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Modeling of the Influence of Ballasted Columns on the Bridge Foundation in Liquefiable Soil: Case of a Bridge Over the Martil River in Northern Morocco

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Abstract

The seismic activity in the area of the works in the north of Morocco is very active due to the approach of the African-Eurasian lithospheric plates, and the foundations of the works are located in liquefiable soil. It is certain that soil liquefaction is a phenomenon that presents a potential risk and a major challenge for the construction of the works. These foundations are subject to shear, bending and frictional forces, which can lead to collapse, with serious consequences for bridge construction. The combination of pile foundations with soil treatment against liquefaction by weighted columns seems to be a unique solution for the bridge over the Martil River. The objective is to evaluate the effect of implementing wet weighted columns in liquefiable soil on the piers of a bridge under construction. We applied the finite element method using the PLAXIS software to determine the safety distance to be respected between the ballasted column and the piers in order to avoid any damage to the deep foundations of the bridge structures. The verification of this spacing was validated by the sonic testing method, which verified the continuity of the piles, detecting the presence of cracks or anomalies along the shaft and at the end. The homogeneity and quality of the concrete are assessed, and defects are precisely located, including at the end of the pile. And the solution was to keep a distance of 2 m to minimize the impact of the vibrations of the ballasted column machine on the concrete piles.

Keywords

Stone column, Liquefaction phenomenon, PLAXIS software, Vibro-compaction, Sonic auscultation

Introduction

The technique of soil reinforcement by ballasted columns is widely used to improve the capacity of soils with poor characteristics [1], to reduce their settlement or to limit the risks of liquefaction. However, in this article, we will deal with a particular case of protection of the foundations of a bridge over Oued Martil in the north of Morocco against the phenomenon of liquefaction of the soil. To this end, it is necessary to define the influence of the ballasted columns on the reinforced concrete piles, this type of composite foundation requires a verification of the lateral forces introduced during the installation of the columns on the piles [2]. The objective of this work is to present the approach used to model the impact of the implementation of wet-laid ballasted columns on their immediate environment. For this purpose, a finite element model, using the PLAXIS 2D software, was deployed to evaluate the influence of the execution of the column on the adjacent piles planned as a type of deep foundation in the area of the piers and abutments of a bridge [3]. The following is a presentation of the geotechnical

model of the soil around the column with the main parameters used, the method of modelling the effect of the column installation and the determination of the distance beyond which the impact of the installation becomes negligible [4].

The site is located in northern Morocco, 3 km from the city of Tetouan towards the city of Chefchaouen. Figure 1 shows the location of the site under study. The project consists of the construction of a bridge over the Martil River at KP 52+400 at the level of the expressway connecting the city of Tetouan and Chefchaouen in northern Morocco [1].

In order to protect the foundation of the structure against the soil liquefaction phenomenon [5], we use the ballasted columns technique [6]. The implantation plan is illustrated in figure 2 with 2 m between pile and ballasted column. The position of the ballasted columns relative to the piles is indicated in figure 2.

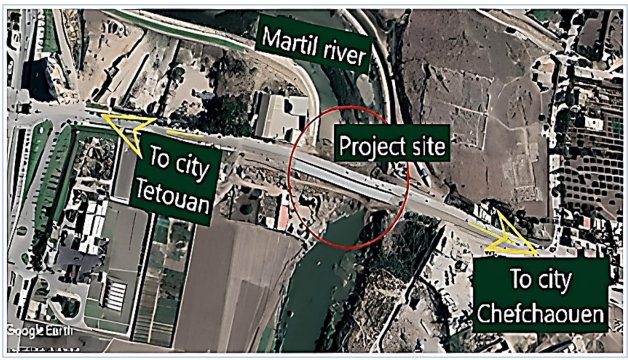


Figure 1: Location of the site project.

Materials and Method

We carried out pressure meter tests to define the lithological cross-section of the soil, and to assess the risk of soil liquefaction using the SPT (Standard Penetration Test) and CPT (Cone Penetration Test) methods. Finally, we used PLAXIS software to assess the zone of influence.

