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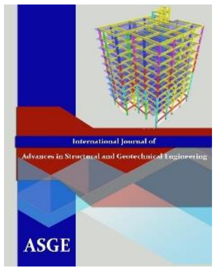

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Effect of Earthquake Conditions on Soil Properties of Roads

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ABSTRACT

In Egypt, a huge quantity of natural and synthetic wastes are eliminated every year. Hence, the process of recycling them by mixing with soil is one of the cheapest and most effective ways to dispose those wastes and protect the environment. Also, Interest in the construction of modern road networks has become one of the first priorities in Egypt. This paper presents an experimental and numerical study about the effects of mixing rice straw (RS) and tyre chips (TC) with two types of sand on the properties of the mixtures using the experimental triaxial test. Then, study numerically the effect of earthquakes on the previous soil types. This paper discusses mainly two types of natural and synthetic wastes and two Egyptian types of sandy soils, namely Gamasa sand (S1) and Yellow sand (S5). These types of sandy soils are the most common soils used in road foundations in Egypt. This research presents innovative manner which has not been studied before with Egyptian soils. Six types of mixtures and two control specimens have been tested to determine the basic soil and shear strength characteristics for each of them. Wady El-Natroon / Al-Alameen road foundation is selected as a study case. Numerical analysis using Geostudio- Quake/w were conducted to study the effect of earthquakes on it to select the best mixture to use in it from these mixtures under the dynamic condition. Finally, the clear and strong advantage of using this wastes is the safe and economic disposal of the mentioned natural and synthetic waste materials. Also, the improved soil, which always used in road foundations under earthquake conditions will save time and money in the specific works. This study recommended using the proposed mixture of (S8) which has the best enhanced soil shear characteristics comparing with the other mixtures.

Keywords: *Natural Fibers, Synthetic Fibers, Soil enhancement, Triaxial test. Earthquakes, Quake/w, Wady El-Natroon / Al-Alameen road.*

INTRODUCTION

Soil reinforcement is defined as a process used to improve the engineering (mechanical) characteristics of soil, to improve its stability, to increase its bearing capacity and to reduce settlement and lateral deformation. In this way, using waste materials generated from agricultural and industrial processes which defined as natural and synthetic fibers to reinforce soil is an old and traditional idea. Consequently, randomly distributed fiber reinforced soils have recently attracted attention in Geotechnical engineering.

Recently, fiber is generally divided into two main categories: one is the natural fibers like rice straw, wheat straw, coir, bagasse, and jute,….etc. because they have the advantages of availability and low cost and the disadvantage of environmental pollution when burned or not. Others are synthetic (man- made) fibers, such as polypropylene fiber, polyvinyl alcohol fiber and nylon fiber,….etc. It can be seen as a waste, not reusable, non biodegrable and environmentally pollutant such as the water bottles, the car's tyres and the plastic bags,….etc[1]. Generally, the use of wastes as alternate soil improvement material has had a great deal of interest in recent years. Agricultural (natural) wastes such as Coconut (coir) fiber, Sisal, Palm fibers, Jute, Flax, Barely straw, Bamboo, Cane [1], rice straw, wheat straw[2], [3], natural vernacular fibers of Grewia Optivia (Beul) and Pinus Roxburghii (Chir Pine) [4], Short Hibiscus cannabinus fibers[5] and Industrial(synthetic) wastes such as Polypropylene (PP) fibers, Polyester (PET) fibers, Polyethylene (PE) fibers, Glass fibers, Nylon fiber, Steel fibers, Polyvinyl alcohol (PVA) fibers[1], waste fishing net[6], wool fibres of various fibre lengths[7], polyester fibres[8], Waste Gypsum Board Paper[9], polypropylene fibers[10], Synthetic wick fibers[11], Waste Plastic Bottle Strips[12], [13], polyethylene terephthalate (PET) fibers[14], Lime[15], Tyre Ash material burnt in air[16], recycled aggregates from demolition waste[17], [18], Ground Granulated Blast Furnace Slag (GGBS)[19], Crushed Glass[20], [21], waste sawdus[22], [23], A combination of several material such as polypropylene fibers and fly ash[24], polypropylene fiber and four types of agriculture wastes (wheat straw, rice straw, jute)[25], cement and polypropylene fiber[26], silica fume–scrap tire rubber fiber mixture[27], recycled gypsum and waste plastic trays[28], polyethylene waste material and cement[29], rice husk ash and cement[30], cement, lime and rice husk ash (CLR)[31], marble dust and fly ash[32]. Egypt is very rich in agro-waste resources. One of the most abundant and readily available agro-waste resources in the country is rice straw. Rice straw has become a very serious problem in Egypt due to the huge production of straw of about ٥.٢٣٦million tons /year. Being a suitable material for insects and pests. Rice straw is considered a problem for the farmers who store it near their houses or fields. The farmers then burn the straw causing black clouds and severe pollution in the Egyptian atmosphere. Rice grown in Egypt from two million feddans (two billion acres) to 1.6 million feddans. According to the Egyptian Environmental Affairs Agency/Egyptian Ministry of Environment/annual report for agricultural waste. Dated 16/9/2018[33].

Using the sand box model to simulate the slope failure mechanism under reinforced and unreinforced soil using rice straw fibers. Slope stability may increase significantly by adding rice straw to sandy soil. Generally, whenever rice straw proportion increases the slope stability. The optimum rice straw content that gives the maximum stress in the form of slope stability is in the range of 0.75 % by weight. Sand mixed with 1.0 % rice straw by weight leads to increasing the angle of internal friction (Ø) by 46.63%, as compared by only the host sand[34].

