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To cite this article: N. A. S. Kamarudin *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **527** 012059

IOP Conf. Series: Materials Science and Engineering **527** (2019) 012059 doi:10.1088/1757-899X/527/1/012059

Effects of u-shaped subgrade concrete panel on subgrade deformation

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Abstract. California Bearing Ratio of subgrade lesser than 5% requires a treatment work either by stabilisation or strengthening method. In this study, the latter concept was chosen for the application of U-shaped Subgrade Concrete Panel as it is a method that has less disturbance to the native soil. As the name suggested, this U-shaped Subgrade Concrete Panel is a precast U-shaped concrete panel to be installed into the subgrade soil in an inverted direction. It is divided into two sections; the horizontal panel and vertical webs beneath the panel. Hence, the objective of this paper is to present the effect of applying the U-shaped Subgrade Concrete Panel into subgrade soil with a CBR value of less than 3%. There are 3 sizes of control panel used; square panel with dimension of 150 mm x 150 mm x 50 mm, 300 mm x 300 mm x 50 mm, and 600 mm x 600 mm x 70 mm, and 6 types of U-shaped Subgrade Concrete Panel; square area of 150 mm x 150 mm, 300 mm x 300 mm, and 600 mm x 600 mm. While the depth of the U-shaped Subgrade Concrete Panel varies from 100 mm, 125 mm, 150 mm, 200 mm, 270 mm, and 370 mm. The static load test was applied to centre, edge, and corner point of the panel, as to study the interlocking effect when it is subjected to a localised load. As the study was conducted in the laboratory, the condition of the subgrade soil fully controlled by monitoring the moisture content and the density of the soil in the test box. Settlement of the subgrade soil after compactions was observed and recorded as part of the initial conditions before the static load test was applied to the panel. After the compaction of the subgrade, it shows that a longer web section had caused lesser settlement compared to the control panel, indicating better resistance towards lateral movement under the U-shaped Subgrade Concrete Panel.

1. Introduction

Similar to another geotechnical engineering, weak subgrade under the pavement structure usually associated with the nature of the soil itself and quality of the construction works, and it leads to the problematic pavement if suitable treatment is not taken. The lifetime of a specific road depends greatly on the subgrade layer condition, where the design of the pavement require soil with a CBR value of 5% and more [1, 2]. Moreover, problematic roads such as undulating settlement, transverse cracking, and rutting usually traced back to the subgrade conditions such as the settlement and low bearing capacity [3].

Three principles of the differences between general geotechnical and highway geotechnics are the location of the water table; it must be under the subgrade formation level and should be sealed. Second, the load repetition can be analogically understood by the behaviour of earthquake and wave loading behaviour, and the third difference is that with a single application of wheel load could lead to irrecoverable plastic and viscous strain to the pavement structure [4]. By principle, soil compaction should be able to provide the subgrade with the required strength. However, when the strength either not enough or impossible to be achieved, two ways of improving the strength of the subgrade is either by stabilisation or strengthening methods. Soil improvements represent a critical function in geotechnical engineering since it is the only way to stabilise and enhance the soil properties [5]. Stabilisation often involves mixing of the soil with lime, cement, a combination of lime and cement, and other cement-like product [6]. Several techniques to mix the stabilisation agents includes a pre-mixing method, lightweight treated method, and the commonly used, deep mixing method since it is suitable for all type of soil [7]. Strengthening methods usually involve the application of geocell [8], geotextile, and stone column [8] for which these are the popular technique to strengthen the bearing capacity of the weak subgrade. Although there is no popular literature available on application of inverted U-shaped concrete for low bearing capacity soil strengthening, several literature reviews conducted for strengthening of sand using geosynthetic reinforcements on strip and square footing mostly agreed that the optimum length shall lie in between 2B to 8B, where B is referred to the width of the reinforcement [9]. Other than the effect of the reinforcement length, the depth and shape of the reinforcement may also contribute to the effectiveness of the improvement method [10], where wedge and T-shape foundation supply resistance to the structural loads. The web section that is the vertical component of the USSP in this study depicted a combination of horizontal and vertical soil reinforcement, where studies by [10-12] were referred. Using the same concept of the vertical reinforcement such as the diaphragm wall (Figure 1) or micropiles helps to activate the lateral confinement to the soil under the footing.