Context and geotechnical reconnaissance

The exploitation of the pressiometric drillings carried out in the structure shows that the lithology encountered in figure 3. It is made up primarily of a sandy marl deposit that extends

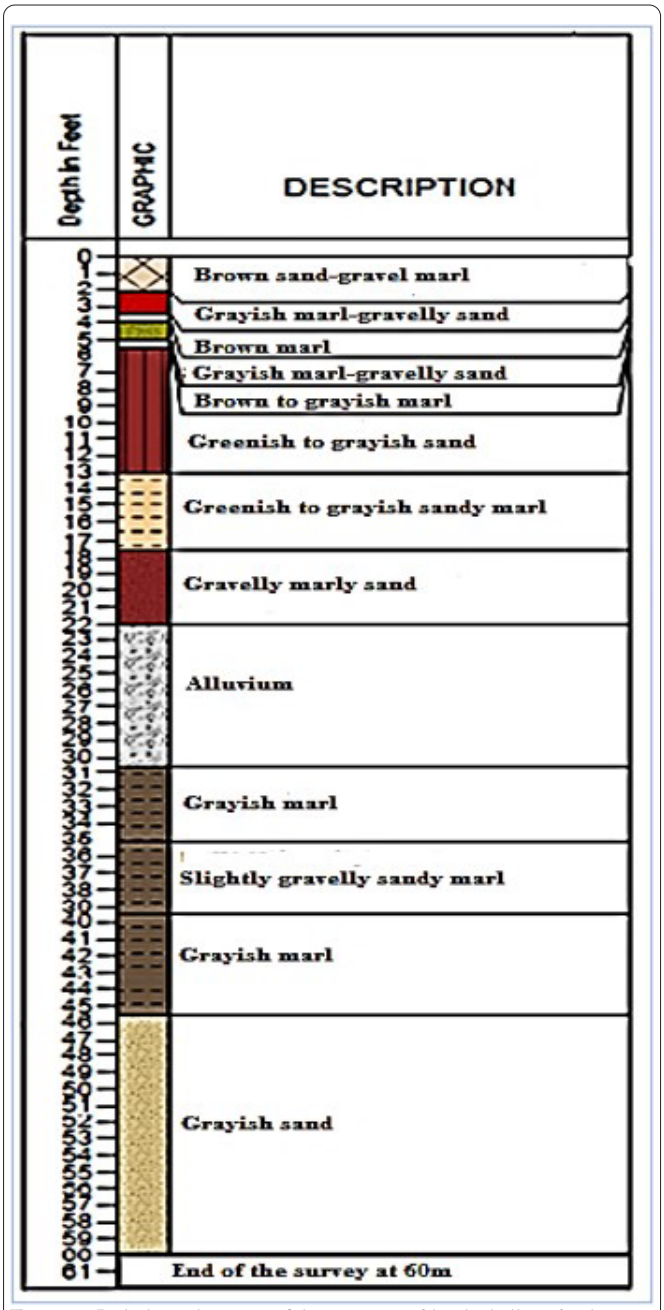


Figure 3: Lithological section of the area treated by the ballasted columns.

