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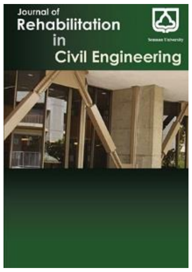

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Evaluation of RAP Engineering Characteristics in Layered Soil

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ABSTRACT

The current investigation used 16 model tests with two alternative foundation shapes, one strip and the other square, for a total of eight model tests for each foundation type. A model test was conducted only on natural soils to evaluate the two types of foundation and both circumstances of improvement utilizing RAP. The model square footing was laid on a layer of (RAP), with the varied widths (1.25B and 1.75B) and different thicknesses (0.25 B, 0.50 B, and 0.75 B in which B=footing width). Six model tests are tested in two widths (1.25B and 2.50B) in model strip footing treated (RAP), and three thicknesses (0.50B, 1B, and 1.5B) in each width are done. The settlement improvement factor was utilized to show the (RAP) layer's influence. The data suggested that the (RAP) layer beneath the foundations influenced settlement significantly. The RAP material in a square footing with a depth of 0.75 B offered the most efficient settlement reduction, with the lowest settlement improvement factor of all model tests. A model test was run with a RAP width of B and a depth of 0.25 B. It was discovered that RAP soil treatment reduced settlement by 0.34, implying that treated soil settled by 34% less than untreated soil.

1. Introduction

The utilization of reused materials in development ventures has become more predominant in many countries in recent years. Because of a general overview of public roadway organizations, it was accounted for that around millions of tons of asphalt paving material are right now being processed every year. Over the last 20 years, recycled materials in building projects have grown in popularity in the United States. According to a nationwide survey of

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state highway departments conducted in 1996, nearly 50 million tons of asphalt paving material are reportedly milled annually [1]. According to the National Asphalt Pavement Association (NAPA), approximately 71.9 million tons of RAP were used in the United States in 2014 to construct new pavements. This indicates that RAP saves American taxpayers about USD 2.5 billion every year [2]. Other studies suggest that asphalt paving removed per year exceeds 100 million tons [3]. The Fig. 1 demonstrate the scraping deteriorated asphalt pavement from the highway connecting Baghdad and Babylon (about 85 kilometers (53 miles) south of Baghdad) in Iraq and shipping it to be reused as a reclaimed pavement material.

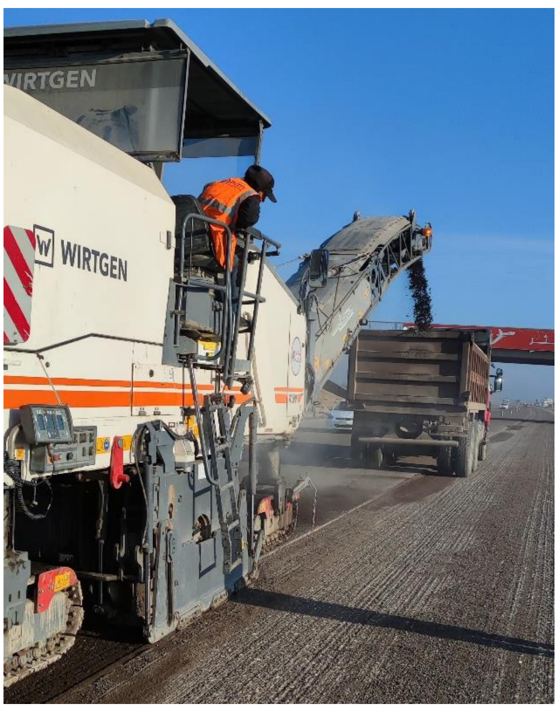

Fig. 1. Scraping up damaged asphalt, Baghdad – Babylon highway-Iraq (2021).

Occasionally in this region, a substrate of compacted granular material is applied over the soft deposit to provide a raised surface for construction equipment operation. The granular fill serves as a stable base, distributing the load over a larger area and allowing an additional load. (Fig. 2) illustrates a granular trench [4].

