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Numerical Modeling of Sandy Subgrade Reinforcement by Deep Soil Mixing from Ceramic Industries Wastewater Additive

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Abstract: Todays, development of road transportation and settlement of roads on different subgrade are problems of pavement industry. Desert and beach sands in different parts of the world are the results of load bearing, instability and failure against shear stresses. In other points of view, industries produce different wastewaters whose entrance to the natural environment results in environmental problems. This study utilizes numerical models to improve roadbeds made in sandy areas using ceramic industries wastewater. The goal is to investigate the application of experiment results of mixing ceramic industries wastewater, cement and dune sands in different geometrical models of reinforcing weak subgrade. The analysis of pavement reaction has been modeled in software. Using modeling of refined sand as subgrade or pavement layers stabilizer, surface layer settlement was calculated. The maximum settlement calculated from the modeling was compared with international standards.

Keywords: Natural environment protection, ceramic industries wastewater, software modeling, pavement improvement, surface settlement

1. Introduction

There have been different industries around cities and roads and part of their wastage or wastewater is usable in parts of civil and construction activities. Exploiting the wastewater for improvement and reinforcement of pavement bed soil is common. Bed soil has different types and features in different regions, as an example there is a lot of sand in deserts or beaches known to be loose and highly deformable. To reduce the disadvantages of these kinds of soils, load carrying elements are used in stabilization. The most important standards of improvement for beds have been soil layers stabilization in past studies. The innovation in this study is to stabilize smooth sands making deep elements in roadbeds. Moreover, industrial wastewater with features close to pozzolan is used instead of cement for stabilization. Therefore, consumption of cement declines. Researcher has considered less used wastewater in past studies. However, regarding characteristics of constituents and the dimensions of their particles, they are considered as pozzolan and cement substitute.

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Nomenclature:
δ_s Compressive stress
ϵ_s Compressive strain
Δ_s surface layer settlement

2. Literature Review

Deep soil mixing method has been used for refinement of buildings and weak bed soil in north European and Southeast Asian countries (Neves, Lima, Goncalves, 2016). Deep soil mixing (DSM) is a public work engineering, deep groundwork procedure where a binder or cohesive material, typically cement, is injected into the earth for soil stabilization and land reclamation (Horpibulsuk, Miura, Koga, and Nagaraj, 2015). In ground stabilization uses it is typically used to obtain a better load comportment ability of the standing soil as shown in Fig. 1 (Porbaha, Shibuya, Kishida, 2000). (Rutherford, 2004), fund that, DSM is effectually used in excavations both in combination with and in change of customary methods, where it results in more economical and suitable solutions for the strength of the structure and the prevention of seepage and drainage. Even though, DSM is used for excavation mechanism in many projects, presently, no standard technique has been developed and the different applications have not been valued (Rutherford, 2004). This method is known consistent with sustainable development and environment protection because of the least change in soil conditions and movements (Wang, Fu, Zhou, 2016).

There are different methods for design of this executive operation such as FHWA[1] regulations or European standard of EN14679 (Jamsawang,Yoobanpot, 2016). Designing in this method is based on determining the pattern of columns setting of load-carrying elements, their diameter, number, distance and depth or height and done by finite element method and software here. In 2016, Neves et al. used two-dimensional analysis in ADINA2 for modeling reinforced soil by Geotechnics (Neves, Lima, Goncalves, 2016). Also in 2016 Wang et al. presented a three-dimensional finite element model in order to simulate and stabilize highways subgrade soils. Wang, Fu, and Zhou studied the use of cement columns for highway bed soil stabilization using three-dimensional analysis in 2016. They studied measured parameters including settlement, stress distribution between soil and cement, lateral settlement of deep columns as well as thickness of pavement layer (Wang, Fu, Zhou, 2016).

Takahashi, at al. mentioned the use of Sodium meta-silicate alkaline wastage as cemented in deep soil mixing for stabilization and increasing soil strength (Takahashi, Morikawa, Fujii, and Kitazume, 2018). Saberian et al. studied dimensions and distance of elements or load-carrying columns in road pavement by modeling in PLAXIS[3] (Saberian, Moradi, Vali, and Li, 2018). In sandy soils, using deep soil mixing has been extensively considered in protection of environmental resources of soils, Scanlan and Pavies has studied this topic in 2019 (Scanlan, Davies, 2019). Horpibulsuk, studied from both investigations have been combined with former basic laboratory studies on induced cementation of cement-admixed clays. A useful method is recommended for received at different factors in the setting up of columnar inclusion to produce composite earth of the required usual strength (Horpibulsuk, Miura, Koga, and Nagaraj, 2015). (Yi et al., 2019) indicated that the additional pressure in the earth and the column in the extremely compressible soil layer were much lesser in the variable-diameter column-improved ground than in the conventional column-improved ground. The variable-diameter column-improved ground yielded less total deflection and less post-construction deflection compared to the conventional column-improved earth (Yi, Liu, Puppala, and Jing, 2019).