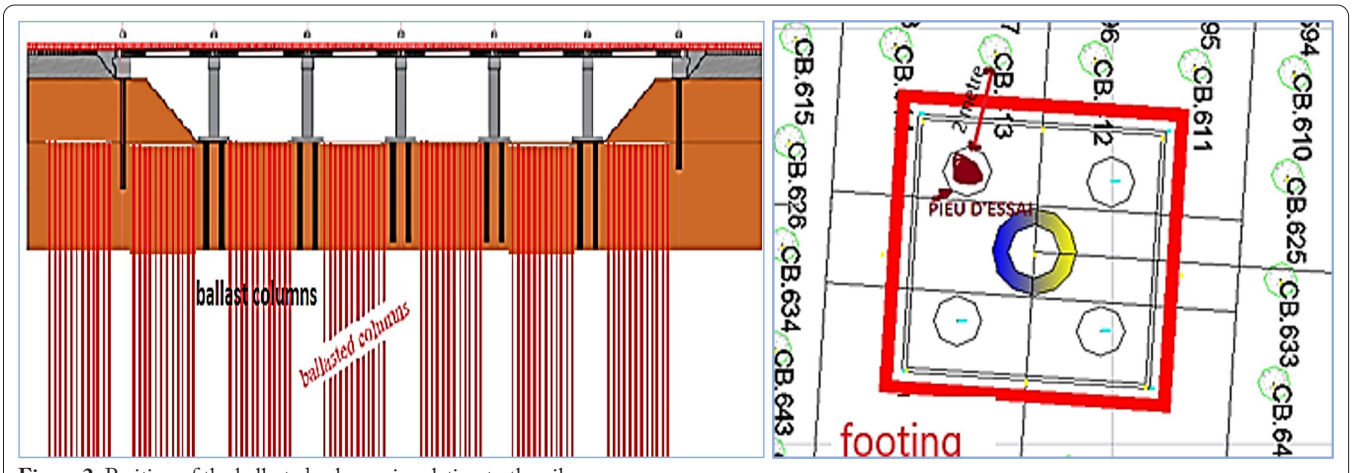


Figure 2: Position of the ballasted columns in relation to the piles.

Table 1: The geotechnical parameters adopted in the modeling of the different layers.

Formation (Soil type)	Thickness (m)	Deformation modulus Ey (kPa)	Cohesion C (kPa)	Internal friction angle	Dilatancy angle
Sandy Marls	32	5,000	5	20	-
Alluviums	8	40,000	5	35	5
Lower sands	20	100,000	5	35	5
stone columns	-	60,000	0	38	8

around 32 m. The first 22 m of which are thought to be liquefiable, it is principally composed of alluvium layers that are overlaid at a depth of around 8 m. Beyond a depth of 40 m in relation to the natural terrain (TN), marl and indurated sand are encountered up to a depth of 60 m [7].

The exploitation of the pressiometric drillings carried out in the area of the structure shows that the lithology encountered shown in figure 1 is globally constituted of a sandy marl formation over a depth of about 32 m. From a stratigraphic perspective, the succession of the following formations makes up the lithology of the ground [8].

Figure 3 shows the Lithological section of the area treated by the ballasted columns. Above and down to the bottom of the borehole, greyish marly sands with cemented sand passage are encountered [9].

In the case of the in-place reinforcement project, it should be noted that the ballasted columns were chosen for the treatment, over a depth of approximately 22 m of the surface sandy marls considered liquefiable [10]. The columns are therefore of the floating type with a behavior that will be primarily controlled by their surrounding soil made up of the upper sandy marls encountered between the level of the natural ground and that of the TN-32 m. The first approach consists of using the Mohr Coulomb model to investigate the behavior of the sol. The geotechnical parameters used in the modeling of the various layers of soil are provided in table 1.

According to the studies carried out by the most suitable method to treat the soil over the entire depth concerned by the liquefaction phenomenon remains by far the wet ballasted columns [11]. This method uses a sufficiently powerful vibrator. Table 2 shows the characteristics of the vibrator used during the realization of the columns at the level of the bridge on Oued Martil.

Modeling method of the implementation of a ballasted column

In order to model the effect of the implementation of a ballasted column, we used the software PLAXIS in axisymmetric mode, and this, in order to account for the symmetry of revolution of the ballasted column [12]. PLAXIS a is standard software based on finite element algorithm specifically designed for geotechnical engineers to model, to analyze used deformation as well as stability. The geometry of the adopted numerical model is presented in detail in figure 4.

Note that the width modelled for the ballasted column is taken to be equal to 40 cm, i.e., half the diameter of the column used in the reinforcement project, which is 80 cm. The width "d" of the model was deliberately chosen to be large (equal to 10 m) compared with the diameter of the column,

Table 2: Vibrator's parameters.