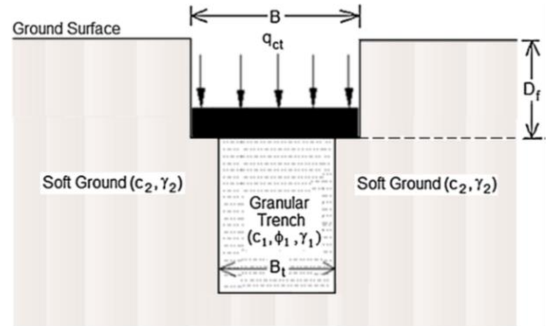

Fig. 2. Strip footing in soft ground stabilized with granular trench (after [4]).

In general, on Coulomb's criterion for soil yielding, sheer ability is expected to increase along a granular trench's length when shear stress is applied. For strip reinforced ground, this function has been developed with the general understanding that some strength is needed [5].

It was studied in a model of granular base and soft soil in place in the laboratory [6, 7]; as the maximum trench depth was achieved, the bearing capacity was unchanged and remained constant as the following: Bearing capacity increased in response to the maximum trench depth but remained constant at trench depth-dependent after that.

The temperature was the most influential parameter on the resilience modulus of asphalt concrete mixtures incorporating RAP elements. When the RAP content is raised, or a stiffer asphalt binder is used, the resilient modulus of asphalt concrete mixtures increases. The results also showed that decreasing the temperature and increasing the asphalt binder content relative to the optimal asphalt binder content increased the robust modulus [8].

The provision of granular trenches below the strip footing improves the load-carrying capacity. For a given volume of soil used as refill material, the rectangular shape is more efficient than the triangular shape in reducing the settlements. The efficiency of rectangular and triangular fills depends on the geometric proportions of these shapes. In a rectangular trench, the optimum increase in the load-carrying capacity is obtained when the trench's width is twice the foundation's width. In the case of triangular trenches, the optimum width of the trench was 2.5 times the width of the footing. The provision of geosynthetic encapsulation improves the load-carrying capacity for a given settlement. However, in all cases, the additional improvement obtained by encapsulation was marginal, as depicted in Fig. (3)[9] . The probability of employing a granular trench reinforced randomly using Geogrid Micro-Mesh (GMM) to accomplish more significant soil adjustment in terms of carrying capacity ratio, and settlement reduction is explored using a series of 25 laboratory model experiments as the GMM ratio was increased to 1.2 percent, carrying capacity and settlement elimination improved steadily [10].

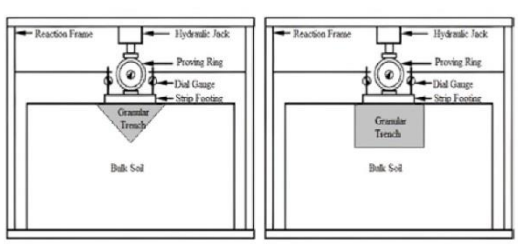

Fig. 3. Load-testing configuration schematic diagram [9].

By placing a single vertical granular trench beneath a strip footing and a granular column beneath a circular footing, the bearing capability of soft clay foundations in undrained condition can be determined. The researchers used finite elements and an optimization method in addition to a lower bound plane strain and axisymmetric limit analysis. The efficiency factor (z) was determined by altering the diameter of the column (trench width) and the diameter of the circular footing (strip footing width), where Bt represents the column diameter (trench width), and Bf signifies the circular footing diameter (strip footing width) (Fig. 4). The efficiency factor (z) utilized in this analysis is compared to the analytical expression developed by Stuedlein and Holtz (2013) based on Mitchell's findings (1981) in Table 1. [11].

Recycled asphalt pavement (RAP) and cement aggregate are evaluated as part of the permeability and bearing capacity of aggregate base courses manufactured from recovered asphalt pavement (RAP). A mixture of RAP was tested in the laboratory using bitumen content, sieve analysis, modified proctor, soaked California bearing ratio (CBR), and constant-level permeability tests. As the fraction of RAP in the mixture climbed, the CBR values decreased substantially [12].