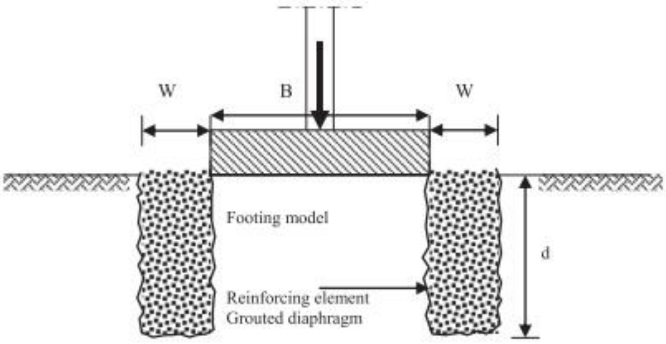

Figure 1. Combination of horizontal and vertical reinforcement [10].

The major concern of the studies highlighted is to reduce or eliminate the settlement of the soil, by varying the distance of the vertical reinforcement from the edge of the footing and the depth of reinforcement. As reported by [11], the length of the reinforcement in 1.5 to 2.0 times the width of the square footing, while [12,13] suggested that the most economic depth of the diaphragm wall should be equal to the width of the footing. From this point of view, USSP is designed with a flat, horizontal section of square plan area and coupled with vertical web sections at both ends under the panel section.

In this paper, the effects of the U-shaped Subgrade Concrete Panel (USSP) installed in subgrade soil with 2% CBR value is presented. The aim of the paper is to present the deformations of the subgrade soil when the static load was applied to each type of USSP in an experimental work conducted in the laboratory.

2. Methodology

This section briefly presents the development of the USSP and details of the USSP shape and dimension, as well as the methodology of the static load test conducted on to the USSP.

IOP Conf. Series: Materials Science and Engineering **527** (2019) 012059 doi:10.1088/1757-899X/527/1/012059

2.1. USSP shape and dimension

This USSP was generally developed by adopting the shape of the inverted U-shaped drain, or a channel with an opening at the bottom side. The USSP is divided into two parts, that is the panel section and the web section. The load applied to the USSP shall be received by the panel section and latter to the web sections. Initially, the web section is incorporate into the design of the USSP to provide a confining effect and thus, to the control the shear movement of the soil when loads are applied.

There are 3 types of a control panel used in this study that is the CP150, with dimension of 150 mm width times 150 mm length times 50 mm thick. CP300 has a dimension of 300 mm x 300 mm x 50 mm, while the CP600 dimension is 600 mm x 600 mm x 70 mm. Overall, there are 6 types of USSP that have been grouped into three categories, that is category I, II, III. USSP150-100 and USSP150-125 have panel dimension similar to CP150, but the webs sections have an effective height of one-third and half of the width. For USSP category II, USSP300-150 and USSP300-200 the web's effective height is 100 mm and 150 mm, respectively. Meanwhile, for USSP600-270 and USSP600-370, the web's effective height is 200 mm and 300 mm, respectively. All of the USSP category and dimensions are tabulated in Table 1.

Table 1. Category and dimension of the control panel and the USSP.

Type	Length	Width (mm)	Height	Name	Category
Control Panel (CP)	150	150	50	CP150	I
	300	300	50	CP300	II
	600	600	70	CP600	III
U-shaped Subgrade Concrete Panel (USSP)	150	150	100	USSP150-100	I
	150	150	125	USSP150-125	I
	300	300	150	USSP300-150	II
	300	300	200	USSP300-200	II
	600	600	270	USSP600-270	III
	600	600	370	USSP600-370	III

This USSP is made of concrete with a compressive strength of 35 N/mm^2. One layer of BRC of DA-6 was installed in the panel section to ensure the USSP does not break during handling and installation. Figure 2(a) and (b) illustrates the shape and dimension of the USSP with W stand for width or sometimes is regarded as b, L for length, H for total height, h_p for panel thickness, h_e for effective height, and e for web base width.