The disposal of used tyres is a huge environmental problem in Egypt. About 20 million tons of waste tyres material per year in the year (2017) caused by the Egyptian vehicle industries development and the rate of the massive increase of imported cars. Burning the used tyres is the most popular concept in Egypt. Burning the used tyres as a cheap fuel for brick and pottery industries. A lot of toxic fumes produced from the burning process that is an environmental pollutant. The disposal process of the used tyres is considered a major problem in the waste stream as it is highly found everywhere. Providing a new concept for Egypt to benefit of scrap tire and resolving a local environmental problem by using it with soil for soil improvement is very important[35], [36].

Sand particles are brittle, but was found to be more ductile with rubber mixed. Using of recycled tyres in the applications of civil engineering as a lightweight material has been growing in the last two decades. Mixing recycled tires in various shapes and ratios with different types of soils have been used as backfilling on slopes, retaining walls and embankments. Recently, using it under foundations as a damping material in hazard seismic areas has a huge importance. Many types of tests have been performed to investigate the mechanical properties of recycled tyres mixed with sandy soils such as various types of triaxial and consolidometer tests. The use of recycled tyres and sand mixtures has a huge effect on unit weight, shear strength, stiffness and deformation modulus (E_{50}). Generally, mixtures unit weight decreased with the increasing of tyres content ratio and the failure behavior of the mixtures changed from brittle to ductile behavior. The ductile behavior of the sand-tyres mixtures had many advantages such as increasing the seismic isolation layers beneath the foundations of structures in seismic zones. All types of the sand – tyres mixtures had been decreased the shear strength of the mixtures except the 5% tyres content in the mixture by weight, which exhibited higher shear strength[37].

In this paper, six types of mixtures and two control specimens have been tested to determine the basic soil characteristics and shear strength characteristics for each of them. Triaxial experiments were performed on various sand- rice straw (RS) and tyre chips (TC) mixtures using static triaxial apparatus. Samples were constructed at the maximum dry density and optimum moisture content to consider engineering applications in dry regions.

Research Objectives

The main objectives of this research are to reuse the natural and synthetic waste materials to enhance the basic soil characteristics to have a clean environment. This wastes can be mixed with different types of sandy soils in a single or double form to have a strong soil to build projects. Investigate experimentally the effects of mixing the synthetic waste tyre chips (TC) and the natural waste rice straw (RS) in several manners with two types of sandy soils (namely Gamasa sand (S1) and Yellow sand (S5)) on the properties of the mixtures. Numerically, determination the effect of earthquake on Wady El-Natroon / Al-Alameen road when using this types of mixed soil in the road body. Finally, Determination the basic soil and shear strength characteristics, choosing the best mixed soil to use in the previouse mentioned road, Compare the results and give notices are the first goal. The engineering properties of used materials were determined by conducting laboratory tests according to the American Society for Testing and Materials (ASTM Standards).

Experimental equipment

Using Triaxial Digital machine to determine exactly the mechanical shear strength of the tested soil. All triaxial experiments have been conducted on samples with 70 mm diameter and 140 mm high. An automatic data logger system was used to record the load, deformation, and inner and outer specimen pressures. Using Linear Variable Deferential Transformers (LVDTs) with a displacement range of about 40 mm and load cell with a capacity of 20 KN, axial strains and axial load were measured, respectively. Cell pressure and pore pressure were also recorded by using two pressure transducers connected to the data logger system. This apparatus and others (modified proctor test, sieve analysis, sensitive balance, oven,…etc.) used in this research exist in soil mechanics and foundation laboratory, Engineering Faculty, Mansoura University, Egypt.

Materials

Raw Sand

Two main sets of triaxial tests were performed on two main types of sandy soils. The first was Gamasa sand with (S1) symbol. The main source of this type of sand is northern Mediterranean seacoast in Egypt, especially in the area extending from the city of Gamasa, El-Dakahlia governorate to the city of Baltim, Kafr El-Sheikh governorate. The second was yellow sand with (S5) symbol. The main source of this type of sand is the sand quarries in El-Sharkia governorate. The clean sandy soil used in these tests (S1 and S5) was obtained locally. The used sandy soils have been classified as poor graded sand (SP) according to the Unified Soil Classification System (USCS) with (ASTM D2487-06)[38]. The specific gravity for the used soils (S1) and (S5) is (2.683544) and (2.642706) respectively, according to (ASTM D854 – 06)[39]. The effective diameter for the two types of sand particles at D_{10} is (0.17 and 0.21) mm respectively. According to the gradation curve, shown in Figure (1), the uniformity coefficient is (1.71 and 0.85) and the curvature coefficient is approximately (1.17 and 2.24) respectively. Figure (2.a) shows Modified Proctor Test results for soils S1, S2, S3 and S4. While, Figure (2.b) shows Modified Proctor Test results for soils S5, S6, S7 and S8. The resultant Soil properties are summarized in Table (1).