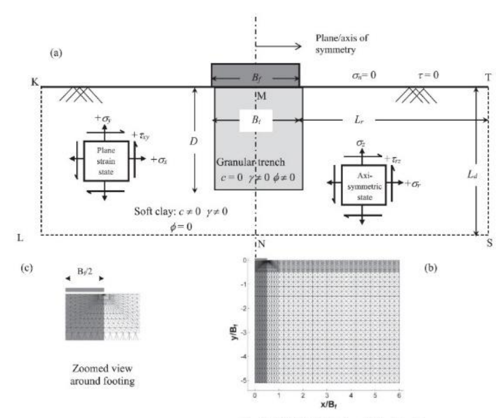

Fig. 4. (a) A diagram illustrating the problem, (b) a regular finite element mesh for a strip/circular footing with granular trench, and (c) a magnified image of the mesh surrounding the footing]11].

Table 1. The efficiency factor (ζ).

Type of footing	B_t/B_f	Efficiency factor (ζ)	
		Present analysis	Stuedlein and Holtz (2013), using tests results of Mitchell (1981)
Strip footing with a granular trench	0.2	1.523	1.646
	0.6	2.180	2.939
Circular footing with a granular column	0.2	1.193	1.984
	0.6	2.554	3.455

The effects of computational modeling for static bearing capabilities of shallow foundations using FLAC2D with and without trench are compared. Additionally, the effect of the depth of the granular trench on bearing capacity was investigated, and the optimum depth was determined. The installation of a trench raises the ultimate bearing capacity by at least 80%. However, after a trench is drilled to a specified depth, the bearing capacity increases until it reaches a maximum value, at which point it stays constant. The upper bound theorem is used to determine a base's bearing potential in granular trench-stabilized soil. If the trench material has a higher value, a more considerable increase in bearing potential may be expected. The ideal trench depth determined in this investigation is around 5m using FLAC2D [13]. RAP will be utilized to reduce the plasticity and swell potential of the clay. RAP might be used to pave roads or to construct an earth dam that would restrict soil permeability. Deformation should be the primary consideration when creating a laterite-RAP soil mixture for use as a paving material. The plasticity index and saturated CBR of RAP soil combinations dropped to less than 12% and larger than 30%, respectively[14]. The UCS values of the samples at the relevant OMCs continuously declined as the RAP share in RCA, (Recycled Concrete Aggregate) increased from 0% to 20%. RCA samples, meanwhile, demonstrated significant UCS as a result of the cement mortar's influence. Greater CBR values at their associated OMCs and MDDs indicated the high strength of RCA samples. When the RAP exceeded 15%, RCA samples tended to lower the soaked CBR. As a result, RAP substitution above 15% reduces load-bearing capability below the standard limit of high-quality base layer material. Technically, RCA with RAP of up to 15% is suitable for use as a foundation material in unbound structural layers of high traffic volume roads. RCA with 20% RAP is ideal for use as a sub-base material in high volume roads (equivalent standard axle, ESA >106) or as a base layer material in low volume roads (ESA 106), where the minimum wet CBR is 60% [15]. Reclaimed asphalt pavement is one of the most often used waste products (RAP). The usage of RAP can assist in lowering the cost of a project and ensuring that it is environmentally friendly. Previous research has demonstrated the benefits of RAP in terms of its capacity to deliver comparable or even superior results to virgin or original mixtures when adequately manufactured and administered. Among the advantages of RAP, mixtures are their excellent resistance to moisture and density [16].

This study aims to determine the suitability of RAP as a replacement material for a footing resting on soft clay. A trench filled with replaced soil will be extended to different lengths to establish the proper proportions.

2. Experimental work

2.1. Materials used

2.1.1. Soil used

Two types of soil are used in this investigation

1. Clay soil samples were gathered 0.50 m below the surface of the ground at a site south of Baghdad. The soil was subjected to a series of experimental tests to assess its properties. Among these steps are the following:

1-Grain size distribution (sieve analysis and hydrometer tests) under ASTM D422 standards.

2-Atterberg limits (liquid and liquid limits) under ASTM D4813 standard.

The soil contains 9% sand, 64% silt, and 27% clay, according to the test findings. The soil is classified as ML inorganic sandy clayey silt by the Unified Soil Classification System. The physical parameters of the soil are summarized in Table 2.

