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ASSESSMENT OF SETTLEMENT BEHAVIOR OF REINFORCED CONCRETE SLAB FOUNDATION UNDER FULL LOAD TEST

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ABSTRACT: This research deals with the process of conducting a loading test on a reinforced concrete slab foundation that is used to support and operate an oil well driller rig in the Majnoon oil field located in southern Iraq. The purpose of conducting the loading test is to evaluate the foundation condition during and after the test and to ascertain the ability of the slab foundation to withstand the forces generated during the drilling of the well. The reason behind conducting this test is the occurrence of a settlement in the slab foundation after construction as a result of a change (rising and dropping) in the water table level by 3.5 m. Concrete blocks were used to simulate and conduct the 600-ton loading test applied over a period of 32 days. Twelve points distributed at the worst zone in the slab foundation have been installed to measure the foundation deflections that occurred in the foundation. The results showed that both the total and differential measured settlement values of the critical foundation zone are less than the permissible values according to the project specifications and that the purpose of the assessment was achieved.

Keywords: Foundation loading test, RC Slab foundation, Rig forces, Foundation settlement, Destructive test.

1. INTRODUCTION

The loading test for foundations is considered one of the more important tests used to judge the structural suitability of the foundation, and this is similar to other applications of loading tests that are used in beams, ceilings, and bridges. The importance of this test lies in the fact that it is the final decision that will be taken to decide whether the tested foundation is valid, invalid, or needs specific treatment. For a broader idea about the nature and applications of this test, one can refer to Fellenius [1], who work with a good survey of this test was presented by collecting previous studies associated with this kind of test in which many useful ideas can be found from these studies, as he mentioned more than fifty examinations around the world.

The analysis of the interaction mechanism between the soil and the foundation structures has been developed for many years. As mentioned above, the loading test in most construction applications is a vital and decisive test applicable in renewing and old structures, which can be used for evaluating the validity and serviceability of different parts of the structure

In such cases, however, the problem is usually not related to the evaluation of the construction materials and the original status of the supported soil, but to the change of the nature of the soil properties from their initial properties that were used in the design of the foundations. Below are some researches and studies related to the loading foundation tests.

Unfortunately, the research and studies published on load tests for foundations are very few compared to the rest of the tests for various building materials. The reason for this is due to the high cost of the load tests, as well as to their need for a long and sufficient time to take into account the many factors affecting the test, as well as to the potential dangers of the load test. With all of this, a section of load tests for foundations has been included below as follows.

Charles *et al* [2] employed a field test to find the relationship between the settlement and the time of shallow-filled sites under low construction loading by using a weighted rubbish skip. Results showed that for a one-month test conducted on a a site in London that the fill might be extra appropriate as a foundation material than capacity had been anticipated.

Khing *et al.* [3] conducted an experimental study to determine the ultimate capacity of a strip foundation by loading a model performed on loading tests on an eccentrically loaded strip foundation that was supported by geogrid-reinforced multi-layered sandy soil. The obtained test result was used to develop an empirical relationship to find the bearing capacity reduction factor. The developed relationship could be used to estimate the foundation's ultimate bearing capacity if it is subjected to eccentricity.

Maurya *et al* [4] made many footing load tests on single and three-column groups for assessment of the step-up effect after installation of stone columns in the sub-surface condition, rammed stone columns were used for ground improvement. The experimental load settlement results of the improved ground were compared with the adopted criteria to find the preferred factor of safety based on the experiential settlement.

McCabe *et al.* [5] listed a series of full-scale loading tests that are considered instrumented field tests of shallow footings and deep foundations carried out in soft silt deposits that lie beneath much of the greater Belfast area.

Alani *et al* [6] conducted experimental tests on plane concrete slabs rested on ground. The aim of the study is to investigate the structural response and deformation modes of the concrete slab under various loading conditions. The experimental results were compared with some theoretical methods available in design codes. A noticeable difference was found between the two procedures.

Cajka *et al* [7] studied the deformation pattern in a concrete tile rested on clay and subjected to centric load. The measured deformations were compared with analytical results obtained using Nexis32 software. The analytical results were found to be higher than the experimental results. The simplicity involved in analytical model was recognized to be the main reasons for this difference.

Buchta *et al* [8] employed some experimental testing of slab foundation in order to generate numerical models and adjust the numerical model's parameters for the improved fit of the facts for suitably relating the interaction between the subsoil profile and the foundation structures. The target of the work was to make the foundation design more competitive for safety and economics.