Parameter	Unit	Vibrator HD150
Diameter	mm	310
Frequency	Hz	50
Weight	Kg	2550
Hydraulics pressure	KPa	200

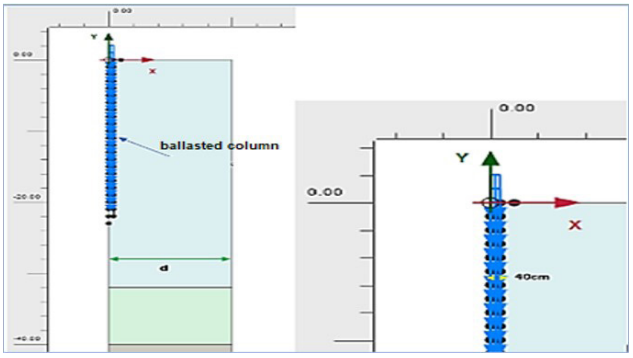


Figure 4: Illustration of the phasing adopted during the modelling.

in order to explore the maximum influence of the column's installation on its surroundings.

Using the soil and column geometry and parameter data, we modelled an elementary cell modeling, followed by full column modeling. For the remainder of this work, numerical simulation of column implementation was deployed using the following phasing:

- Initialization of the stress field,
- Cutting the length of the column into the shortest possible elements, with a length not exceeding 1 m,
- Inserting a perfectly elastic rubber-like material in the 1m long sections and performing the rubber loading. The horizontal stress is normally equal to half the vertical stress applied to the rubber layer ($\nu = 0.5$). This depends on the pressure applied by the vibrator used to make the ballasted columns. With a value of 200 kPa, the horizontal stress is 100 kPa,
- After loading the rubber layers, we replaced the rubber with the column material (20/40 ballast), and
- As shown in figure 5, we continue this process from the bottom to the top, until we finish the entire length of the column at the level of the natural ground.

This approach allows us to determine the stresses in the soil mass produced after the vibrator loading. Once the horizontal stress within the soil has been generated, the soil modulus value is increased.

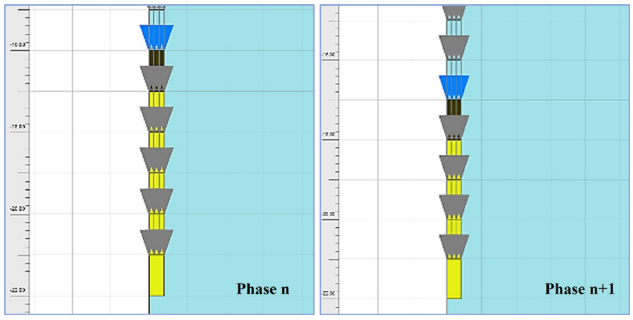


Figure 5: Illustration of the division adopted during the modelling process.

Results and Discussion

The results obtained by these models allow us to understand the behavior after loading the column. Figure 6 shows the deformation of the column at the end of the steps described above. The result of the modeling highlights a lateral expansion of the column in the surrounding soil which can reflect the implementation in reality. The displacement process shown in figure 6 highlights mapping of the lateral displacements induced, only, by the process of implementation of the column. Figure 7 shows a mapping of the lateral displacements induced, solely, by the column implementation process.

To estimate the minimum safety distance to be respected in the case of columns intercalated with piles, a numerical model is carried out to evaluate the radial variation of the displacement around the column illustrated by figure 8. Typically, in the present case and when taking into account for the surrounding soil, it can be stated that from 2 m from the center of the column, the lateral displacement variation becomes negligible.

Figure 9 shows the variation of the horizontal stress field after the implementation of the column. It can be seen that from 2 m from the axis of the column, the vertical stress area returns to its horizontal position after the initialization of the