Symbol	Soil Type	O.M.C %	M.D.D (gm/cm^3)
S1	Gamasa sand	7.25%	1.744

S2	Gamasa sand+1% Rice straw (RS)	10.25%	1.694
S3	Gamasa sand+5%Tyres (TC)	6.50%	1.733
S4	Gamasa sand+1%Rice Straw (RS) +5%tyres (TC)	10.50%	1.695
S5	Yellow sand	9.75%	1.711
S6	yellow sand+1%RiceStraw (RS)	11.25%	1.653
S7	yellow sand+5%tyres (TC)	11.70%	1.68
S8	yellow sand+1%RiceStraw (RS)+5%tyres (TC)	13.50%	1.644

Table (1) compaction characteristics of mixtures derived from Modified Proctor Test.

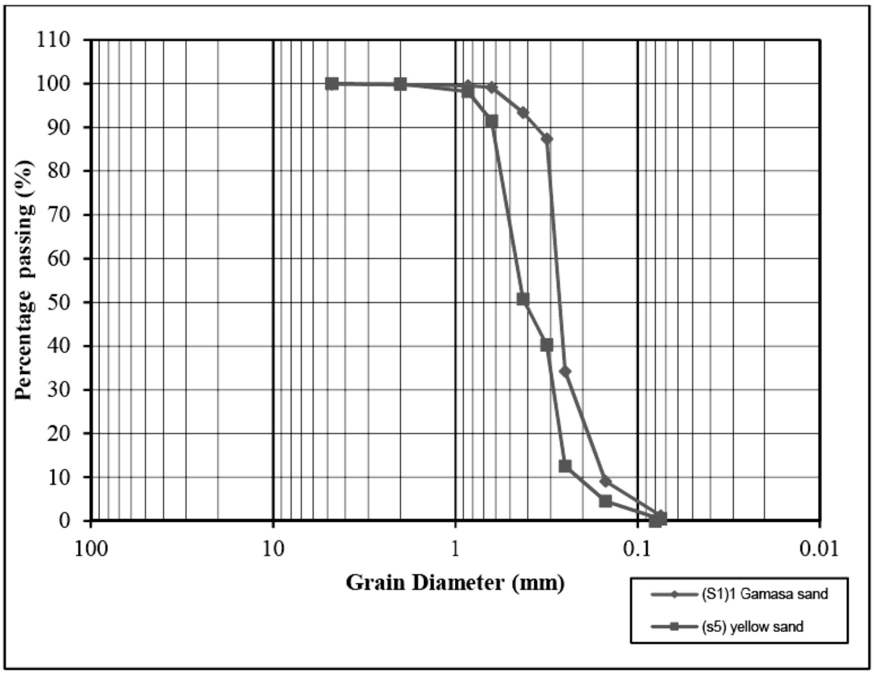

Fig. 1: The host sand gradation curve

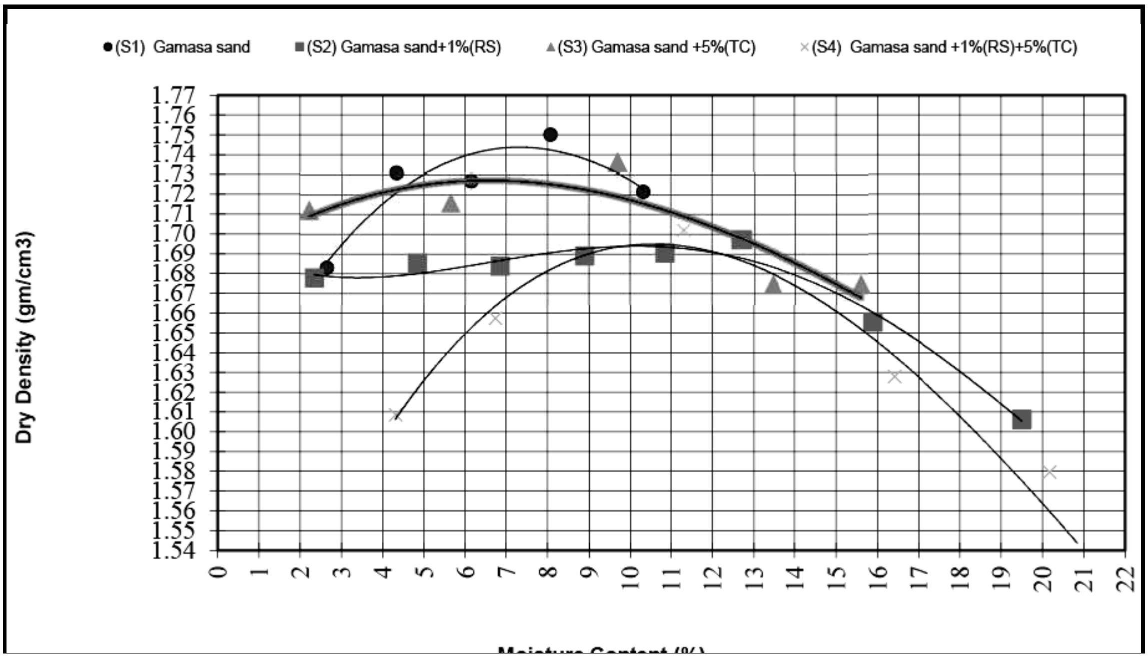

Fig. 2.a.: Modified Proctor Test results for soils S1, S2, S3 and

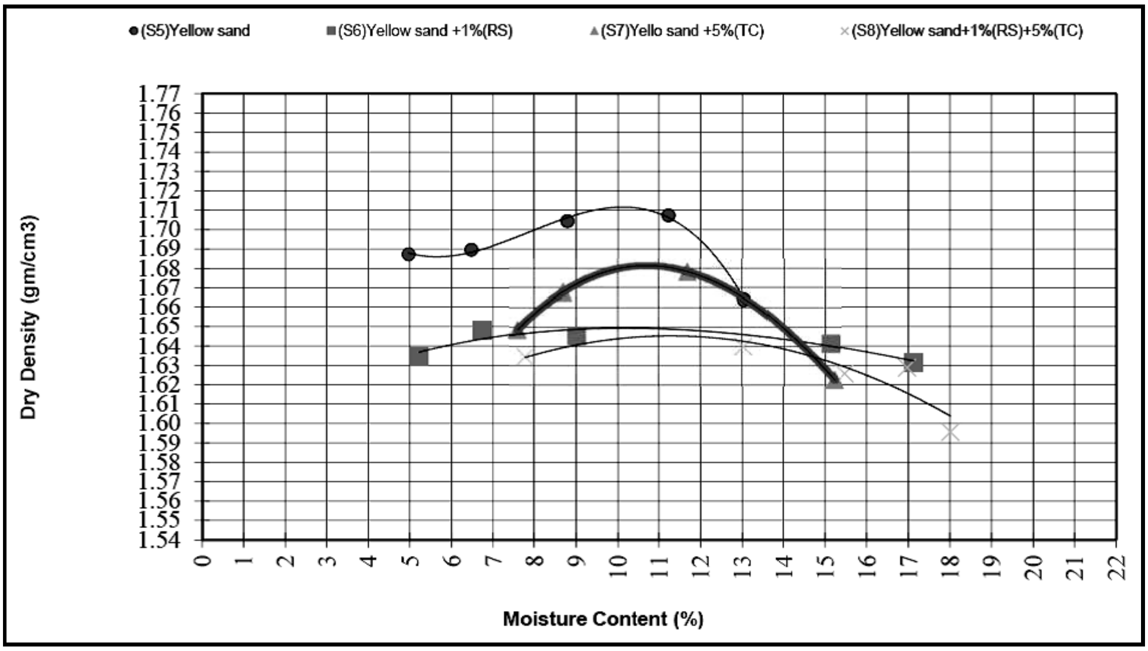

Fig. 2.b. Modified Proctor Test results for soils S5, S6, S7 and S8

Rice Straw (RS*)*

The source of rice straw (RS) is the agriculture fields localized at Sherbin city, El-Dakahlia governorate, Egypt. Using rice straw as a reinforced material by mixing it with several types of soils, the required length which can be used in soil lab. should be 10-30 mm. So, it can be welldistributed in soil samples. Therefore, rice straw (RS) was cut to approximate length 10-20 mm and the internodes as possible as usual in the middle [40].

Tyre chips (TC)

The source of the used tyre chips is generated from local factory produce tyre chips, shreds and powder which localized at Sherbin city, El-Dakahlia governorate, Egypt. The average weight of scrap automobile tires is 89 N (20 lb) and 445 N (100 lb) for truck tires [41]. The tyre chips (TC) were used in the laboratory tests is according to (ASTM Standards- D6270 − 08 (Reapproved 2012))[42].

Experimental work