Cajka *et al.* [9] work with several experimental measurements and numerical analysis of prestressed reinforced concrete slab foundations to study the soil foundation interaction in the Technical University of Ostrava by constructing a testing device to study this phenomenon. He was experimentally investigated and compared the test results with numerical models. The foundation stab was rested on the ground, and the static load test simulated the column loading of a square shape throughout the load test. The measurements were taken for horizontal deformations, the tension inside the slab, and the contact surface between the foundation structure and subsoil, and these measured data were compared with results obtained by numerical FEM modeling.

Tarawneh *et al* [10] performed a set of shallow foundation load tests on sands which were previously tested by both cone penetration tests CPT and pressure meter tests PMT at different locations to establish soil properties. Empirical methods were utilized to calculate the settlement results used the data obtained from CPT and PMT tests. Moreover, CPT results were calibrated to find standard penetration results using an artificial neural network model.

2. RESEARCH SIGNIFICANCE

There are many important differences between the case study in the present paper and the other tests mentioned above, and these differences can be summarized as follows. In the current test, the loads used in the test are heavy (600.0 tons), while in previous studies, they are lesser. The second point is related to the importance of the tested foundation of the rig base of the oil well in the Majnoon oil field. Third, the routine test duration is approximately three days, but the present test takes 33 days. Finally, the problem associated with this test is related to the environmental effects that have few studies in the world.

3. FOUNDATION LOADING TEST

This section deals with the main steps of foundation loading test which involve the description of the foundation problem followed with the numerical analysis that carried before conducting the loading test and finally the statement method adopted to the foundation loading test.

3.1 Foundation Problem

The reinforced concrete foundation was established in 2016 to support an oil drilling rig (ZPEC rig) in an oil field which is located in southern Iraq. After the construction, the foundation was not used until 2020. During that pause period (approximately four years), it was observed that settlement occurred in different parts of the foundation (the highest value was 80 mm). A root cause analysis was conducted to explore the main reason behind the observed settlement. Moreover, data collected from geotechnical investigations conducted in 2018 and 2020 were studied and compared. It was found that the increase in the water table at the good pad and the accompanying washing of fine particles of soil beneath the foundation and degradation in potential soil parameters, as shown in Fig. 1, where the groundwater table during December 2018 was encountered at 4.0 m below natural ground level (-5 m EMG), while during February 2020 the groundwater ranged from 1.0 to 1. 5m below finished ground level (+0.0 m EGM). This increase in the water table is due to heavy rainfall/flooding, which took place over the year 2019, as well as seasonal groundwater fluctuations. Therefore, a numerical investigation was carried out aimed at stimulating the structural behavior of the foundation under the influence of loads that occurred during the drilling process of the well. The results of the study were inconclusive for the expectations regarding the structural behavior of the foundation and the response of soil that occurred due to the change in soil properties during the 4 years leading to conduct a load test for the slab foundation.

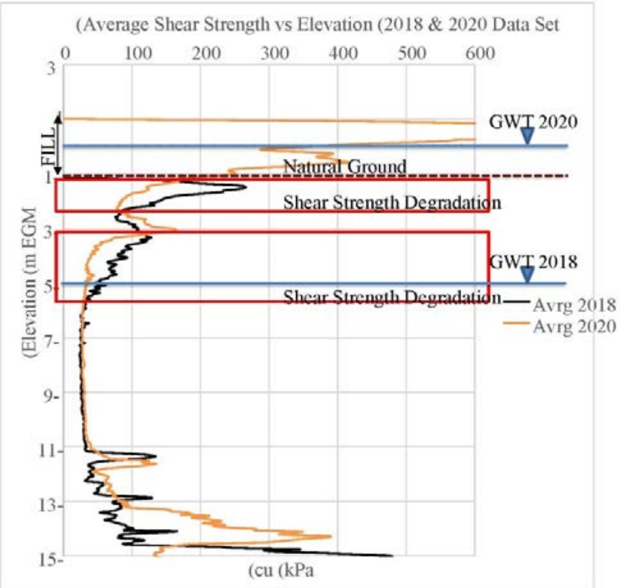

Fig. 1. Comparing shear strength parameters between 2018 and 2020 based on CPT data.

3.2 Numerical Analysis

The theoretical study was conducted using PlAXIS 3D which is used here to validate other foundation recommendations to limit the settlement to the structural design requirements. Geotechnical design parameters have been generated based on field and laboratory data. The parameters presented in Table 1 were used to develop the numerical model. The rig pathway slab as well as the load distribution from the rig (ZPEC) have been modeled as presented in Figs. (2 to 4). Long-term and short-term settlements were calculated. Both shear and settlement criteria were verified involving the following cases:

1- The year 2018 geotechnical investigation ground model (water table at 4.0 m below natural ground level) to estimate the settlement values (immediate and consolidation for 1 m excavation + 2 m fill + weight of right pathway slab) and the settlement (immediate and consolidation for 1 m excavation + 2 m fill + weight of rig pathway slab + load distribution from the rig (ZPEC)).