In other hands, using wastage and controlling production of industrial wastage like construction waste has been studied by many researchers. Nagapan et al. studied production control of construction waste including ceramic industries wastage (Nagapan, et al. 2018). Moreover, Khabiri investigated the application of construction wastage as substitute materials (Khabiri, 2010). Ngadiman and Rahman et al. investigated approaches to reduce undesirable effects of construction wastage and consider environmental issues in construction activities (Ngadiman,et al. 2017). Using industrial wastage and their application as improving materials for building components have been investigated in many researches including a study by Akeem et al. about usage of sawdust as a proper Pozzolan in pavement and road-making industry as a substitute for cement in pavement in 2017 (Akeem, Solomon, Ajayi, Adedoyin, Adegboyega, 2017). According to Shahidul's comments in his paper, the results were presented below (Shahidul, 2018):

- Due to great water content, Dry Mixing technique is operative for stabilization peat subgrade.
- Using fly ash, blast furnace slag, or other waste can quicken reaction rate during soil stabilization and improvement.
- By some primary load after installation of soil-cement column can moreover increase strength of treated soil (Shahidul, 2018).

A review of the references showed that wastewater of tile and ceramic industry was not used to stabilize the weak soil and subgrade. The distance and layout of the elements of the Load bearing has made a significant impact on the

[1] The Federal Highway Administration (FHWA)
[2] Automatic Dynamic Incremental Nonlinear Analysis
[3] Geotechnical Professionals. 2d & 3d Finite Element

pavement settlement. The purpose of this paper is to describe impact of distance and layout of the load bearing elements on pavement stress and strain and choosing the optimal layout for these elements. In the methodology of this research, the surface settlement is measured and controlled by making different models of load-carrying elements made of deep soil mixing of sand, cement and industrial wastewater.

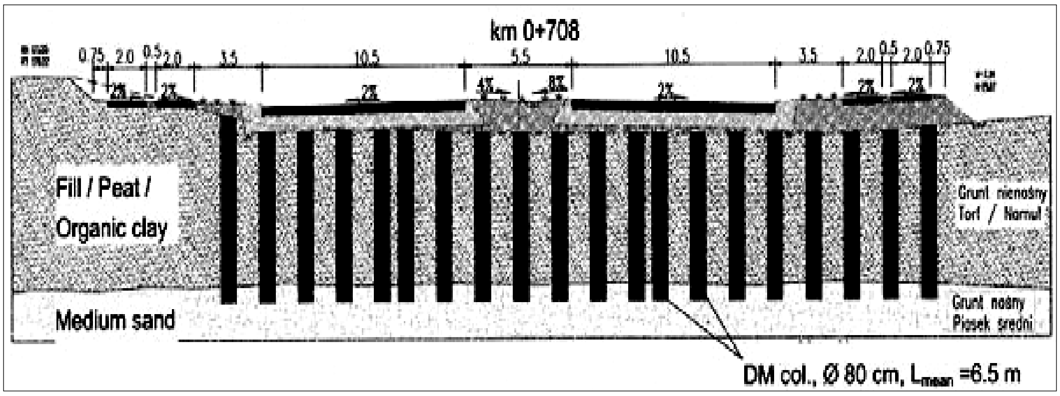


Fig. 1 - A cross section of the pavement with deep soil mixing process. (Shahidul, 2018)

3. Numerical investigation and modeling

In this study, looking into the results of axial strength of samples from experiments, modeling was performed in software. Elements dimensions and setting of reinforcing elements of sandy bed soil have been the studied parameters. As transverse section of road surface is constant, the simulation has been performed in ABAQUS[4] software in two-dimensions. The dimensions of model for bed soil are 20 meters in horizontal direction, 10 meters deep and 7.4 meters wide shown in Fig. 2. Also load-carrying elements were modeled in two sides of the road made up of sand processed with ceramic industrial wastewater and cement. In the second stage, one other element was assumed in the middle of the road and the results were compared with the past simulation.