Table (1) shows compaction characteristics of mixtures derived from Modified Proctor Test according to (ASTM standards. D1557 – 09)[43]. All specimens were prepared in the same manner and at about the same compaction energy. A set of unconsolidated undrained triaxial tests (UU) were carried out on sand samples as a control sample and fiber-reinforced sandy soils, according to (ASTM standards.D2850- 95 (Reapproved 1999)) [44]. The compressive strength of a soil is determined in terms of the total stress. In this test method, fluid flow is not permitted from or into the soil specimen as the load is applied, therefore the resulting pore pressure, and hence strength, differs from that developed in the case where drainage can occur. The test specimens are partially saturated and compacted according to their max. dry density and optimum water content, consolidation must occur when the confining pressure is applied and during shear, even though drainage is not permitted. Hence, if several partially saturated specimens of the same material are tested at different confining stresses, they will not have the same undrained shear strength. The applied axial load under strain-controlled conditions with a strain rate of (0.42 mm/min), the confining pressure is equal to 100 kPa, 200 kPa and 300 kPa to define the shear strength parameters. Used strain rate calculated according to (ASTM Standard D 2850, 1995(Reapproved 1999)) [44] and equal to (0.3% /minute) of the sample height. Figure (3.a). shows preparation of soil sample (S8) in triaxial cell. Figure (3.b). shows shear failure in Soil sample (S1).

Fig.3.a: Soil sample (S8) in triaxial cell

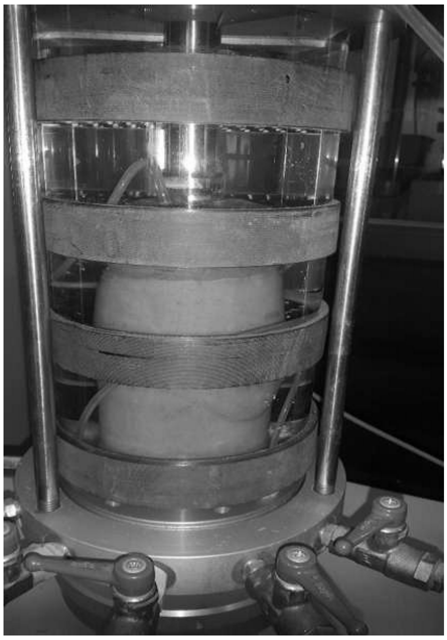

Fig. 3.b: Shear failure in Soil sample (S1)