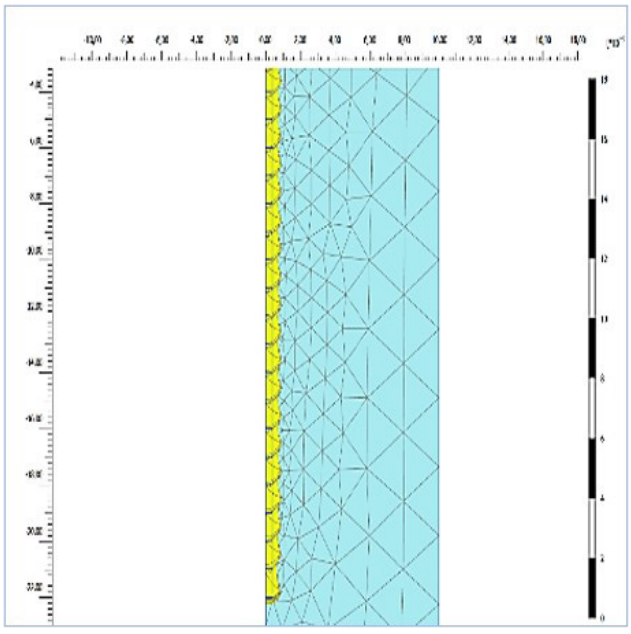


Figure 6: Illustration of the deformation of the column.

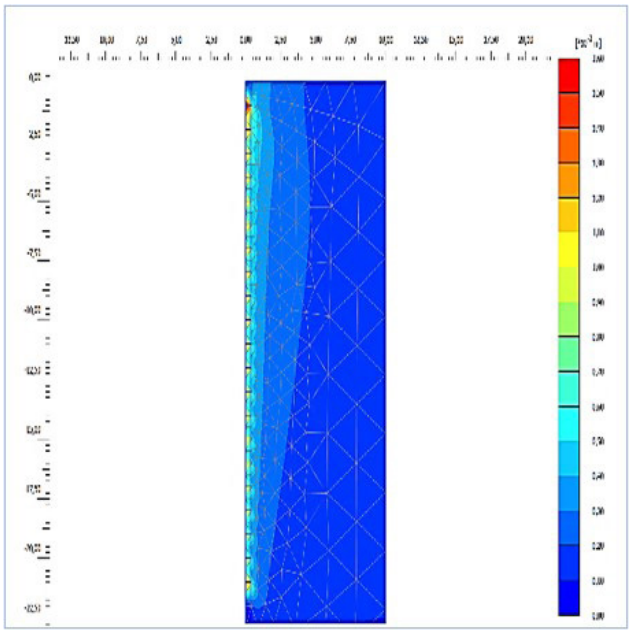


Figure 7: Mapping of the lateral displacements induced during the implementation of the column.

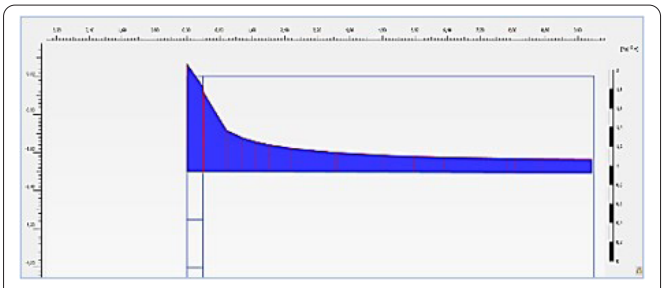


Figure 8: Radial variation of the displacement around the column.

stresses, indicating that there is no influence beyond that distance. Consequently, the piles can be executed in parallel or at the same time as the ballasted columns without any particular stability problem, provided that a minimum safety distance of 2 m is left.

To evaluate the *in-situ* influence of the ballasted columns on the deep foundations, we have used the sonic auscultation method. In the following section, we apply this method to follow the variations in the quality of the concrete, to precisely locate the possible singularities and to appreciate the homogeneity of the concrete over the whole height of the pile elements.

Sonic auscultation of piles

The sonic auscultation method is used to check the continuity of deep foundations and piles by detecting the presence of cracks or anomalies along the shaft and at the tip. The homogeneity and quality of the concrete can be assessed, and defects precisely located, including at the pile tip. Sonic coring is a continuous measurement along the pile of the sound propagation time between a transmitting probe and a receiving probe.