2-The year 2020 geotechnical investigation ground model (water table at 1.0 m below finished ground level), settlement values (immediate and consolidation for 1 m excavation + 2 m fill), settlement values (immediate and consolidation for 1 m excavation + 2 m fill + weight of right pathway slab), and the settlement values (immediate and consolidation for 1 m excavation + 2 m fill + weight of right pathway slab + load distribution from the rig (ZPEC)).

The summary of the analytical is given in Table 2 which illustrated the resultant settlement for each load case in the years 2018 and 2020.

Table 1. Geotechnical design parameters based on 2018 Geotechnical Investigation

Layer	Depth (m)	γ (kN/m^3)	Φ (°)	Cu (kPa)	E (MPa)	ν
Fill soil	0.6	19.0	33	-	30	0.33
Stiff clay	3.0	19.5	-	90	12	0.42
Soft clay	9.0	18.0	-	30	4	0.42
Firm to stiff clay	9.0	19.5	-	80	25	0.42
Stiff clay/dense sand	9.0	20.0	30	250	50	0.35
Hard clay/dense sand	10	20.0	32	-	25	0.35

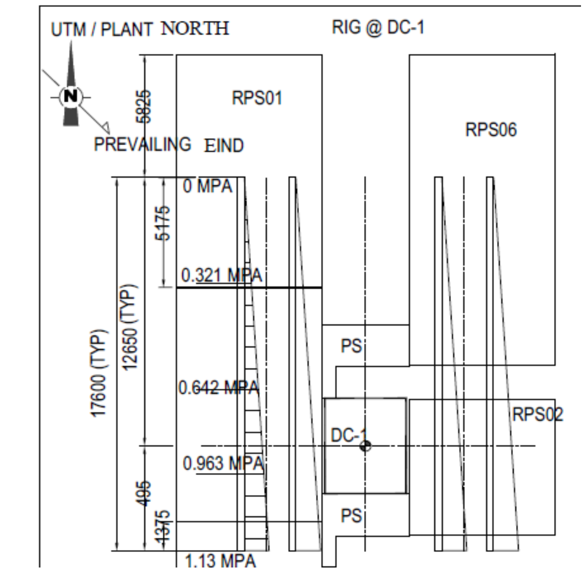

Fig. 2. Stresses distribution on slab foundation which supported the rig (ZPEC).

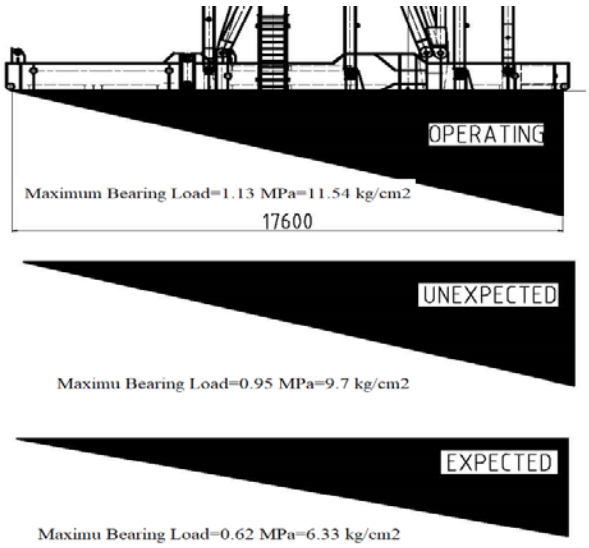

Fig. 3. Resultant forces on the foundation slab

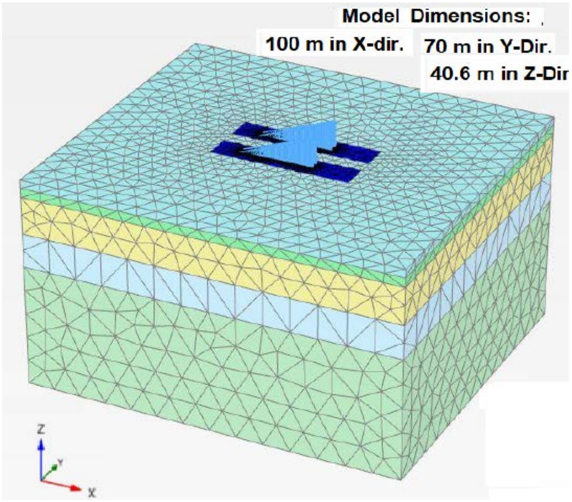

Fig. 4. Model of the PLAXIS 3D software

Table 2. Settlement values for each considered stage using 2018 and 2020 models

Stage	2018 Model (mm)	2020 Model (mm)
Settlement (immediate): 1 m excavation + 2 m fill	13.3	25.6
Settlement (immediate): 1 m excavation + 2 m fill + weight of right pathway slab	24.3	37.2
Settlement (immediate): 1 m excavation + 2 m fill + weight of rig pathway slab + load distribution from rig (ZPEC)	120.7	145.0
Settlement (consolidation)	33.5	36.6