Table (2) the laboratory Soil Characteristics for different mixtures results from triaxial test

Symbol	Soil Type	O.M.C %	M.D.D (gm/cm^3)	Ø°	C (kpa)	E (kpa)	μ %	G (kpa)
S1	Gamasa sand	7.25%	1.744	37.933	25	39609.79465	0.635754212	12107.50196
S2	Gamasa sand+1% (RS)	10.25%	1.694	39.204	19	37590.21551	0.605755329	11704.83909
S3	Gamasa sand+5%(TC)	6.50%	1.733	36.183	21	49526.76788	0.631531396	15178.00025
S4	Gamasa sand+1%(RS)+5%(TC)	10.50%	1.695	38.374	23	18289.26108	0.622746479	5635.279854
S5	Yellow sand	9.75%	1.711	35.51	44	76350.68471	0.455502201	26228.29586
S6	yellow sand+1%(RS)	11.25%	1.653	36.164	39	25075.17508	0.38526281	9050.692368
S7	yellow sand+5%(TC)	11.70%	1.68	39.032	21	67691.68547	0.404915499	24091.01668
S8	yellow sand+1%(RS)+5%(TC)	13.50%	1.644	35.976	61	14648.06336	0.374310804	5329.239688

Where:

O.M.C	Optimum moisture content %	E	moduluse of Elasticity (kpa)
M.D.D	Max. dry density (gm/cm^3)	μ	Poissson'ratio %
Ø	Angle of internal friction (degree)	G	Shear Modulus (kpa)
C	Cohesion (kpa)		

Results of experimental work

As a result of this experimental study, the following results can be concluded

1. The used sand samples which, enhanced by a 1% rice straw (RS) by weight of sand as a modified alternative method to increase ductility and decrease the maximum dry density by 2.86% and 3.39% and increase the optimum moisture content by 41.38% and 15.38% for (S1) and (S5) respectively. Also, it enhanced the angle of internal friction (Ø) by 3.35% and 1.84%, respectively, and decrease the cohesion (C) for the examined samples.
2. Using tyre chips (TC) with percent 5% by weight of sand samples achieves best soil characteristics with (S5) samples more than (S1) samples.
3. Comparing the soil samples (S7) with (S5). It can be found that the maximum dry density decreased by 1.82% and the optimum moisture content increased by 20%. Also, the value of angle of internal friction increased by 9.92%, which be the best increasing ratio.
4. Adding (RS) and (TC) to (S1) to produce (S4), and to (S5) to produce (S8) enhancing the soil characteristics. The angle of internal friction (Ø) increased by 1.16% and 1.312% for (S4) and (S8) respectively. Also, the cohesion increased by 38.64% for (S8) only.
5. Comparing (S4) and (S8) with (S1) and (S5). It can be found that the maximum dry density decreased by 2.81% and 3.91% and the optimum moisture content increased by 44.83% and 38.46% respectively.
6. The final result is the soil mixture (S8) almost has the best soil characteristics.

Numerical analysis

Most of engineering problems can be described mathematically. Mainly, it takes the form of integrals or partial differential equations which defined on geometrically complicated domains of interest. Numerical models are the major tools to solve large-scale engineering problems in Geotechnical engineering.

Why studying Earthquake effect

The study of earthquake activity and seismic hazard assessment of Egypt is very important due to the great and rapid spreading of large projects and investments in national projects, especially the nuclear power plant that will be installed in the northern part of Egypt and the new national road networks. Egypt is characterized by low seismicity, but it has experienced occurring of damaging earthquake effect through its history. The seismotectonic surveying of Egypt suggests that large earthquakes are possible to occur along the Gulf of Aqaba–Dead Sea fracture.

Figure (4) shows the past 25 years earthquakes maps in Egypt, recorded till august 2018, which had the magnitude of 1.5 or greater. It's clear that in the last year there was a moderate earthquake located in Helwan, Cairo governorate with magnitude 3.3. These maps are published in the united states geological survey (USGS) website, The (USGS) Earthquake Hazards Program is part of the National Earthquake Hazards Reduction Program (NEHRP), USA[45].

The Finite Element Method (FEM)

The numerical technique like (FEM) must be used to solve more complex and practical problems. The (FEM) divides the studied domain into a number of nodes and elements. Then it relaxes continues solution of the studied equations to an approximate discrete solution at the specified nodes using a selected base function. The desired solution within any element can be predicted from the nodal solution in combination with base function[46].
The three fundamental aspects of finite element modeling is:

- Discretization or meshing.
- Defining material properties
- Boundary conditions.