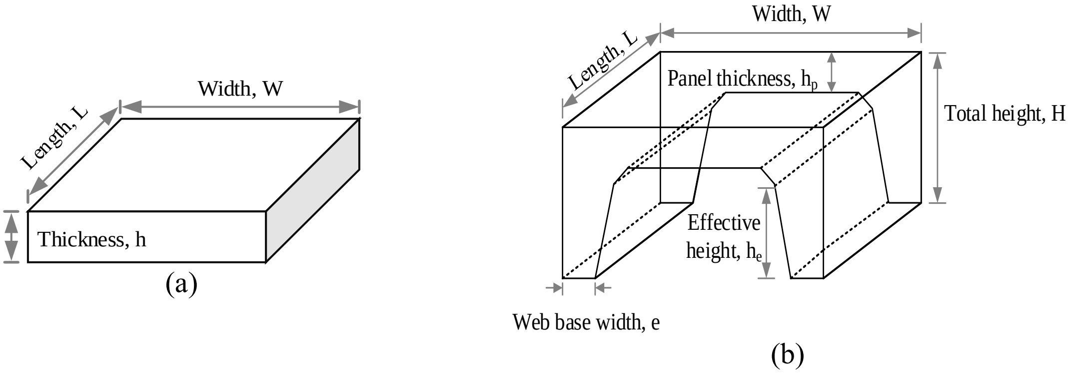

Figure 2. Dimension of (a) control panel (b) U-shaped Subgrade Concrete Panel (USSP).

2.2. Static load test

This study used the modified form of static load test conducted by [14,15] as in Figure 3. The test was conducted within a rigid steel box with a dimension of 1000 mm x 1000 mm in plan and 600 mm in depth. Loads were applied to every cycle by a manual plunger that connected to the hydraulic jack and a load cell of capacity 100 kN. The transducer and load cell readings were recorded using data logger model CR800. Each panel was tested at three different points, which is the centre, edge, and corner point. Each type of panels was first tested in a single arrangement. Multiple panels were tested in Stretcher Bond pattern for USSP category I and II, as well as the control panel for category I and II.

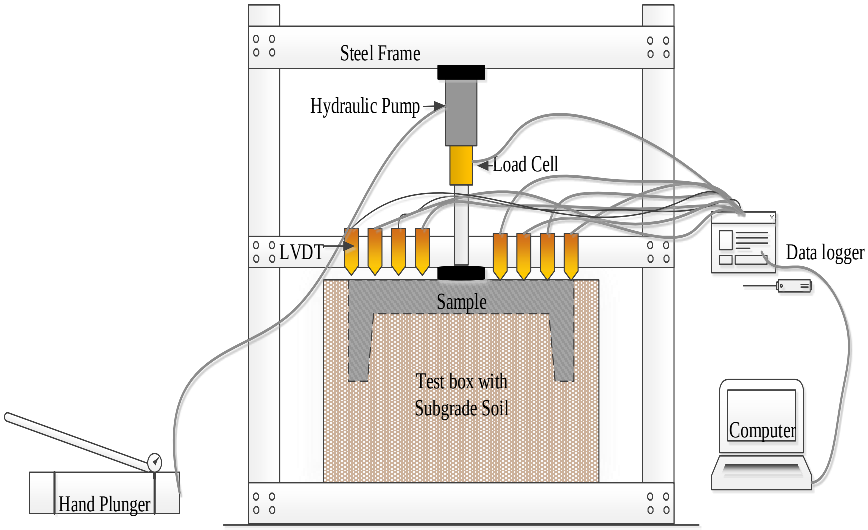

Figure 3. Static load test setup for USSP.

The soil used in this study has been imported from the School of Electrical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Malaysia. The soil was subjected to a compaction test, where optimum moisture content (OMC) and maximum dry density (MDD) of the soil was obtained. The preparation of the subgrade soil into the steel box started by mixing dry soils with required moisture, in this case, 4.5% moisture content by weight was added to the dry soil. Using a drum mixer, the soils were mixed and poured into the steel box until almost full. Next, the USSP was placed into the steel box and vibrated with 6 time passes using a plate-type compactor of 800 N static load at a frequency of 4000 rotation per minute.

The height of the subgrade soil before, after first cycle compaction and second cycle compaction, is represented by h_1, h_2, and h_3, respectively. The compaction of the subgrade soil in the test box is a vital step as the height of the soil at the end of the second cycle compaction with USSP installed in placed determine the density of the subgrade. The measurement of any settlement or heaving of the soil is picked up by the transducers placed on the soil and surface of the USSP. Manually, the plunger was pumped to load the cell with 1kN increment at every 3 seconds. The application of the static load was continued until either no further load increment or no further displacement are recorded. At the end of the test, all behaviour of the USSP and soil was physically observed and recorded to supplement the data collected by the data logger. The arrangement of the USSP and location of test point on the USSP is as in Figure 4 (a), (b), (c), (d), and (e).

