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Modeling of Segmental Pile with Variable Flexural Rigidity on Winkler Foundation Subjected to Monotonic Loading

Yasser IO Yahia[1]*, baykal G[2] and Hesham Alsharie[1]

[1]*Department of Civil Engineering, Jaresh University, Jordan*

[2]*Department of Civil Engineering, Bogazici University, Turkey*

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***Corresponding author:** Yasser I O Yahia, Department of Civil Engineering, Jaresh University, Jordan

Abstract

Alternating mortar blocks and rubber pads are connected to each other by a cable passing through the center of each block to form a fixed beam/pile model with variable flexural rigidity. The fixed beam/pile model is supported on manufactured springs with 1K, and 3K (K=4 N/mm) spring constants to partially represent sandy soil at different relative densities. Varying tension loads are applied to the cable to achieve desired flexural rigidity for the fixed beam/pile model. Using static load three-point beam tests are conducted and the load-deflection behavior is recorded, from which representative flexural rigidity values are obtained. From the measured deflections, corresponding spring forces are determined. From the spring reaction forces, the boundary conditions are obtained and integrated to obtain the shear forces. With the second integration, moment values are determined. With non-dimensional method (NDM), the results were compared. The stress maps obtained from prescale films are used to back-calculate the moment distribution along the fixed beam. The magnitude of the moment obtained from the back calculation of prescale stress maps are up to two times of that obtained from the load-deflection measurements which is due to small number of deflection measurements which underestimated the beam curvature.

Keywords: Flexural rigidity; Spring constant stiffness; NDM; P-y curves;

Introduction

The load bearing capacity of the columns can be optimized by the geotechnical engineer by varying the ring tensile module and percentage area of columns in the embankment base [1]. The pullout load is analyzed by the vertical effective stress [2]. The use of stone columns as a technique of soil reinforcement is frequently implemented in soft cohesive soil [3]. Solution to the general problem can also apply to a variety of onshore cases including pile-supported earthquake resistance structures, power poles, and pile supported structures which may be subjected to lateral blast forces or wind forces. Some structural foundations and compression members like stone columns have less resistance against lateral load which result in failure due to lateral loading application [4,5]. Therefore, some researchers published papers regarding improvement of the behavior of foundation members against lateral loading. The problem of the laterally loaded pile is originally of particular interest in the offshore industry [6,7]. Lateral loads from wind and waves are frequently the most critical factor in the design of such structures [8-10].

The main aim of this paper is to develop a segmental pile with variable flexural rigidity system SPVFR whose flexural rigidity can be controlled, and to investigate the behavior of the pile model under lateral load. The advantages of controlling the flexural rigidity of the pile model can be summarized as the prevention of the total collapse by enabling the system to bend without breaking under horizontal forces. To achieve the previous objectives an experimental research program has been carried out where the influence of each variable on the behavior of a segmental structural member has been investigated as well as the stress, forces and p-y curves are developed.

Introduction of the Pile Model SPVFR

In this study, a new proposed segmental pile is analyzed in laboratory environment to improve the properties of weak soil under lateral load. The Segmental Pile with Variable Flexural Rigidity SPVFR is composed of concrete blocks and rubber connected with pre-stressed wire anchor system. The engineering properties of materials which are used for developing the pile model are determined. Three different post-tension forces are applied to the pile system (750N, 1500N, and 2250N) and tested to measure the flexural rigidity of the pile model. The pile model is placed on elastic springs, which represent the range of the soil stiffness (loose-dense). By applying static loading at the mid and top point of the SPVFR specimen, the deflection and lateral load are measured. A post-tension force of 2250N is selected and the performance of the SPVFR under static loading are investigated for maximum deflection of 4mm at the midpoint of the SPVFR, which is equivalent of 8% of the pile diameter. In addition, the p-y curves are constructed corresponding to the static loading.