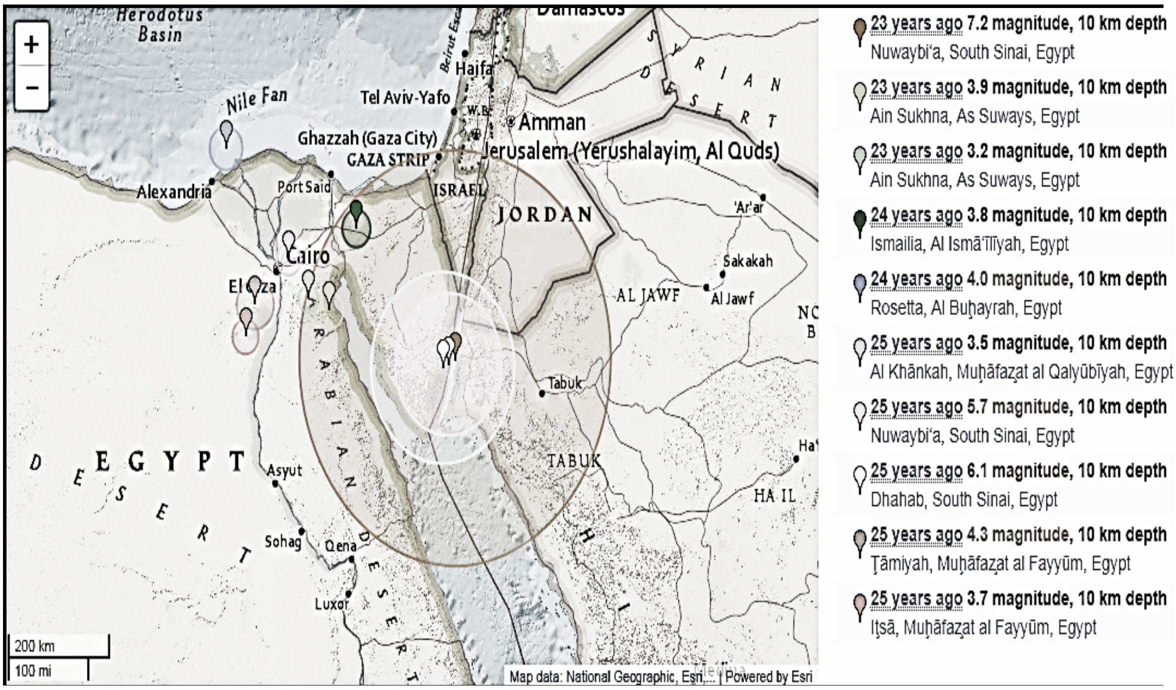

Fig.4: The past 25 years earthquakes in Egypt, August2018.

Numerical modeling using GeoStudio - Quake/w

Analysis of the static and seismic stability of natural and man-made embankments is a challenging Geotechnical problem. The objective of this research is to study the effect of earthquake shaking on roads stability using Geo Studio - Quake/w software 2012 Program.

Wady El-Natroon / Al-Alameen road as a case study

The main objective is to study the effect of earthquakes on the constructed road from Marina -Alameen (on the Mediterranean coastal region) in the North to Wady El-Natroon in the South with length about 133 km. It is including a main road with 2 directions; each direction has

3 lanes and its scope of works consists of the embankment, concrete partitions, guiding signs. Figure (5) shows the used cross section in the numerical analysis.

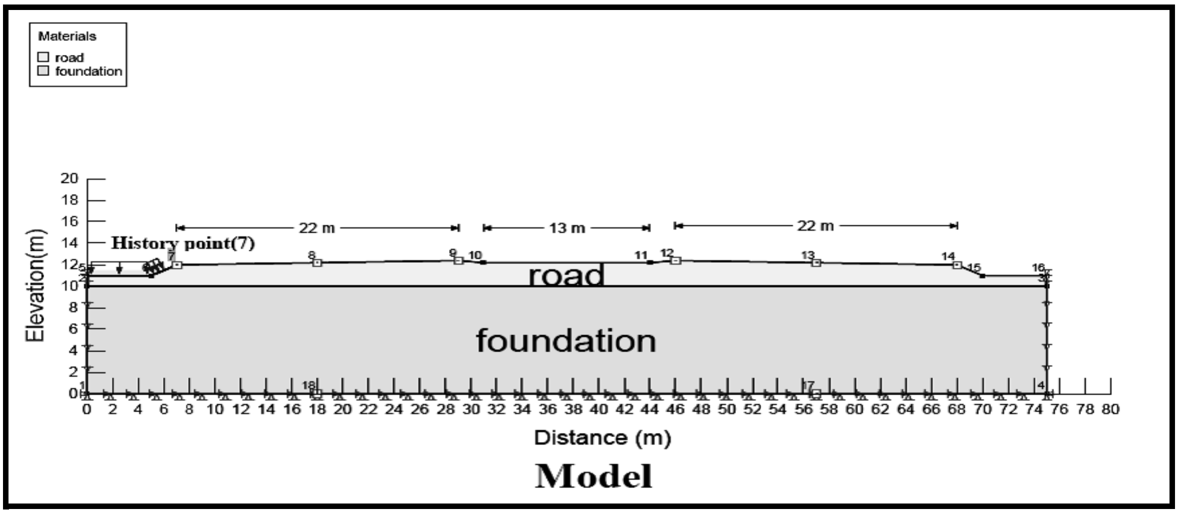

Fig.5: Cross section of Wady El-Natroon / Al-Alameen road .

Actually, this paper uses the executed fully details cross section. The main soil type which formed the cross section is (A-3) according the (AASHTO- T88) classification. This soil is fine coastal sand with low quantities of silt and is similar to Gamasa sand (S1) which used in the experimental analysis. So, the numerical analysis was carried out using the soil (S1) as a control specimen and the soil types (S2 to S8) as alternatives in the road material to choose the best material to use in this road under the earthquake condition.

This model assumed the worst case in using this road. This case assumed that there was a heavy rainfall with an accumulated amount of water with a height 0.5 meter at the left side and zero meter in the right side and the ground water table rises in between the previous mentioned two levels.