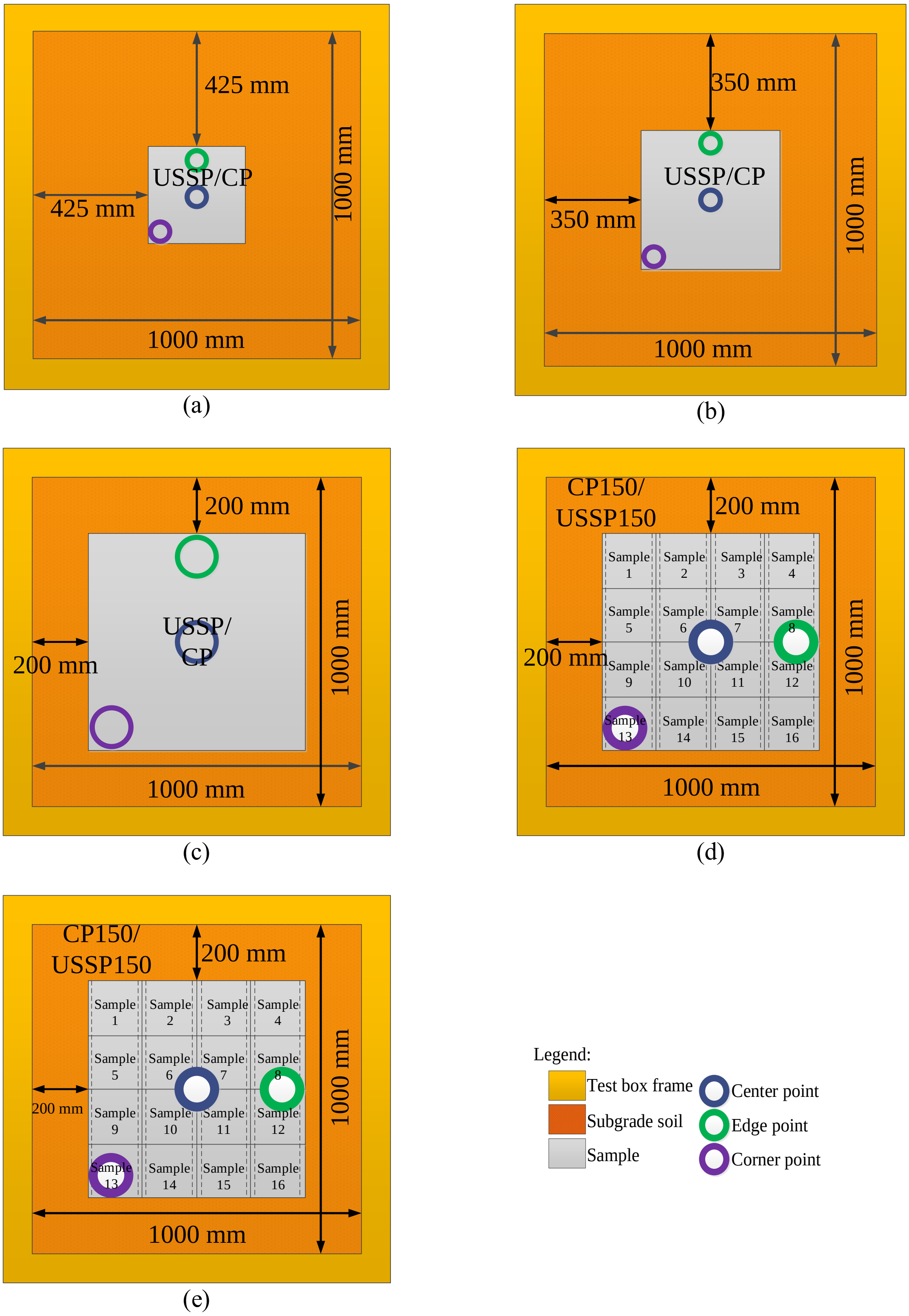

Figure 4. Single panel arrangement for USSP (a) category I, (b) category II, (c) category III, (d) category I in Stretcher Bond, and (e) category II in Stretcher Bond.