Non-Dimensional Method (NDM)

This model is based on p-y curves and numerical solutions that were obtained by hand-operated calculators. This model offered at the time a desirable solution to fully design piles in both the ultimate limit state and serviceability limit state while including nonlinear soil behavior. With the NDM, it is possible to check on real p-y analyses and good insight into the problem can be obtained. Another major possibility is that the decision on which p-y curve to use is completely open. The disadvantages of the model are that the soil must be homogeneous. The pile must have a constant bending stiffness over the length of the pile. And most importantly, the calculation procedure is time consuming. In this research, full p-y analyses have been executed with the program M-Pile. This program uses p-y curves recommended by the American Petrol Institute, (API). Therefore, the analyses with the NDM use other p-y curves, namely those developed by Reese & Matlock .

SPVFR on Winkler Foundation

In this study, MTS equipment is used to evaluate the stress and displacement of the SPVFR during static loading. Displacement controlled test procedure is applied.

Type of loading

Static loading: At the tip-point of the SPVFR

Construction of p-y curves of the SPVFR: The p-y curves of segmental pile with variable flexural rigidity are determined at P-y curves at 171mm from pile tip. The load is increased gradually for each 1mm deflection, followed with unloading until maximum deflection is reached. To evaluate the lateral capacity of the SPVFR, the maximum value of deflection 4mm is used (8% of pile diameter).

Results and Discussion

Stress distribution on the prescale films along SPVFR due to post-tension force

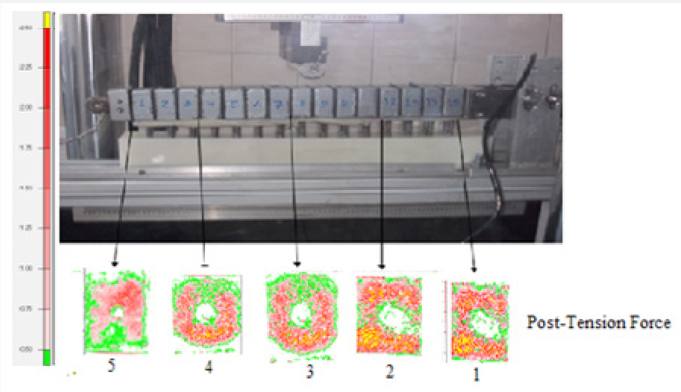

Figure 1: Shows Stress Distribution of the Prescale Films Due to Post-Tension Forces.

The stress distributions concentrated at prescale films number 1 and 2. The position of these prescale films is nearby the fixed part of the pile model as shown in Figure 1. it is also observed that after the prestress forces applied to the pile model a concave shape developed whereas the stress distribution of the lower part of the prescale films 1.01 times more than the stress distribution of the upper part of the prescale films. The total average stress of all prescale films is 1.041MPa. The stress distributions provided by scale details are shown in Figure 1.

Stress distribution on the prescale films along SPVFR due to static load/ top point

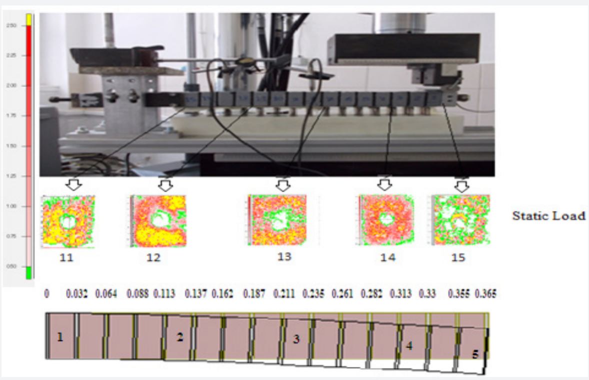

Figure 2: Stress Distribution of the Prescale Films Due to Post-Tension Forces and Lateral Load.