The measuring tubes are metal with an internal diameter of 40 mm. Heating tubes with a gas thread at the end are

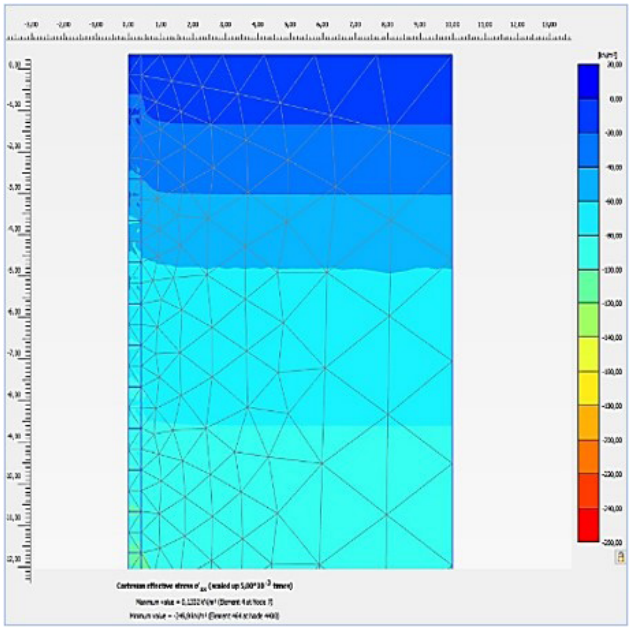


Figure 9: The variation of the horizontal stress field after implementation of the column.

perfectly suitable. If the project includes core drilling tubes, these must have an internal diameter of at least 100 mm and also be threaded to the gas pitch. Pipes must be connected using screwed sleeves (welded connections are not permitted). Figure 10 and figure 11 illustrate the position of the monitoring tubes in relation to the reinforcement cage.

Figure 12 shows that the pile that was inspected under the effect of the execution of the ballasted columns with a distance of 2 m shows no anomalies, however the continuity and homogeneity of the concrete over the entire height of the piles.

Using the results of this model and after analyzing the sound auscultation tests of the pile, it clearly shows that it did not detect any anomalies or problems such as pile movement or loss of strength.

Conclusions

We examined the effects of soil liquefaction in a seismic zone, which is a major problem and obstacle when constructing foundations for structures, as the said foundations are liable to subside or collapse under the effect of shear, flexural or frictional stresses. We assessed the effects of wet placement of ballasted columns in liquefiable soil on piles, as well as the phasing of the work. This work was prompted by the scale of the damage to be avoided, which could occur without respecting the phasing of the work and the minimum distance between the ballasted column and the pile.

The stakes are high from a technical and economic point of view, and naturally the choice of solutions is closely linked to the budget allocated to the project. In the specific case of the Martil River bridge under consideration, an influence distance of 2 m is required. This estimate was tested by modeling using PLAXIS software. This result was confirmed by sound auscultation tests. From this analysis, we have confirmed that the bearing capacity of piles is closely linked to the distance of influence and the lithology of the soil under consideration.



Figure 10: The armature cage with auscultation tubes.



Figure 11: Mounting the armature cage with auscultation tubes.

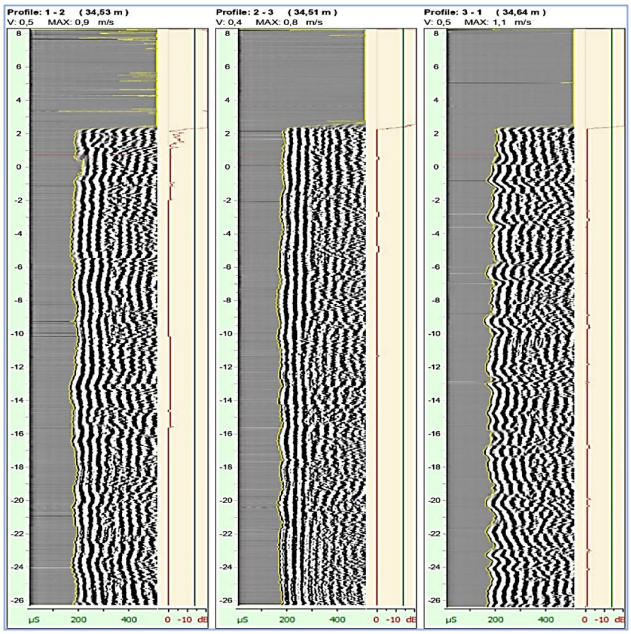


Figure 12: Auscultation of the pile.