The model has eight history points which have fully recorded results data. This paper uses the recorded results at the historical point number seven as shown in fig.(5). It is the worst-hit region in the road sector under the earthquake condition. El-Centro earthquake (1940) data was used in this model with acceleration (0.34842 g).

Quake/W software is based on the equivalent linear method. It was used in 2D dynamic analyses in this study. The numerical code of this software has a finite element approach in which the governing motion equation for dynamic response of a system can be expressed as:

$$[M]\{\ddot{u}\}+ [C]\{\dot{u}\}+ [K]\{u\}= \{F\}$$

Where: [M] is mass matrix, [C] is damping matrix, [K] is stiffness matrix, {F} is vector of loads, $\{\ddot{u}\}$ is nodal acceleration vector, $\{\dot{u}\}$ is nodal velocity vector, {u} is nodal displacement vector. Damping term is usually defined as a linear combination of mass (m) and rigidity (k).

Results of 2D Dynamic Analyses

Using numerical modeling tools GeoStudio / Quake/w to simulate various types of soil used in the road cross section against seismic motions. It is observed that the numerical modeling tools are robust to solve seismic stability problems, both in static and dynamic state.
This study is an attempt to simulate the behavior of several soil types under seismic conditions. The availability of the used data is conducted from experimental tests as mentioned before. The results are approximately the same in all history points with small and non-notable differences.

So, all the following results are taken from the historical point number seven because it has the highest ground water table as explained before.

As shown in figures (6, 7 and 8) using hosted sand (S1) and (S5) exhibit vast displacement in vertical and horizontal directions with relative to the original position. Also, the generation of pore water pressure during seismic shaking is notable with large volume.

Using mixed soil with rice straw and tyre chips both in single or double form improve the workability of the road under the earthquake conditions, decrease the relative displacement in vertical and horizontal directions. Also, decrease the pore water pressure then, prevent occurring the liquefaction process and keeping the road stable after seismic shaking.

The soil mixture (S8) exhibit the best workability over the other types of mixed soil.

All the other measured soil characteristics tend to be the same performance under the same conditions.

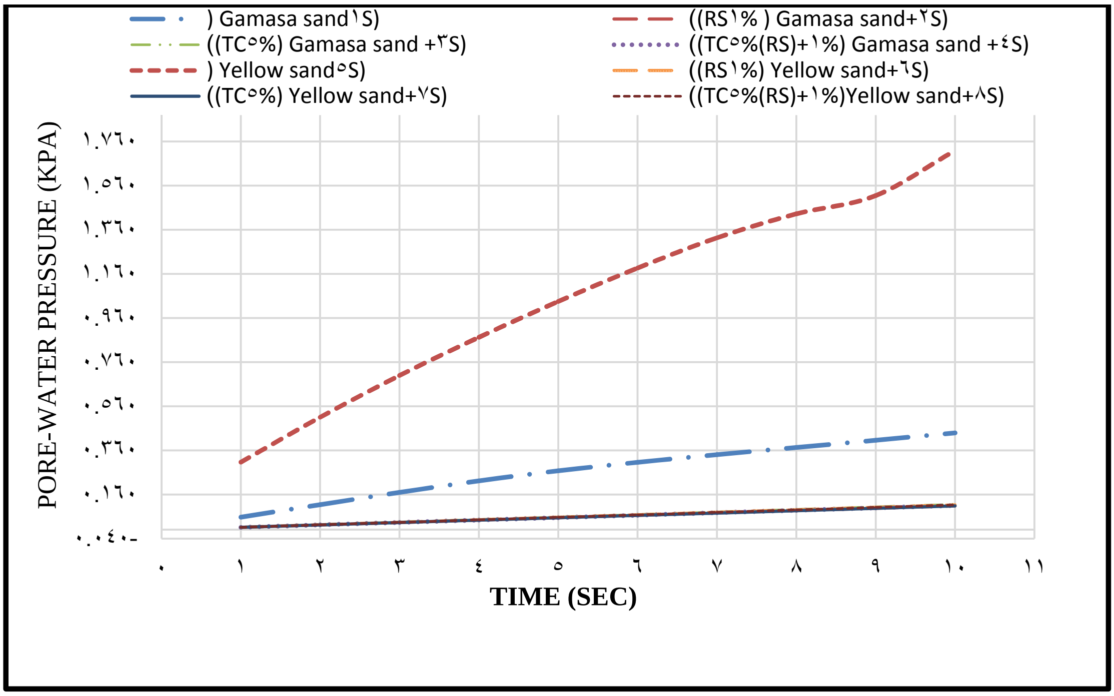

Fig.6: pore water pressure vs time of Wady El-Natroon / Al-Alameen road under earthquake condition using all soil types.