3. Results and discussion

From the soil compaction test, the OMC obtained for the soil is 27.5% with 1810 kg/m^3 MDD. The CBR value of the soil at OMC condition is 6%. Hence, approximately 4.5% additional moisture content added to the soil to reduce the density to 1774 kg/m^3, resulting in the CBR value of 2%. This condition is prepared for the soil in the steel box, to stimulate weak subgrade condition. The soil properties used in the steel box is presented in Table 2.

Table 2. Soil properties used for the subgrade in a steel box.

Moisture content	Density	Plastic Index	Type of soil	CBR value
32%	1774 kg/m^3	27	Elastic silt with sand	2%

The density, moisture content, test points of the static load are the fixed parameters used in this study while the subgrade settlement, heaving, and USSP displacement were the variable parameters. Throughout the experimental work, the density of the subgrade soil in the steel box was ensured to remain within 2% CBR value, that is 98% MDD.

3.1. The relationship between subgrade settlement with USSP dimension

For USSP category I, the settlement increases as much as 2.1% and 2.7% when the effective height over width ratio (h_e/b) increase from 0.33 to 0.50. Meanwhile, for USSP category II and III shows a decrease of settlement when h_e/b of the USSP increase. As the effective height increase, it allows a better resistance towards lateral movement under the USSP. Thus, increase in the USSP effective height induce better confinement under it and resulting in a reduction of the settlement, where it is found similar to the study by [11]. For multiple USSP category II, settlement of the USSP decreases as the h_e/b increase, but fluctuation of settlement occurred for multiple USSP category I. The results are presented in Figure 5.

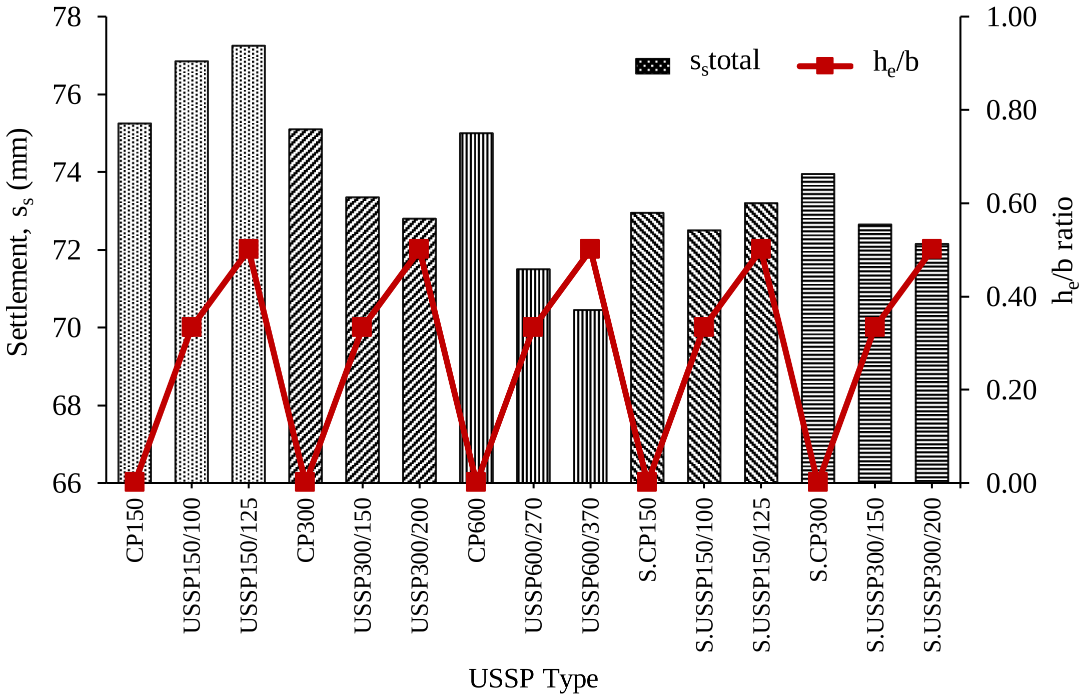

Figure 5. Relationship between subgrade settlement with h_e/b ratio.