4 TEST STATEMENT METHOD

4.1 Test Load

The loading test required concrete blocks with dimensions of (1m × 2m × 1m) which are not readily available. Therefore, block sizes of (Type-A: 1.2m × 1.2m × 1.0m), (Type-B: 1.2m × 2.4m × 0.6m) and (Type-C: 1.3m × 1.3m × 1.2m) with masses of (3.46 tons), (4.15 tons) and (4.87 tons), respectively were used to satisfy the recommended magnitude and distribution of loading. The layout of the loading area with respect to skid and cellar locations is shown in Fig. 5. The blocks were placed on four layers (increments) as listed in Table (3) in order to simulate the existing drilling loads illustrated in the indicated figures resulting in the total load (mass) equal to (600) tons in which the blocks are numbered according to their placement sequence.

4.2 Data collection

4.2.1 Monitoring Points

The locations of twelve settlement monitoring points are illustrated in Fig. 5 which are distributed sequentially from the inner side to the outer side as the following manner. Segment one associated to points (1, 2, 11, 12) while Segment two related to points (3, 4, 9, 10) and Segment three for points (5, 6, 7, 8). A monitoring point should comprise a metal survey pin as shown in Fig. 6, that is set into the top of the concrete pathway slab.

4.2.2 Measurement Devices

Two Total Station surveying devices, one on each side of the loaded area, were provided at the site location for the data collecting process. Each device was located at a minimum distance of (25m) apart from the loading area. The accuracy required for measurements was (1.0mm).

4.2.3 Periodicity of the readings

1- Twelve readings were recorded for the monitoring points, before placement of blocks.
2- After completing the placement of each layer, the load is maintained for around 2 days, where the readings were taken on the following timings (1, 8, 15, 30, 45, 60 and 1440) minutes and at the beginning of the next working day.
3- After completing the fourth layer (at full test load), the load remains maintained for 20 days and readings for the twelve points were taken on the following times:
First day; (1, 8, 15, 30, 45, 60) minutes.
Second day to the 20th day; every (24) hours.
4- For the unloading phase, the readings were taken after the full removal of each layer on the following times: (1, 8, 15, 30, 45, 60, 1440) minutes.

Table 3. Test load characteristics of rig is at DC-1

Layer	Item	Type-A Blocks	Type-B Blocks	Type-C Blocks	Total (Number-Mass)
1	Number	52	4	-	56
	Mass (t)	179.92	16.6	-	196.52
2	Number	-	-	32	32
	Mass (t)	-	-	155.84	155.84
3	Number	-	-	27	27
	Mass (t)	-	-	131.49	131.49
4	Number	-	1	23	24
	Mass (t)	-	4.15	112.01	116.16
Total	Number	52	5	82	139
	Mass (t)	179.92	20.75	399.34	600.01

5. RESULTS AND DISCUSSION

Throughout the loading test, any damage in the foundation was not observed, accordingly the main parameter that controls the behavior of the tested slab foundation under the effect of the applied load is the settlement. The data collection during the loading test are recorded in specified tables in which the main resulting data are summarized in Tables 4 to 6 for slab segments 1,2, and 3 respectively.

A comparison of the experimental results to the numerical predictions shows that the numerical models was weaker than the actual model by large amount as (120.7/16.4=7.36) for model 2018 and (145.0/16.4=8.84) for model 2020. This effects can be attributed to the conservation assumptions of the numerical model than the actual state for the soil profile beneath the slab foundation.

In these Tables, the creep effect is considered as the full load remain for 20 days so that the creep value is estimated as the difference between the settlement value at the end time of applied full load minus the settlement value at start time of fill load applied. The creep ratio is found by dividing the creep values with the maximum settlement for corresponding point multiplied by 100. The average values of creep ratio for each segments are found to be equal to (3.6%, 1.3%, 3.4%) for slab segments one, two, and three, respectively. These values indicate that the creep effect has considered as minor portion of total settlement during.