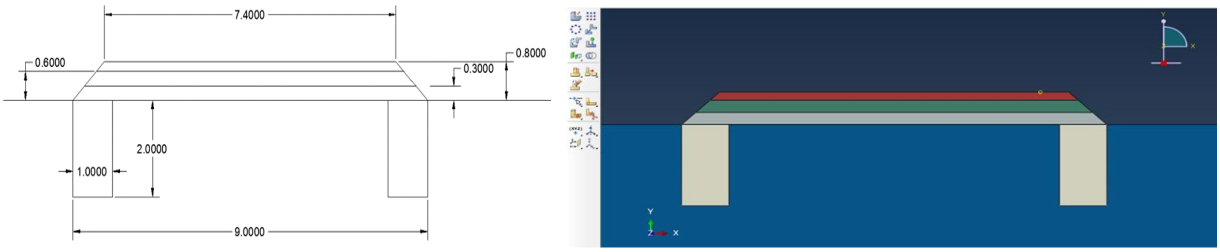


Fig. 2 - (a) Dimensions of the constituents in the software; (b) Geometrical model in ABAQUS software.

3.1 Material Characteristics

Because of low thickness of layers and cracks propagated under loading, the assumed behavior is non-linear. So, Mohr-Columb model is used. All the parts made of sand except load-carrying elements follow this mechanical behavior. But the load-carrying elements follow elastic behavior. Table 1 introduces material characteristics and behavior. The behavior of all layers is assumed to be elastic and the Poisson coefficient of the layers ranges from top to bottom 0.35, 0.40 and 0.45. (Rahman, Lutz, Finn, Schmauder, and Aicher, 2007).

[4] Finite Element Analysis and Computer-Aided Engineering

Table 1 - The characteristics of different materials and layer in modeling. (Rahman, et. al. 2007)

Parameter and Specifications	*Amount*
The number of load-carrying elements in a row	*2 or 3*
Height load-carrying elements (m)	*2*
Surface Layer Elastic modulus(Mpa)	*2175*
Surface Layer tackiness(cm)	*10*
Base Layer Elastic modulus(Mpa)	*415*
Base Layer tackiness(cm)	*25*
Subgrade Layer Elastic modulus(Mpa)	*52*
Subgrade Layer tackiness(cm)	*200*

3.2 Loading and Boundary Conditions

Applied load on the model is of two kinds, one load by trailer's wheel which is applied statically over the pavement. This means that standard load applied by an 850 Kpa trailer was modeled as a circle with a diameter of 11 cm or 8.2 tons and in a distance of 0.6 m from the road edge (Abdellatif, 2013). The other geostatic force is applied to all model elements. In order to achieve a logical answer in finite element software, we must consider the minimum dimensions of the model boundaries. This value for the analysis of the road is 50 times the value of the standard circular radius in the vertical direction and 12 times the value of the standard circular load radius in the horizontal direction. The boundary conditions defined as vertical rollers in side boundaries of soil pile and as fixed under it are shown in Fig. 3. Coarse and fine meshes elements are used for meshing in different locations close to or far from loading area.