The surrounding subgrade soil of the samples tested in this study has been observed experiencing settlement, heaving or no deformation at all, depending on the location of the loading point. Generally, the web sections which represented by the symbol h_e was designed to confine the soil under the panel section. The Percentage Reduction of Settlement (PRS) and Percentage Reduction of Heaving (PRH) is calculated using equation (*1*).

$$PRS/PRH = \frac{S_{unconf} - S_{conf}}{S_{unconf}} \text{ x } 100\% \quad (1)$$

Where

S_{unconf} = Settlement of the unconfined soil, i.e. soil under control panel

S_{conf} = Settlement of the confined soil, i.e. soil under USSP

Table 3 shows the PRS for all points and panels. When the panels were tested in a single arrangement, only USPP300-150 and USSP600-370 show a reduction in settlement experienced by the soil underneath it regardless of the test point location. The PRS for USSP300-150 are 83.5%, 28.1%, and 76.9% when it was load at centre, edge, and corner point, respectively. While PRS for USSP600-370 when loaded at centre, edge, and corner point are 39.2%, 51.0%, and 50.7%, respectively. Meanwhile, when the USSP were arranged in Stretcher Bond arrangement, inconsistent results were observed for multiple S.USSP150-100, S.USSP150-125, S.USSP300-150, and S.USSP300-200 regardless of the location of the loading point. For example, multiple S.USSP150-100 able to fully reduce the settlement when compared to multiple S.CP150 at the centre point, while the PRS at corner point is 32.4%. In contrast, it causes 2.86% higher settlement when loaded at the edge point.

Table 3. Percentage reduction in settlement.

Panel Type	he/b ratio	Centre Point		Edge Point		Corner Point	
		Settlement (mm)	PRS (%)	Settlement (mm)	PRS (%)	Settlement (mm)	PRS (%)
CP150	Control Panel	0.13	0.0	0.00	0.0	0.21	0.0
CP300		1.94	0.0	0.32	0.0	0.78	0.0
CP600		4.18	0.0	0.51	0.0	0.71	0.0
S.CP150		0.23	0.0	1.40	0.0	10.88	0.0
S.CP300		0.63	0.0	0.09	0.0	1.99	0.0
USSP150-100	he/b=0.33	1.92	-1376.9	1.03	-100.0	0.42	-100.0
USSP300-150		0.32	83.5	0.23	28.1	0.18	76.9
USSP600-270		5.23	-25.1	0.33	35.3	0.97	-36.6
S.USSP150-100		0.00	100.0	1.44	-2.9	7.35	32.4
S.USSP300-150		1.39	-120.6	0.00	100.0	0.00	100.0
USSP150-125	he/b=0.50	0.62	-376.9	0.59	-100.0	0.74	-252.4
USSP300-200		0.56	71.1	1.42	-343.8	4.88	-525.6
USSP600-370		2.54	39.2	0.25	51.0	0.35	50.7
S.USSP150-125		0.59	-156.5	0.62	55.7	3.20	70.6
S.USSP300-200		2.44	-287.3	1.66	-1744.4	0.03	98.5

Heaving also occurred at the surrounding soil and the data is presented in Table 4. Significant reduction in heaving, presented by Percentage Reduction in Heaving (PRH) was observed when USSP150-100, USSP150-125, USSP300-150, and USSP300-200 were loaded at edge point with the PRH values of 97.6%, 100%, 82.1%, and 86.6%, respectively. Corner point loads also cause 48.7%, 97.8%, 84.8%, and 18.1% PRH for the same panels mentioned above. USSP600-270 and USSP600-370 only show heaving reduction when loaded at edge point with 123.5% and 139.8% PRH reduction, respectively. The other points and USSP however, shows more settlement and heaving compared to the control panels, resulting in negative PRS and PRH. On the other hand, when the panels were arranged in Stretcher Bond arrangement, the PRH either be a negative value or no heaving was observed at all. For example, loading the multiple S.CP150 at centre point does not cause any heaving, but 4.09 mm heaving was recorded for multiple S.USSP150-100.

Negative heaving and settlement indicate that the length of the effective height (h_e) does not sufficient to confine the shear movement of the soil when the USSP was a load. Studies conducted by [11], [16] suggested that the best ratio in between depth of vertical reinforcement to the width of the foundation in the sand should be 1, to effectively confine and reduce the settlement, and hence improve the bearing capacity of the subgrade soil by 40%. In this study, however, the ratio of effective depth to the width of the panel does not set to 1. Instead, the h_e/b ratio used are 0.33 and 0.50. When testing USSP with h_e/b equal to 0.33, only USSP300-150 shows positive PRS at all point loads, while for h_e/b equal to 0.50, only USSP600-370 has resulted in positive PRS at centre, edge, and corner point. Hence, it is best to conclude that only USSP300-150 and USSP600-370 able to control the settlement regardless of the test point.