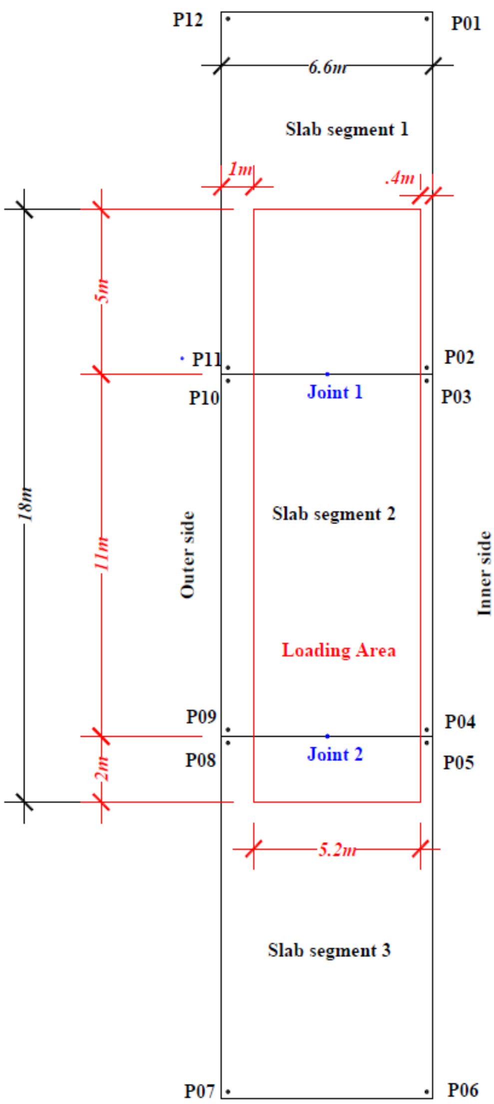

Fig. 5. Test load layout with respect to cellar and skid locations

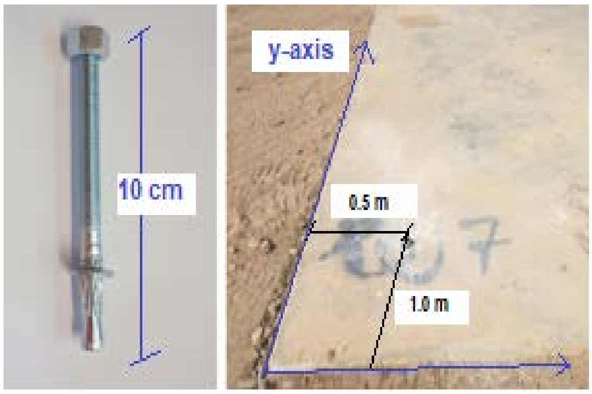

Fig. 6. Typical survey pins

From previous results, it has shown that the creep effect is so small regardless of selected slab segment or point in any slab segment so that this effect can be ignored in the operational process after that. This result can be attributed to the nature of soil profile under the reinforced concrete slab due to the granular material of soil profile is dominate than clays soils near the slab bottom.

The Tables 4 to 6 give an important fact that the major part of settlement is happened at the first loading increment than the other increments. The first increment ratio is determined by dividing the settlement of first loading increment with the maximum settlement value multiplied by 100. For example, the minimum value of the first increment ratio is 55 in seqmqnt1 at point 4. The reason for this result is due to the presence of voids near the bottom foundation that happened due to the change in water level during 4 years. The above results shows an important facts that the environmental effects has been vanished at the end of test due to the permanent deflections that included this effect.

Table 4. Applied load and the corresponding settlement for four points in slab segment 1

Load (tn)	Point 1 (mm)	Point 2 (mm)	Point 3 (mm)	Point 4 (mm)
196.52	11.0	11.0	11.0	9.0
352.36	12.1	12.5	12.9	13.9
483.85	13.5	12.5	15.3	15.0
600.01 (start)	13.7	12.5	15.6	15.4
600.01 (End)	14.0	13.0	16.0	16.4
483.85	13.3	12.7	16.0	16.4
352.36	13.3	12.5	16.0	16.4
196.52	12.8	12.2	15.6	16.4
0.00	12.8	12.2	14.6	16.4
Creep (mm)	0.3	0.5	0.4	1.0
Creep Ratio(%)	2.1	3.8	2.5	6.1
1 Increment Ratio (%)	79	85	69	55

Table 5. Applied load and the corresponding settlement for four points in slab segment 2