2. Uniform fine sand with particle diameter = 0.15 mm, According to the Unified Soil Classification System, the soil is classed as poorly graded sand, SP.

Table 2. Physical properties of soil.

Properties	Value
Liquid limit, L.L.(%)	31
Plastic limit, P.L. (%)	22
Plasticity index, P.I. (%)	9
Specific Gravity	2.67
MDD, (kN/m^3)	19.3
Degree of Saturation	95 %
OMC	12 %
Sand content	9
Silt content	64
Clay content	27
Classification (Unified Soil Classification System)	ML

2.1.2. RAP used

RAP samples were collected by scraping degraded asphalt pavement from the highway's surface linking Baghdad and Babylon. The RAP was subjected to a grain size distribution test in compliance with ASTM D422 requirements to determine their properties (Fig. 5)

Fig. 5. RAP material.

As shown in Fig. 6, the test findings revealed the D_{10}= 0.30, D_{30}= 2.60, and D_{60}= 6.8, with a uniformity coefficient (C_u= 22.67) and coefficient of curvature (C_c=3.31). Table 3 summarizes the physical and mechanical properties of the RAP used in model tests.

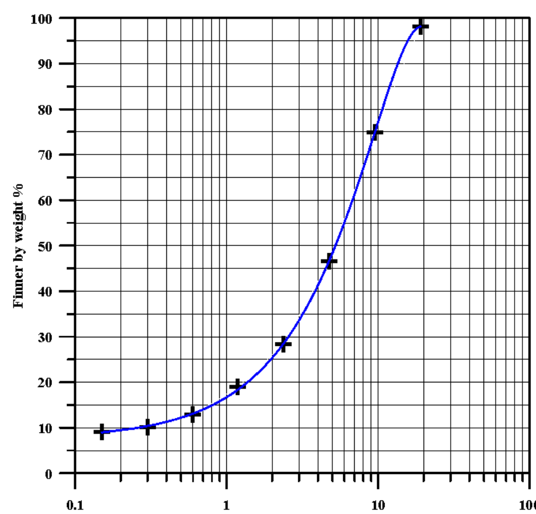

Fig. 6. Grain size distribution of the RAP material.

Table 3. Physical and mechanical properties of RAP.

Type of Property	RAP Properties	
Physical Properties	Unit Weight	19.2 kN/m^3
	Moisture Content	1%
	asphalt Content	5 %
	Asphalt Penetration	60 at 25^0 C
	Absolute Viscosity or Recovered Asphalt Cement	6000 poises at 60˚C
Mechanical Properties	MDD	18.85 kN/m^3
	California Bearing Ratio (CBR)	21 %

2.2 The test setup

2.2.1. Soil tank

The model experiments were done in a test tank constituted of steel plates with a thickness of 5 mm, a square plane of 40 cm x 40 cm, and a height of 45 cm, as illustrated in Fig. 7. The container is adequately stable, and there is no lateral deformation during the soil bed preparation or investigation.

2.2.2. The loading frame

Fig. 8 illustrates the complete setup, consisting of a soil tank, a loading frame, dial gauges, model footing, and accessories.

Fig. 7. Soil Tank.

Fig. 8. Experimental setup.

2.2.3 The Foundation Plates and Accessories

The current laboratory work employs two types of footing models. The first type is a square footing with a side of 135 mm, while the second type is a strip footing with a width of 39 mm and a length of 390 mm. (See Fig. 9).

The following points should be taken into account to be considered in models of footing: 1.Container walls side effect may significantly lower the vertical stress at depth. 1. The container height to diameter ratio shall be equal or less than one to prevent friction on the side of the walls [18].

2. In order to keep K. (coefficient of lateral earth pressure in rest) around the supposed value of non-lateral strain of the container wall, the effect of horizontal deflection should be lower than (h_c/2000) where it is a container height [19].