Table 4. Percentage reduction in Heaving.

Panel Type	he/b ratio	Centre Point		Edge Point		Corner Point	
		heaving (mm)	PRS (%)	heaving (mm)	PRS (%)	heaving (mm)	PRS (%)
CP150	Control Panel	0.00	0.0	-2.10	0.0	-7.79	0.0
CP300		0.00	0.0	-5.98	0.0	-1.71	0.0
CP600		0.00	0.0	4.47	0.0	0.00	0.0
S.CP150		0.00	0.0	0.00	0.0	0.00	0.0
S.CP300		0.00	0.0	0.00	0.0	0.00	0.0
USSP150-100	he/b=0.33	0.00	0.0	-0.05	97.6	-4.00	48.7
USSP300-150		0.00	0.0	-1.07	82.1	-0.26	84.8
USSP600-270		0.00	0.0	-1.05	123.5	0.00	0.0
S.USSP150-100		-4.09	-100.0	-5.23	-100.0	0.00	0.0
S.USSP300-150		0.00	0.0	-10.15	-100.0	-3.35	-100.0
USSP150-125	he/b=0.50	-0.78	-100.0	0.00	100.0	-0.17	97.8
USSP300-200		0.00	0.0	-0.80	86.6	-1.40	18.1
USSP600-370		0.00	0.0	-1.78	139.8	-9.94	-100.0
S.USSP150-125		0.00	0.0	0.00	0.0	0.00	0.0
S.USSP300-200		0.00	0.0	-3.27	-100.0	-4.18	-100.0

3.2. The relationship between Soil Stress and USSP dimension

This section discussed the possible reasons that influence the stresses underneath the USPP. Figure 6 shows the variation of stresses occurred underneath the control panel and USSP against the width of the sample for different effective height ratio at the centre point. From the results, when the panel width is 600 mm, the stress underneath the USSP was not more than 117 kPa for USSP with effective height to panel width ratio (h_e/b) of 0.33 and 0.50. Meanwhile, for panel width of 300 mm, the stresses obtained by USSP300-150 and USSP600-270 were 60.2% and 6.4% lesser compared to the stresses obtained by USSP300-200 and USSP600-370, respectively.

From this pattern, it is worth to justify that effective height increment does not influence the soil stresses; the stresses mostly influenced by the width of the panel. Unlike the pattern obtained by the USSP, the stresses under the control panels have a linear relationship with the panel width. As the width increases, the stresses underneath the control panels decreases. When the width of the panel increases by 1 time of the CP150 width, the stress under CP300 decreases by 37.3% from soil stress under CP150;

while increase of the width from 300 mm to 600 mm, that is twofold of the CP300 width resulted in 50.2% decrement of soil stress under CP600 when compared to CP300.

The result of the soil stress when the USSP were loaded at the edge and corner point shows a similar pattern to the centre point; as the width of the panel increases, the stress under the USSP increases. The analysis of the panel width against the soil stress at centre, edge, and corner point is presented in Figure 6 (a), (b), and (c), respectively.