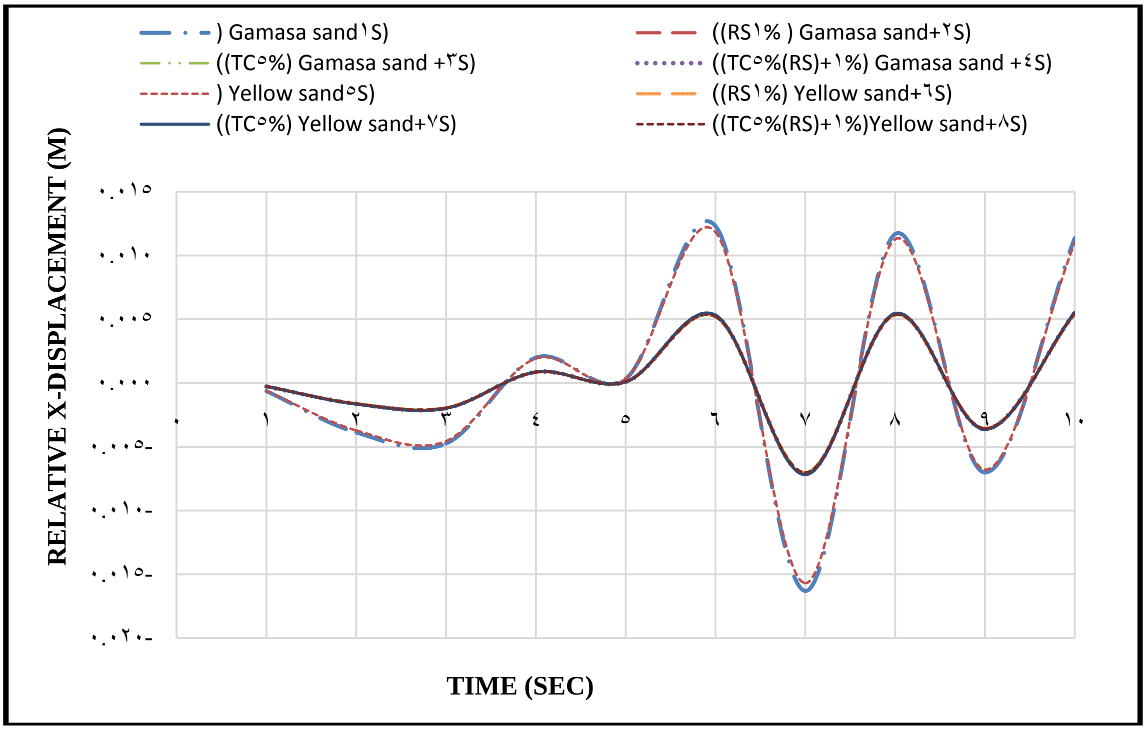

Fig.7: Relative Displacement in horizontal direction (m) vs time of Wady El-Natroon / Al-Alameen road under earthquake condition using all soil types.

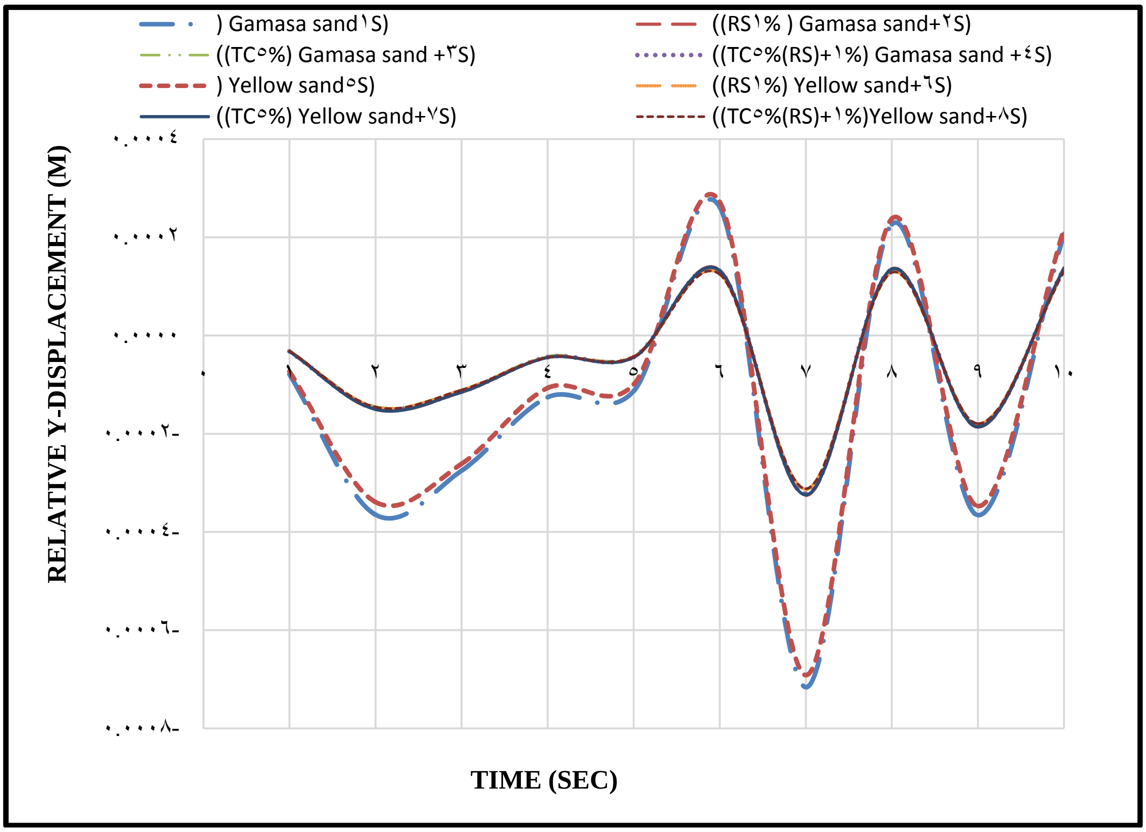

Fig.8: Relative Displacement in vertical direction (m) vs time of Wady El-Natroon / Al-Alameen road under earthquake condition using all soil types.

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