3. Smooth walls are necessary because of the small container size to minimizing arching and side friction 3 [20, 21].

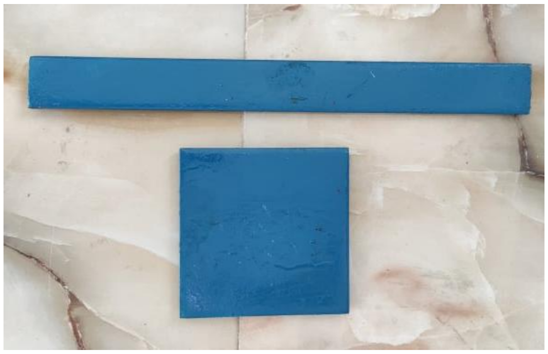

Fig. 9. Models of Square and Strip Footing.

2.4. Model construction and validation

2.4.1. Preparing the soil bed

Before preparing the clay soil, a relationship between the water content and the soil's undrained shear strength was created. This collaboration would help each model maintain the requisite shear strength. An unconfined compression machine was used to calculate shear strength. For this study, the soil was prepared to have an undrained shear strength of 16 kPa.

The natural clay soil was crushed initially with a hammer and then left to air dry for 24 hours before being further crushed with a grinder machine. Next, approximately 14 kg of each air-dried soil was poured into the segment. The small groups were then gradually and thoroughly mixed with an adequate amount of water to obtain a particular shear strength. Following that, the wet soil was cured for five days to complete the saturation. At the end of healing time, the dry river fine sand was proud in the soil tank in 6 layers with a density of 15.6 kN/m3. Each layer was trampled with a plastic hammer. Then the final layer of sand was leveled with the unique wooden trowel. The total thickness of sand layers was 250 mm. The clay was then poured inside the steel container and compacted with a particular tamping tool to achieve a density equivalent to 90% of the maximum dry density. The final thickness of the earth layer was around 50 mm. The operation was done several times before the final thickness of the soil bed was reached. The final clay layer thickness was 150 mm. After finishing the soil bed preparation, it was tightly covered with nylon sheets and cured for four days. Subsequently, A small amount of soil was removed with caution and replaced with RAP. Finally, the RAP material had been tamped with a one-kilogram hammer. The substituted area varied between square footings with RAP layer widths of 1.25B and 1.75B and strip footings with RAP layer widths of 1.25B and 2.5B and a length of 480 mm, (where B = footing width). For square foundations, the depth of soil replacement ranged between 0.25 B and 0.75 B, whereas for strip footings, the depth varied between 0.5B and 1.5B. Figs. from 10 to 15 denote the procedures for preparing the soil bed and testing the model following the research program.

Fig. 10. Elevation of the sand's final layer.

Fig. 11. Compaction of the clay layer.

Fig. 12. Trench under the square footing.

Fig. 13. RAP layer under the square footing.

Fig. 14. Trench under the strip footing.

Fig. 15. RAP layer under the strip footing.

2.4.2. Procedure for model testing

The following sample experiments were conducted under the research program: Static loads were applied to the model footing with a compression machine with a 0.001 kN accuracy, and settlement was measured with a 0.001 mm accuracy linear variable digital transformer (LVDT). This experiment was repeated to obtain more accurate readings. Later, Loads were then applied in 20 N increments through a loading disk in a stress-controlled manner. Each load increment was held at a constant rate of two minutes. Furthermore, Indefinite load intervals were added until the settlement reached 20 mm in square footings and 10 mm in strip footings. In the end, LVDT readings were taken at the start and end of each load increment.

3. Presentation and discussion

The present work examines the influence of RAP materials on the settlement of clay soil using a measure termed settlement improvement factor. The settlement improvement factor can be defined as the ratio of the settlement of soil treated with RAP materials (S_{rap}) to the settlement of untreated natural soil (S).

Figs 17 and 18 relate the settlement improvement factor (S_{rap} /S) plotted versus applied pressure for six model tests of square footing soil treated with RAP material under the footing as follows:

RAP width = 1.25 B and depth = 0.25 B
RAP width = 1.25 B and depth = 0.50 B
RAP width = 1.25 B and depth = 0.75 B
RAP width = 1.75 B and depth = 0.25 B
RAP width = 1.75 B and depth = 0.50 B
RAP width = 1.75 B and depth = 0.75 B

Where the B represented the width of square footing.