Load (tn)	Point 5 (mm)	Point 6 (mm)	Point 7 (mm)	Point 8 (mm)
196.52	11.0	10.0	9.0	11.0
352.36	12.3	13.0	11.0	11.8
483.85	14.0	14.0	11.8	11.8
600.01(start)	14.7	14.0	12.0	12.0
600.01(End)	15.0	14.0	12.4	12.0
483.85	15.0	13.7	12.4	12.0
352.36	15.0	13.5	12.0	12.0
196.52	15.0	13.0	12.0	12.0
0.00	15.0	12.0	12.0	12.0
Creep (mm)	0.3	0.0	0.4	0.0
Creep Ratio (%)	2.0	0.0	3.2	0.0
1 Increment Ratio (%)	73	71	73	92

Table 6. Applied load and the corresponding settlement for four points in slab segment 3

Load (tn)	Point 9 (mm)	Point 10 (mm)	Point 11 (mm)	Point 12 (mm)
196.52	12.2	9.1	10.0	8.6
352.36	14.0	11.0	11.0	9.8
483.85	14.0	12.0	11.4	11.0
600.01(start)	14.0	12.0	11.7	11.0
600.01 (End)	14.7	12.8	11.8	11.2
483.85	14.7	12.8	11.8	10.9
352.36	14.7	12.8	11.4	10.4
196.52	14.6	12.5	11.4	10.4
0.00	14.4	12.2	11.1	10.0
Creep (mm)	0.7	0.8	0.1	0.2
Creep Ratio (%)	4.8	6.3	0.8	1.8
1 Increment Ratio (%)	83	71	85	77

The relationship between the time and the total applied load for the tested foundation of the well pad is shown in Fig. 7. The loading area portion of the foundation slab was located into three segments which were connected by an expansion joint in which each segment was loaded in different magnitudes of loads. The control role of the loading slab test was the observation deflection of the slab in 12 locations, 4 locations at each sentiment as shown in Fig. 5.

For each point, the collected data equals 80 readings which leads to a total number of 960 readings. The test data are drawn into a different pattern in which the first path concerns the inner and outer sides' deflection to recognize the most affected side by the pre-settlement phenomena, while the second pattern focuses on the deflection of each segment part to make the required assessment of the test result. For the above purposes, Figs. (8 and 9) display the time-deflection readings of the inner points (1 to 6) and the outer side points (points 7 to 8) deflection. In a similar manner, Figs. (10 to 12) illustrated the load-deflection of segment 1 (points 1, 2, 11, 12), segments 2 (points 3, 4, 9, 10) and segment 3 (points 5, 6, 7, 8).

From Figs. (8 and 9) it can be seen that the inner side exhibited more deflection than the outer side by (12%) at maximum deflection (point 4 on the inner side compared with point 9 on the outer side). This result reflected the existence of maximum settlement before load test in the inner part of slab foundation and the reason for this result can be attributed to the nature of the foundation slab which has a trench and channel that collected the water from flood and rains during a period of 4 years before load test.

The second remark is associated with the more segment affected by the test as shown in Figs. (10 to 12). Segment 2 shows more deflection value (16.4 mm at point 4) than segment 1(14.0 mm at point 2) and segment 3 (15.0 mm at point 5). This result can be illustrated from the portion of loads applied to each segment as follows:

Segment 1 takes 44.5 tons which represent 7.4 % of the total load while segment 2 takes 454.0 tons which represent 75.7 % of the total load, and segment 3 takes 101.5 tons which represent 16.9 % of the total load.

The third remark is related to the creep effect of the foundation under the maximum load which is equal to 0.4 mm for point 4, and represents 2% during 20 days. The small amount of creep effect can be attributed to the nature of foundation soils which have been replaced for a depth of 0.5 m and good compacted condition during rig construction. These results indicate that the creep effect is so small that cannot cause any problems during the rig operation.

The second stage of the test focuses on the assessment of test load results by three criteria. The first one considers the maximum deflection (16.4 mm for point 4) to be less than the permissible value of the project which is 100.0 mm. The second criterion is concerned with the maximum differential or relative deflection of the three segments (16.0 mm for point 3 and 12.2 mm for point 10) which leads to 3.8 mm differential settlement. This means a percentage of (0.06%), which is less than the permissible limits of the project (1%). This result indicates that the foundation stiffness and rigidity are adequate to resist the operation loads coming from the drilling process.

The last criteria connected with the permanent (plasticity effect) deflection remaining after removing the loads which is equal to 16.4 mm for point 4 which is less than the permissible value of the project (25.0 mm).After the completion of the loading test, the oil rig operation was allowed to make the required drilling and the whole foundation exhibits no damage in foundation slab and no settlement in any foundation parts.

