are input and output data. Therefore, as initially, the input data, which is the tower crane foundation will be modeled. Models for the basics the TC1 and TC2 tower crane sites are as illustrated in Figure 3(a) and 3(b).

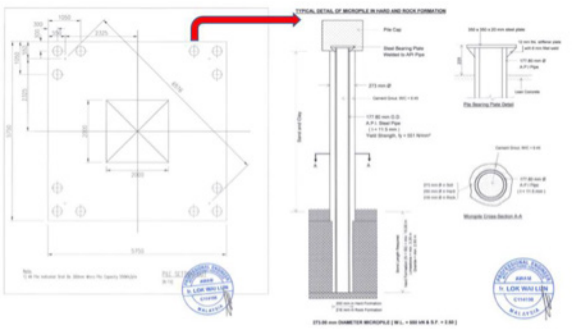

FIGURE 3(a). Model for TC1

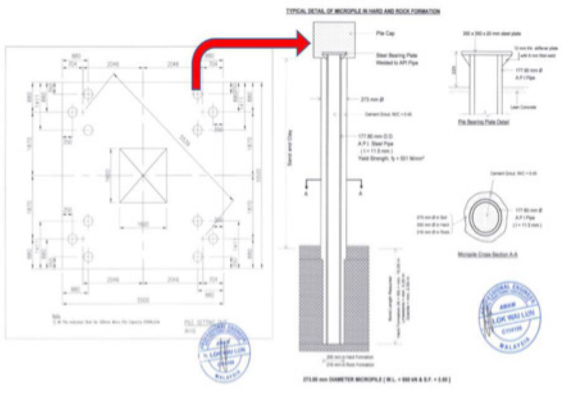

FIGURE 3(b). Model for TC2

The basic model is built, and the maximum load will be applied uniformly distributed load on the foundation tower crane site including self-weight of tower crane foundation and the maximum load. The amount of uniformly distributed load is as follows information inside Table 2.

TABLE 2. Distribution load applied to tower crane foundation

	TC1	TC2
SELF-WEIGHT	5.75 x 5.75 x 2.5 x 24 =1983.75 kN	5.5 x 5.5 x 2.7 x 24 =1960.2 kN
AXIAL LOAD, P (kN)	1107.00	1038.00
DISTRIBUTION LOAD PER METER	1983.75 + (1107 x 5.75 x 5.75) = 38 583.19 kN/m^2	1960.2 + (1038 x 5.5 x 5.5) = 33 359.7 kN/m^2

ANALYSIS AND DISCUSSION

In this study, the basic stability of the tower crane foundation was identified by reaction micro pile against vertical loads received from tower cranes. Discussions will be focussed on the

1. mechanism of load distribution,
2. maximum length of micro piles,
3. variation of micro pile displacement by depth
4. settlement
5. safety factor soil, and
6. the location of the micro pile beneath the tower crane foundation.

MECHANISM OF LOAD DISTRIBUTION

The actual load forced to the tower crane foundation is the sum of foundation self-weight and the load to be carried by the tower crane during construction run. The maximum load that a tower crane can carry is provided by the tower crane maker refers to the catalogue of model tower crane used on site. Each tower crane has a maximum load and tower cranes are not allowed to carry more than maximum allowable load. Overloaded load is likely to lead to failure of pole structure and tower crane jib structure besides leading to the failure of the tower crane's base due to the tower crane imbalance situation. Axial load that comes from tower crane are converted to uniformly distributed loads refer to the formula below and sum it up with the self-weight of foundation as showed as Figure 4.

$$w = P \text{ (load) } x \text{ } A \text{ (Area)} \tag{1}$$

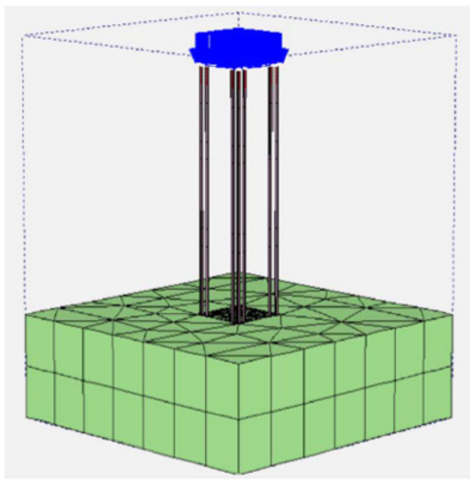

FIGURE 4. Distribution load analysis by Plaxis 3D

Although the position of the micro pile under tower crane foundation looks symmetrical, the results of the analysis are not the same. This is due to the surface of micro piles with plane symmetry gives different analytical results as shown in Figure 5. This is due to skin friction between the soil and each micro piles.