The identical behavior of a definite reduction in the settlement by raising the pressure increases applied was observed in all six model tests conducted on the model. When applied pressure exceeded around 250 kPa, the settlement improvement factor reached

0.34 in the model test with RAP width = 1.25B and depth = 0.25 B, showing a 34% decrease in settlement of soil treated with RAP material compared to untreated soil. When the depth of RAP material is raised while maintaining the width constant, the settlement improvement factor decreases. The final value of settlement improvement factor are 0.17 and 0.085 approximately at applied pressure equal to 300 kPa for soil treated with RAP of depth equal to 0.50B and 0.75B, respectively. Three model studies on soil treated with RAP material with a width of 1.75 B and a depth ranging from 0.25 B to 0.75 B demonstrated the same previously observed behavior. It can be seen from Figs 17 and 18 that the settlement improvement factor reached constant values and continued up to the end of the test. Among all model experiments, the use of RAP material to a depth of 0.75B resulted in the most efficient settlement decrease. i.e., the settlement improvement factor with the lowest value, as illustrated in Figs 17 and 18. The model test that utilizes RAP, with a width of 0.50B, is then the more efficient. Also, it can be noticed a clear improvement in settlement when the width of the RAP layer is increased from 1.25B to 1.75. Figs 19 and 20 relate the settlement improvement factor (S_{rap} /S) plotted versus applied pressure for six instance strip footing tests. Soil treated with RAP material under the footing as follows:

RAP width = 1.25B and depth = 0.50 B
RAP width = 1.25B and depth = 1.00 B
RAP width = 1.25B and depth = 1.50 B
RAP width = 2.50 B and depth = 0.50 B
RAP width = 2.50 B and depth = 1.00 B
RAP width = 2.50 B and depth = 1.50 B
Where, B= width of footing.

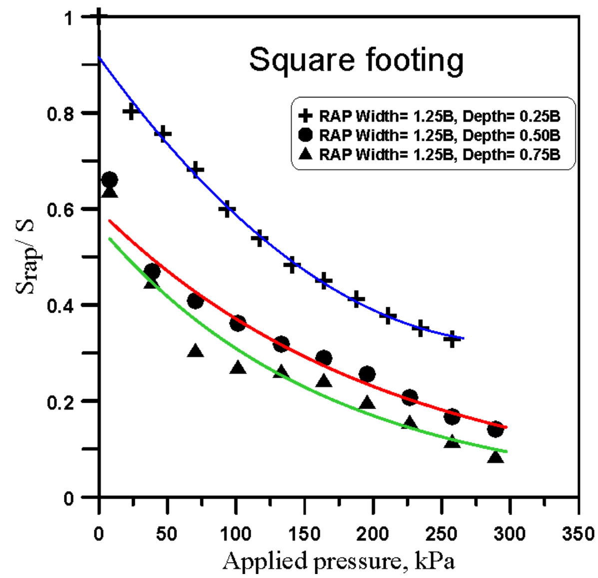

Fig. 17. Applied pressure versus $S_{treated}/S_{untreated}$ Square footing, RAP width = 1.25B.

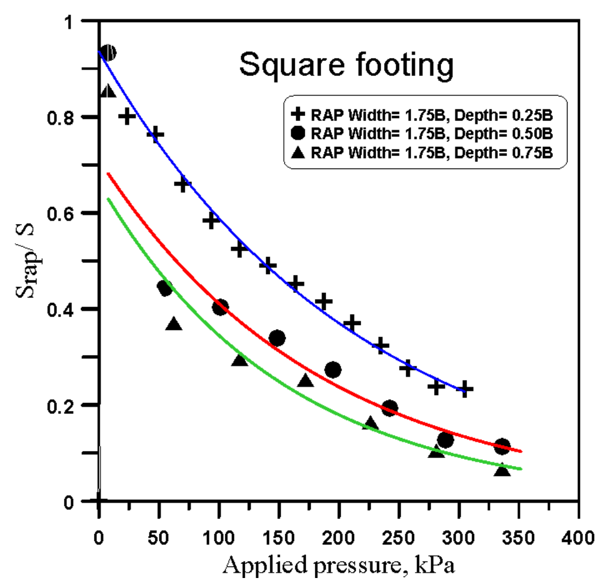

Fig. 18. Applied pressure versus S_{rap} /S for the Square footing, RAP width = 1.75 B.