- Finally, the conclusions of this work are summarized as follows:
- The site is located in a seismic zone with a high risk of soil liquefaction.
- The combination of reinforced concrete piles to ensure bridge stability and ballasted columns to avoid soil liquefaction is possible.
- The load-bearing capacity of the piles is closely linked to the type and influence of the distance between the piles and the ballasted columns.
- The lithology of the soil in place is a decisive factor in the choice of solution.

The prospect of liquefaction can be seen from two different angles: developing software to assess the risk of soil liquefaction, and geological mapping to define areas with liquefiable soils.

Acknowledgements

None.

Conflict of Interest

None.

References

1. Tlidi Y, Bahi L, Ouadif L, Bahi A. 2022. Treatment of liquefiable soils by the ballasted column technique: case of Martil River bridge in the North of Morocco. *Civ Eng Archit* 10(2): 659-668. https://doi.org/10.13189/cea.2022.100221
2. Lee JS, Pande GN. 1998. Analysis of stone-column reinforced foundations. *Int J Numer Anal Methods Geomech* 22(12): 1001-1020. https://doi.org/10.1002/(SICI)1096-9853(199812)22:12<1001::AID-NAG955>3.0.CO;2-I
3. Qi Y, Indraratna B, Ngo T, Ferreira FB. 2021. Advancements in geo-inclusions for ballasted track: constitutive modelling and numerical analysis. *Sustainability* 13(16): 9048. https://doi.org/10.3390/su13169048
4. Franke KW, Wright AD, Ekstrom LT. 2014. Comparative study between two performance-based liquefaction triggering models for the standard penetration test. *J Geotech Geoenviron Eng* 140(5): 04014010. https://doi.org/10.1061/(ASCE)GT.1943-5606.0001094
5. Tlidi Y, Bahi L, Ouadif L, Bahi A, Amrani M. 2022. Treatment by ballasted column against the phenomenon of liquefaction soil: case of the Mohamed VI Tower in Morocco. *Civ Eng Archit* 10(4): 1317-1326. https://doi.org/10.13189/cea.2022.100407
6. Mahdi TA. 2020. Geological model of hartha gormation in Majnoon oilfield, southern Iraq. *Iraqi Geol J* 53(1A): 48-57. https://doi.org/10.46717/igj.53.1a.R4.2020.01.31
7. Ashford SA, Rollins KM, Bradford VSC, Weaver TJ, Baez JI. 2000. Liquefaction mitigation using stone columns around deep foundations: full-scale test results. *Transp Res Rec* 1736(1): 110-118. https://doi.org/10.3141/1736-14
8. Al-Zubaidy AA, Jasim HK, Idan RM. 2021. Mineralogy and chemical composition of basalt stone tools in some Iraqi archaeological sites. *Iraqi Geol J* 54(1C): 101-113. https://doi.org/10.46717/igj.54.1C.8Ms-2021-03-28
9. Al Saoudi NKS, Rahil F, Abbawi Z. 2015. Soft soil improved by stone columns and/or ballast layer. *Proc Inst Civ Eng Ground Improv* 168(3): 179-186. https://doi.org/10.1680/grim.12.00035
10. Nehab N, Baba K, Ouadif L, Cherradi C, Bahi L. 2014. Soft soil strengthening by stone columns: case of the embankment under the bridge "Moulay Youssef" (Rabat/Salé). In International Congress on Materials and Structural Stability, Rabat, Morocco.
11. Bencheikh MBB, Aidoud A, Benamara FZ. 2020. Contribution to the study of soil stabilized by ballast columns. *Civ Environ Eng Rep* 30(3): 234-252. https://doi.org/10.2478/ceer-2020-0042
12. Sebbar N, Lahmili A, Ouadif L, Akhssas A, Bahi L. 2018. Soil treatment in flood areas: case of the road RP4209, in the province of Kenitra (Morocco). In 2nd International Congress on Materials and Structural Stability, Rabat, Morocco.