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The stress distribution of prescale films number 11 and 12 are 1.66MPa and 1.8MPa respectively. The position of these prescale films adjacent to fixed part of the pile model. It is also observed that for each prescale film the stress concentrated at the lower part. The stress value of a prescale film number 13 at mid-span of the pile model is 1.47MPa. The prescale number 15 presented low level of stress 1.04MPa. The displacement of the pile model corresponding to the prescale film number 15 is 0.365mm. At 4mm deflection of elastic media, extra prestress force 500N is developed which increased the stress for all prescale films to 0.2MPa. The total average stresses for all prescale films are 1.46MPa. Figure 2 shows the details of stress distribution of the pile model under lateral load.

P-y curves of SPVFR based on linear springs [1K]/Static Load

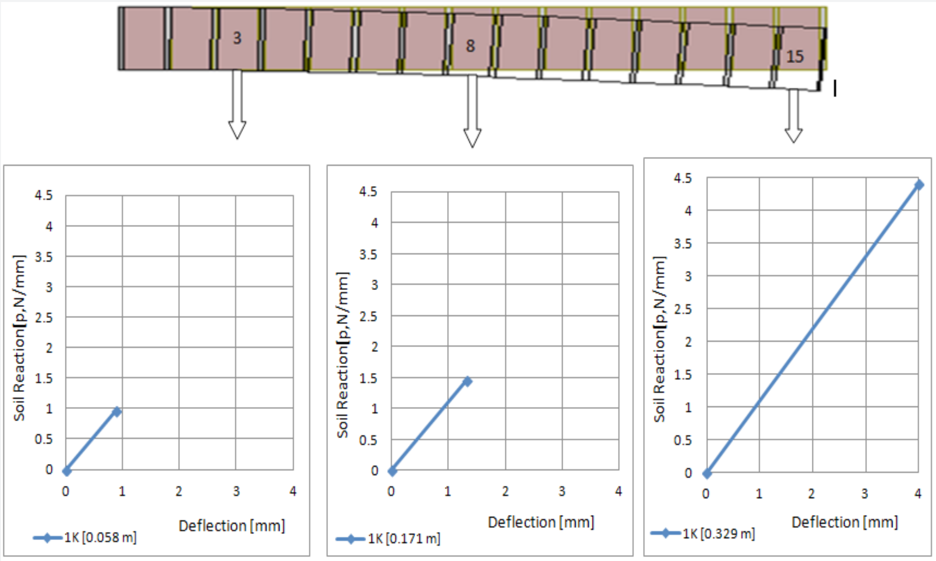

Figure 3: Illustrates the p-y curves of the pile model placed on elastic springs 1K.

The p-y curves of SPVFR at 0.058m give spring reaction of 0.96N/mm which corresponds to 0.87mm deflection. The p-y curves of the pile model at 0.171m from pile tip develop a spring reaction of 1.45N/mm which corresponds to 1.32mm deflection. The p-y curves of the pile model at 0.329m from the tip of the pile produce spring reaction of 4.4N/mm, which corresponds to 4mm deflection. Figure 3 illustrates the p-y curves of the pile model placed on elastic springs 1K.