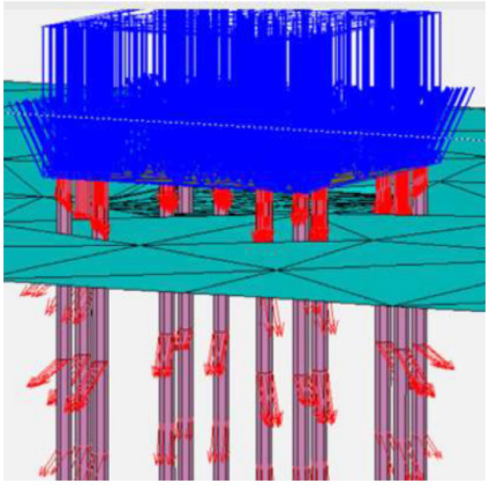

FIGURE 5. Reaction between micro piles with soil

MAXIMUM LENGTH OF MICRO PILE

The stability of the micro pile built to support the basic structure of the tower crane foundation is subjected to a vertical load, lateral load and moment applied. Micro piles tend to suffer due to deflection or bending strain in the soil mass as illustrated in Figure 6. Accordingly, the treatment and response of the soil to each pile length are required to achieve equilibrium. There are many factors that can affect the failure of a micro pile. One of the topics discussed in this study is the length of micro pile.

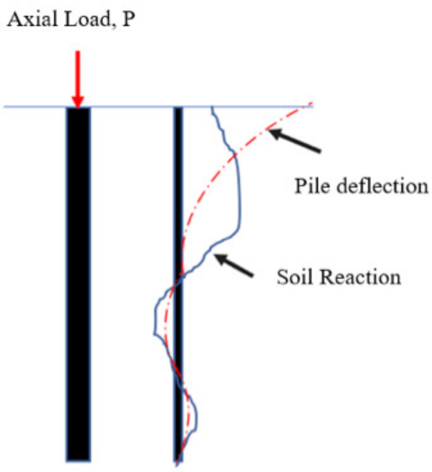

FIGURE 6. Reaction between soil-piles (structure)

The length of the micro bending is seen from the design calculations provided in accordance with BS 8110 Part 1: 1985- "The Structural Use of Concrete" and BS 8004: 1986 "Design of Foundation" in the formation of very soft soil using buckling length, *lc* such as below.

$$Buckling\ Length, l_c = \sqrt{\frac{\pi^2 \times E_s I_c}{K^2 \times P_{cr}}} \quad (2)$$

The micro pile will fail at an end beyond the maximum bending length by applying the allowable load on one micro pile. The allowable load of a micro pile used is 550 kN for the TC1 micro pile and 450 kN for the TC2 micro pile. Using the formula, the curvature length for TC1 micro pile is 9.42 m and 10.41 m for TC2 micro pile. Therefore, the length of the pile used should be less than the length of the curve.

In conclusion, the curvature of the pile is due to the problem of soil-pile interaction which is influenced by the pile dimensions and elastic behaviour, soil strength and stiffness as well as the load applied.

VARIATION OF MICRO PILE DISPLACEMENT BY DEPTH

Force from axial load to pile groups is difficult to be analysed due to the complex soil-structure (micro pile) interactions. The displacement and rotation will occur in the direction in which the load location is applied. The micro pile on the exterior is subjected to high attraction and compression response compared to the micro pile in the centre. This response can be seen in reference to the arrow showing the ground reaction force with the structure in Figure 7.