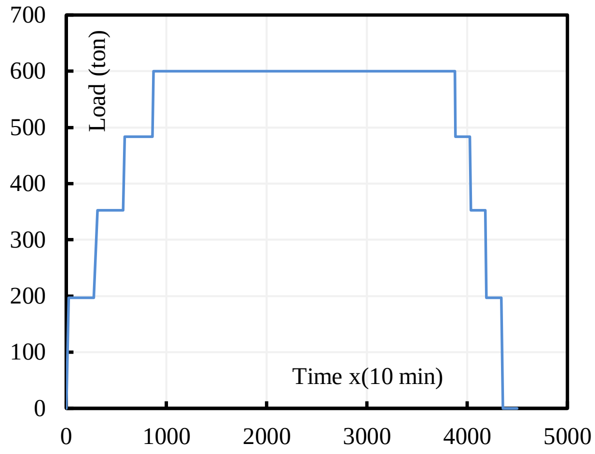

Fig. 7 Relationship between the time and the applied load for the tested foundation

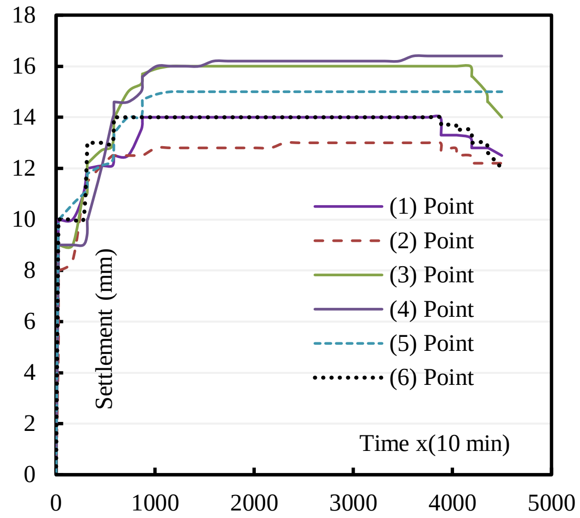

Fig. 8 Relationship between the time and the settlement for the tested foundation

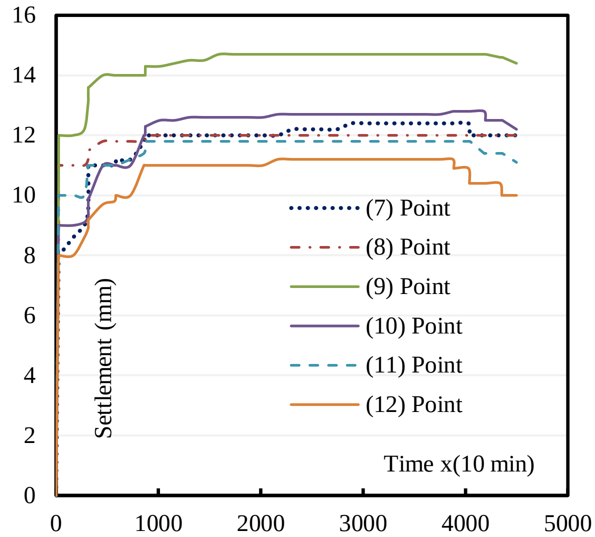

Fig. 9 Relationship between the time and the settlement of for the tested foundation.

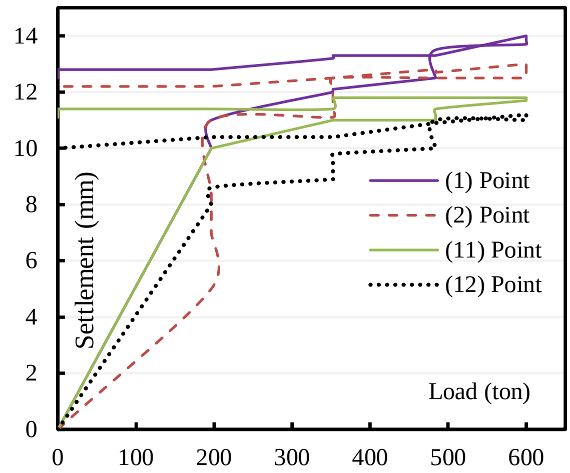

Fig. 10 Relationship between the applied load and the settlement for slab segment 1

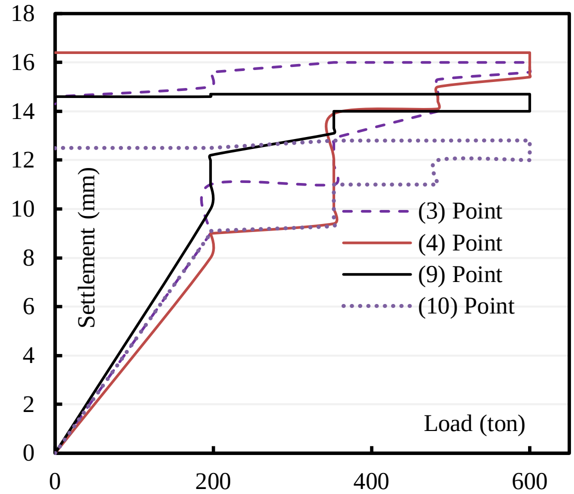

Fig. 11 Relationship between the applied load and the settlement for slab segment 2