P-y curves of SPVFR based on linear springs [3K]/static load

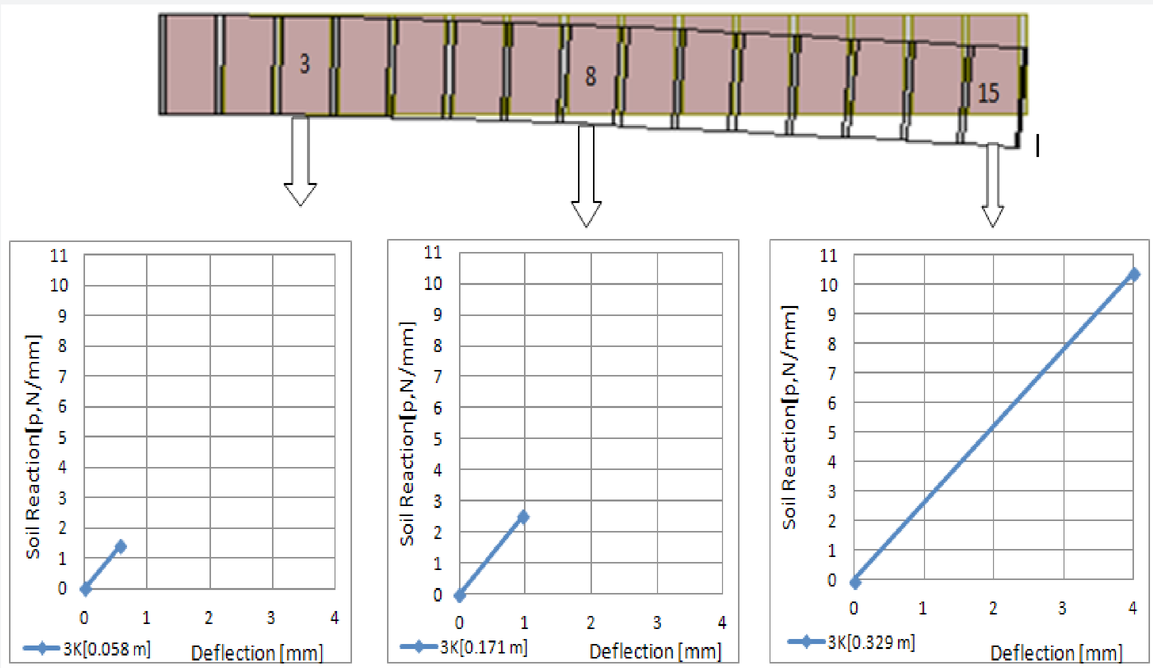

Figure 4: P-y Curves of SPVFR Based on Linear Springs [3K]/Static Load.

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The p-y curves of SPVFR at 0.058mm from the pile tip give spring reaction of 1.43N/mm which corresponds to 0.55mm. In addition, the p-y curves of the pile model at 0.171m from the pile tip produce spring reaction of 2.5N/mm which corresponds to 0.96mm. According to the p-y curves of the pile model 3K at 0.329m from the pile tip, the spring reaction increases up to 10.4N/mm which is corresponds to 4mm deflection at the pile head. Figure 4 shows the p-y curves of the pile model placed on elastic springs 3K.