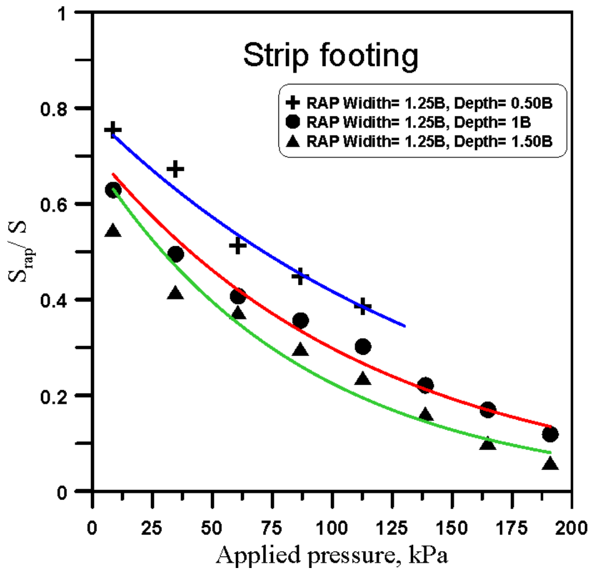

Fig. 19. Applied pressure versus S_{rap} /S for the Strip footing, RAP width = 1.25 B.

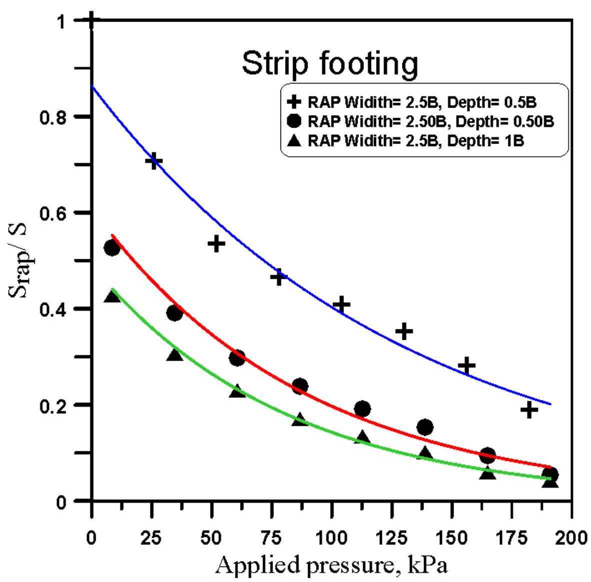

Fig. 20. Applied pressure versus S_{rap} /S for the Strip footing, RAP width = 2.50 B.

4. Conclusion

1. Under increasing loads, all the model tests on the RAP-treated soil revealed that settlement is improved via an observable decrease in settlement improvement factor.
2.The settlement improvement factor decreases as the RAP layer's depth increases while the breadth remains constant. At the ending of the experiments, the improvement in the settlement factor had reached constant values.
3. A model test was performed with a RAP width of B and a depth of 0.25 B. It showed that settlement was 0.34 smaller with RAP soil treatment, meaning 34% less settlement of the treated soil than untreated soil.
4. The RAP material in square footing with a depth of 0.75 B provided the most effective reduction in the settlement, with the lowest settlement improvement factor of all the model studies.
5. For model tests in strip footing of RAP with a width of 1.25 B and depths of 0.50, 1B, and 1.50B, the values of settlement improvement factor at high pressure (200 kPa) are 18%, 12%, and 6%, respectively. For all model tests of soil with RAP layer, the discrepancy of settlement improvement factor decreases when the applied pressure increases, and the distinction reaches its minimum value when the applied pressure ranges from 200 to 350 kPa for all model tests.

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