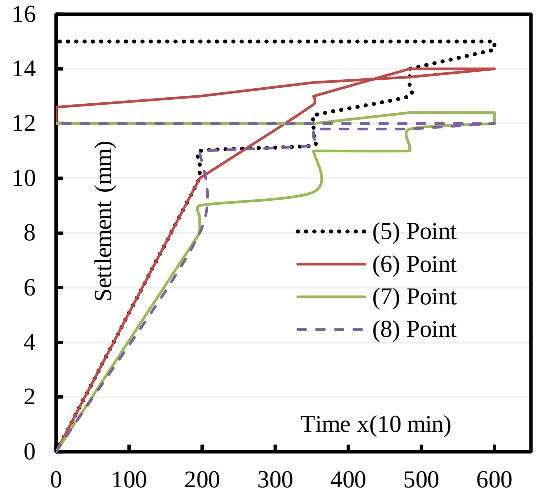

Fig. 12 Relationship between the applied load and the settlement for slab segment 3

6. CONCLUSION

Full load test has been carried in successful manner to check the real foundation condition before the oil rig operation. Prior to carry out the loading test, soil investigation was conducted. It was found that the desiccated clay layer has showed a degradation in shear strength due to saturation (rise in water table to 1 m below finished ground level). The rise in water table has caused an increase in the overall total settlement in comparison to 2018 geotechnical investigation where the water table was at 4 m below natural ground level ground water table. Through the foundation load test, the main conclusions results showed that the test shows that the inner sides of loaded slab was affected more than the outer side by about 12%. Also, the intermediate slab segment was influenced much than the other two segments of the slab. In addition, the major portion of existence settlement occur at first load increments in which the minimum ratio is 55 for point 4 and maximum ratio is 92 for point 8. Moreover, the creep effect of the soil and foundation was so small so that its effect can be neglected. Furthermore, it was found that the maximum settlement (total, permanent, and relative) was less than the permissible values specified by the project pacification. Finally, the structural behavior of the foundation under maximum test load was sufficient to resist the expected operation load.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

[1] Fellenius B. H., Full-Scale Testing and Foundation Design, American Society of Civil Engineers, GSP 227, 2012.

[2] Charles J.A., and Driscoll R., A simple in Situ Load Test for Shallow Fill, Ground Engineering, 1981, pp.31-36.

[3] Khing K. H., DAS B. M., PURI V. K., YEN S. C., and CooK E. C., Ultimate Bearing Capacity of Eccentrically Loaded Strip Foundation on Sand Reinforced with Geogrids, International Symposium on Tsunami Reconstruction with Geosynthesis, Southern Illinois University, Transportation Research Record 1414, 2005, pp.65-70.

[4] Maurya R. R., Sharma B. V. R., and Naresh D. N., Footing Load Tests on Single and Group of Stone Columns, The 16th International Conference on Soil Mechanics and Geotechnical Engineering, 2005, pp.1385-1388.

[5] McCabe B. A., and Phillips D. T., Design Lessons from Full-Scale Foundation Load Tests, 3rd International Conference on Site Characterization Taipei, Taipei, 2008.

[6] Alani A. M., Rizzuto J., and Beckett D., Structural Behavior and Deformation Patterns in Loaded Plain Concrete Ground-Supported Slabs, Journal of Structural Concrete, Vol. 15, Issue 1, 2014, pp.81-93.

[7] Cajka R., Burkovic K., Buchta V. and Fojtík R., Experimental soil-Concrete plate interaction test and numerical models, Journal of Engineering Materials, Vol. 577, 2014, pp.33-36.

[8] Buchta V., Janulikova M., and Fojtik R., Experimental Tests of Reinforced Concrete Foundation Slab, Procedia Engineering, Vol. 114, 2015, pp.530 – 537.

[9] Cajka R., Mynarcik P., and Iabudkova J., Experimental Measurement of Soil-Prestressed Foundation Interaction, International Journal of GEOMATE, Vol. 10, Issue 22, 2018, pp.2101-2108.

[10] Tarawneh B., Nusairat J., and Hakam Y., Load Testing and Settlement of Shallow Foundation on Desert Sands, Journal of Geotechnical Engineering, Vol. 171, Issue 1, 2018, pp. 52-63.