Comparison between experimental data and non-dimensional method

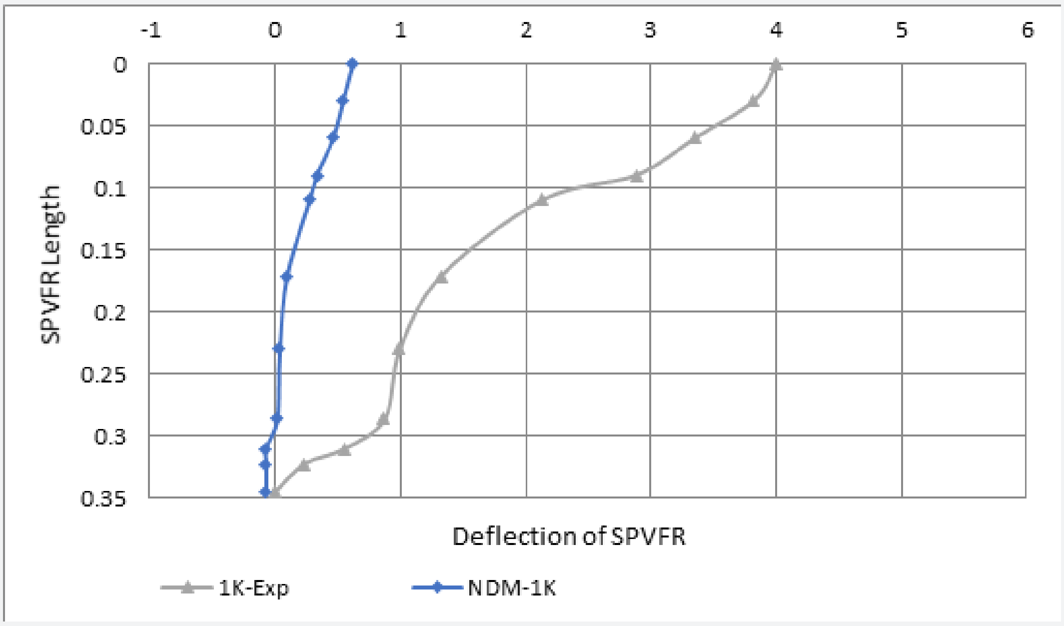

Figure 5: The Deflection Diagram Along SPVFR Length Experimental Data / NDM [1K].

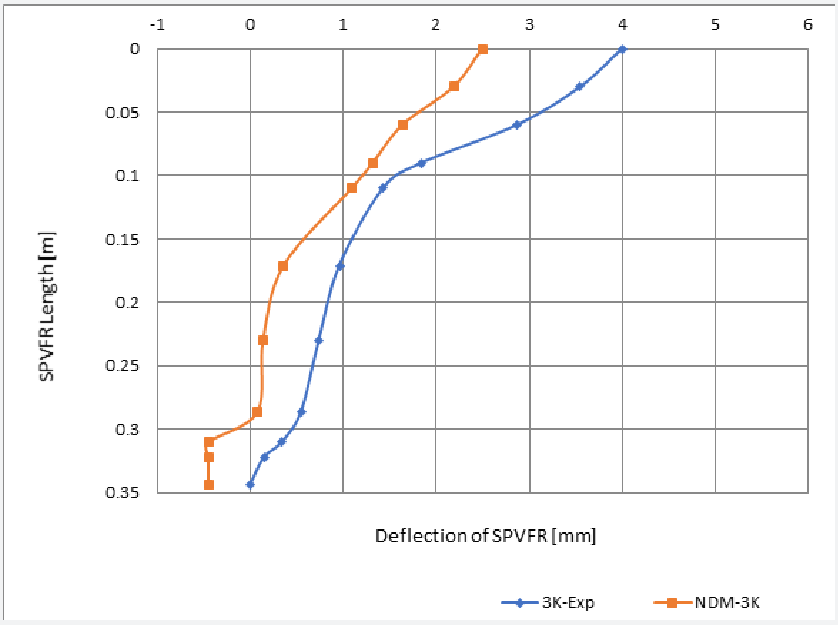

Figure 6: The Deflection Diagram Along SPVFR Length Experimental Data / NDM [3K].

The values of maximum deflection according to laboratory data is 4mm at tip point of SPVFR for 1K and 3k whereas the deflection values are decreased according to NDM by 16% and 63 % for 1K and 3K respectively. So that by increasing the relative density of soil, the deflection values by using NDM approximately comes to same deflection values of experimental test. Figure 5&6 illustrate the deflection Diagram along SPVFR length by using experimental data and NDM.

Conclusion and Recommendation

The following conclusions limited to the experimental setup used in this study. Although the two spring constants used to

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support the pile to represent sand from loose to dense relative density, it must be taken into account that the real soil behavior may be different under real field conditions.

A. It was demonstrated that the segmental pile with a variable flexural rigidity can be practically constructed in the laboratory. Construction of Segmental Pile with Variable Flexural Rigidity SPVFR will be even easier in the field because of commercial availability of anchoring wires and tensioning tools.

B. With the limitations of spring support systems used in this study, changing the spring constant from 1K to 3K [to give an idea for loose-dense sand], did not cause a big change in the load capacity of the pile at 4mm displacement.

C. Although this first study demonstrated that, the new pile construction technique has a very good potential for implementation. Validating the experimental findings field tests recommended.

D. For future work, using high quality of materials and cross-section area with different opening size recommended in order to increase the range of controlling the flexural rigidity segmental pile.

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