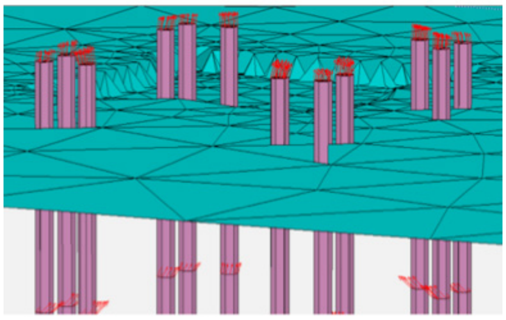

FIGURE 7. The pile reaction between soil-piles (structure) is different for each individual piles and different location of piles

The reaction between soil-pile group to the load imposed is influenced by:

1. geometry of micro pile assemblies
2. interaction between pile
3. the strength or bending of the pile
4. condition of the load used
5. individual reaction of pile
6. decomposition of pile reaction depends on individual pile reaction

The reaction between the micro pile and soil was studied by taking the deflection or displacement readings of each pile. For each of the different depths, readings of each of the twelve micro piles were considered to study the effects of deflection. The results of the analysis are summarized in Figure 8 and 9 and classified according to pile groups as in Figure 10 and 11 for the TC1 and TC2 foundation.

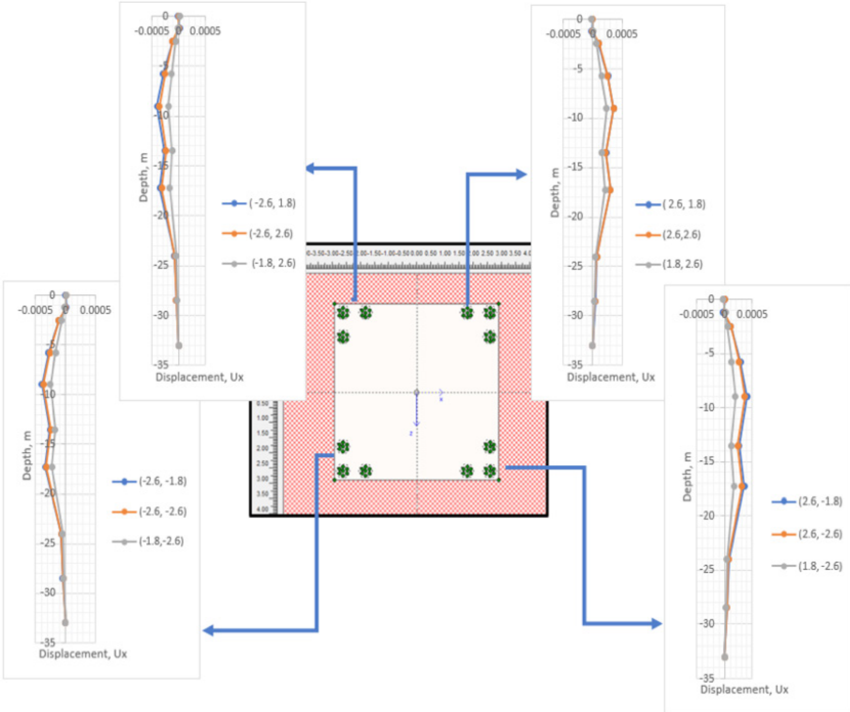

FIGURE 8. Displacement analysis for each micro pile in TC1

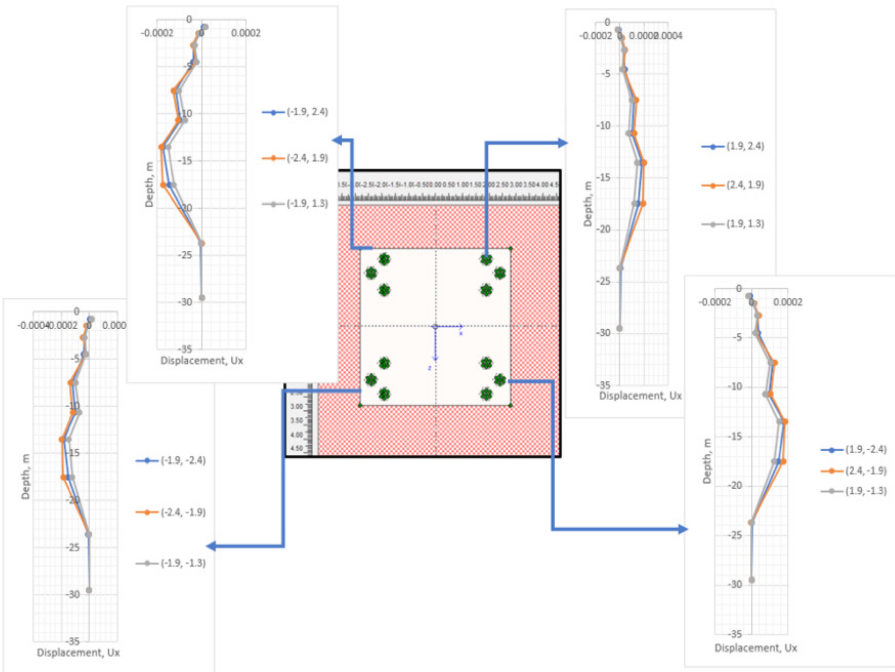

FIGURE 9. Displacement analysis for each micro pile in TC2

FOUNDATION

foundation

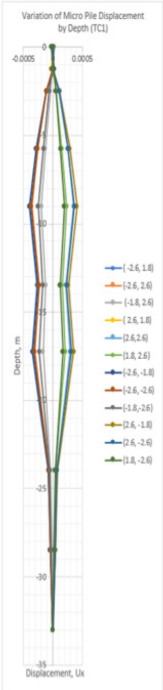

FIGURE 10. Displacement variation for each micro pile at TC1

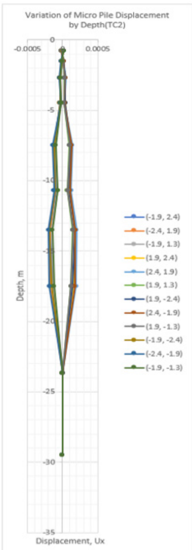

FIGURE 11. Displacement variation for each micro pile at TC2

Maximum Settlement

In geotechnical engineering, sedimentation occurs when there is a vertical movement of soil due to changes in pressure in the earth. Excessive sediment can lead to damage to structures and infrastructure. Most sedimentation occurs when the pressure is applied vertically to the soil above or above the soft or loose soil layer within the soil strata. Among the factors contributing to the settlement are groundwater degradation, soil migration, deep voids, underground excavation for tunnels, caused ground vibrations and seismic events. Application of pile foundation is none other than to reduce the rate of sedimentary strata and transferring the load to the ground. As with other pile types, the behaviours of the pile in the group is influenced by the distance between the individual elements in addition to the pile group layout. This large number of micro pots can reduce the settlement rate. The result of the analysis of two basic models of tower crane found that the maximum sediment value of the soil has the same value as in Table 3.