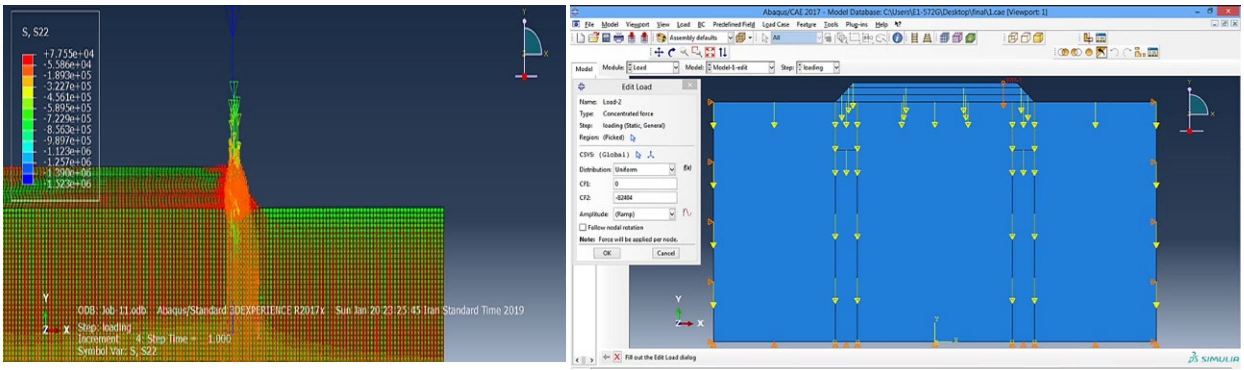


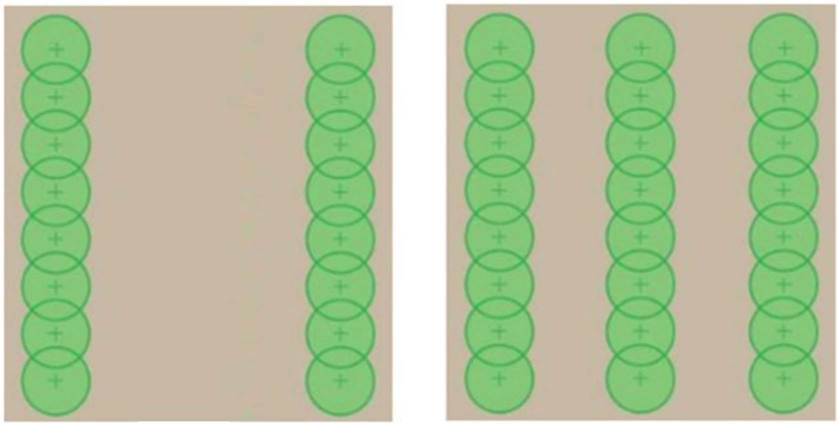
Fig. 3 - (a) Geostatic loading and trailer wheel load; (b) Appling boundary condition to the model.

3.3 Software Validation

In this research, Rahman's research has been modeled to verify the present model. They had the same model of pavement with elastic behavior. The result of present research showed a maximum settlement of 0.0063 m in pavement surface while this parameter was found 0.0065 in Rahman's simulation with less than 5% difference (Rahman, Lutz, Finn, Schmauder, and Aicher, 2007).

4. Results and Discussion

To investigate the functionality of sandy materials reinforced with cement and ceramic industries wastewater, two models were made (Fig. 4) and analyzed in two ways. First, the stresses and settlements under geostatic load and second stresses and settlements related to geotechnical stresses and loading simultaneously were investigated.



A B

Fig. 4 - Modeling plan (a) Load-carrying elements beside the road; (b) Load-carrying elements beside and in the middle of the road.

The depth of the deep soil mixing or the height of the elements is 2 m, their diameters are 1 m and the axis-to-axis distance of elements is 8 m in model 1 (besides the way) and 4 m in model 2 (beside and in the middle of the road). The results of different simulations are demonstrated in Fig. 5. Settlements and stresses resulted from loading in model 1 and 2 are compared graphically and shown in Table 3.

Table 3 - Summary of the analytical modeling results and their comparison.

Characteristic	Measurement Unit	Model 1	Model 2
Δ_s(Geostatic settlement of pavement surface)	Mm	94.55	94.355
Δ_s (Geostatic settlement and surface load)	Mm	103.77	105.77
$^{\delta}$s (Geostatic stress of pavement surface)	Kpa	3.50	3.05
$^{\delta}$s (Geostatic stress and pavement surface load)	Mpa	1.523	1.561
Δs (Maximum settlement resulted from loading)	Mm	11.15	11.35
$^{\delta}$s (Maximum stress resulted from loading)	Mpa	1.5195	1.5295

The difference of the two modeling results are in load-carrying elements. As the difference in stress and settlements are negligible, model 1 is prioritized for being more executive and economical. The reason for small difference is the long distance between load-carrying elements. Off course in both models, the calculated settlements in design and setting of elements are less than maximum allowable international standards and acceptable. Asphalt institute has defined a maximum allowable settlement of 12.7 mm as acceptable for roadbed while TRRL[5] has defined this amount to be 10.16 mm (Houng, 2004).

5. Conclusion

Measured parameters from performed experiments in the laboratory for using cement and ceramic industries dried wastewater in sandy beds were used for modeling in software and definition of elastic and mechanical characteristics of these materials in two different pavement modeling. The results showed that:

1. The results of geostatic and vehicle wheels loading shows that for each analysis, the results were similar. But model 1 where load-carrying elements are located only in two sides of the pavement is economically and executively more desirable.
2. Surface settlement in loading point is 9.2 mm which is considered acceptable comparing with allowable settlement limit of 10 mm. so functionality of load-carrying elements (cylinders with a diameter of 1 m and height of 2 m) is countable.
3. As a whole, stabilization and improvements of sandy roadbeds in beach and desert regions using deep soil mixing from ceramic industries wastewater material processed with cement can be a desirable option. Because from an environmental point of view, industrial wastage is used and there is no need to transfer a large amount of sands which are inappropriate as bed soil and may change the environment negatively.

[5] England transportation research organization

Other researchers are recommended to use the other industrial wastewaters in sustainable development and stabilization of weak soils. Also, the functionality of this solution in refinement and improvement of bed soil can be studied in real scale.

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