TABLE 3. Maximum settlement value

	TC1	TC2
Maximum Settlement Value	0.1959 m	0.219 m

Micro piles used as the foundation of the tower crane counteract the compressive load significantly by shifting the load to the earth strata, have higher strength and therefore, the sediment becomes low. It shows as in Figure 12.

CONCLUSION

In general, this study was conducted in relation to the basic stability of the tower crane foundation which used the micro pile as a deep foundation. This study can be divided into four main work processes beginning with data collection and site selection for the construction of the study model. Subsequently, site visits were conducted to look at the current state of the site as well as to obtain documents from key contractors and competent firms responsible for the construction of the tower crane foundation. A review of the basic design of the tower crane is carried out to ensure that the design complies with the standards set forth in BS 8110 Part 1: 1985 "The Structural Use of Concrete", BS 8004: 1986 "Design of Foundation" and the Tower Crane Manufacturer's Manual.

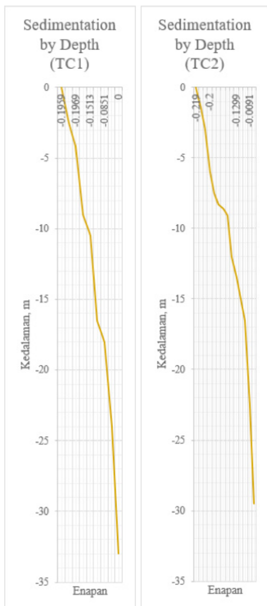

FIGURE 12. Sedimentation by depth for TC1 and TC2

Two basic models of tower crane sites were created using Plaxis 3D software. As a result of the analysis, the behaviours of soil treatments can be identified through soil-structure reactions. The basic stability of the tower crane site can be ensured by using software outputs that provide the suction and displacement values that guarantee the basic stability of the tower crane. Overall, this study has achieved its goal of predicting the stability of the tower crane's basic structure using finite element method and successfully meeting the objectives stated.

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