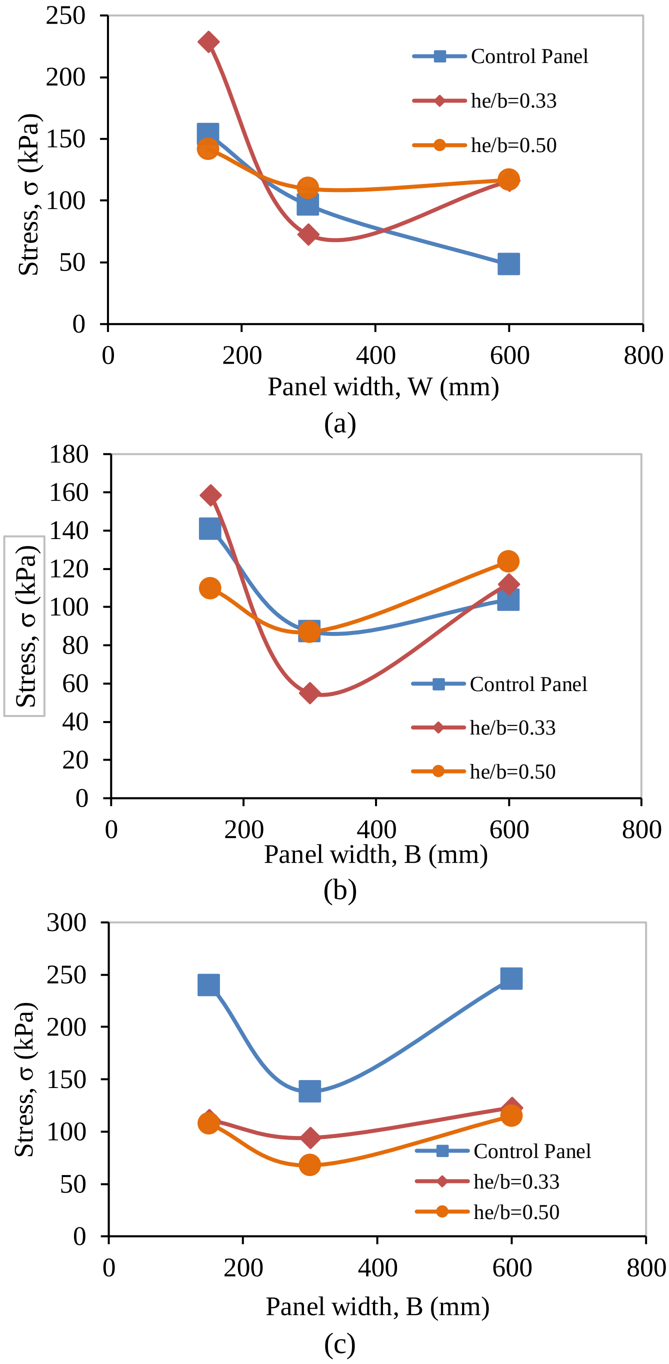

Figure 6. Variation of soil stress against panel width for different effective height ratio at (a) centre point (b) edge point (c) corner point.

It is important to note that the determination of the stress carried by the USSP depends on the effective area of the sample that interacts with the surrounding soil. Application of the static load to the samples causes either lifting or settling of the sample, depending on the point of testing. From the result of stresses, it can be concluded that when the width of the control panel and USSP is set at 600 mm, the stress underneath the samples is always less than 150 kPa, which is rather a consistent result compared to panel with width of 150 mm and 300 mm, regardless of the point of testing.

4. Conclusion

From the experimental work conducted, it can be clearly seen that the USSP-600-370 can reduce more than 39% of the settlement experienced by CP600 whether the point of the test was at centre, edge, or corner. It is also proven that USSP with a width of 600 mm resulted in less than 150 kPa stresses underneath it for all three points of testing. From the Percentage Reduction of Settlement (PRS), it can be concluded that only USSP300-150 and USSP600-370 able to reduce the settlement effectively regardless of the point of testing. Meanwhile, for PRH, the heaving of the surrounding soil is less than 11 mm, which mean the USSP does not critically give an effect to soil heave problem. It is also can be concluded that only USSP category III able to withstand consistent stress regardless of the h_e/b ratio. Comparison in between USSP600-270 and USSP600-370 shows that USSP600-370 is the best USSP since its displaced 9.8% and 54.0% lesser than USSP600-270 at centre and edge point.

5. References

[1] A. T193, "AASHTO Guide for Design of Pavement Structures." AASHTO Publications, United Kingdom, 2003
[2] Jabatan Kerja Raya, *Manual on Pavement Design ATJ 5/85 JKR*. 1985
[3] Liley C 2018 Rutting : Causes, Prevention, and Repairs
[4] Brown S F Keynote Lecture: Soil Mechanics for Pavement Engineers 2003 in *Transportation Geotechnics: Proceedings of the Symposium Held at the Nottingham Trent University School of Property and Construction* M. W. Frost, Ed. Thomas Telford Limited 24.
[5] Kazemian S, Huat B B K, Rasad A B and Maassoumeh 2011 A State of Art Review of Peat : Geotechnical Engineering Perspective *Int. J. Phys. Sci.* **6(8)** 1974–1981
[6] Vedula M, Nath P and Chandrashekar B P 2001 A Critical Review of Innovative Rural Road Construction Techniques and Their Impacts *Proceedings of Technology Demonstration Projects, (Technical) NRRDA* 1–7
[7] Rashid A S A, Bunawan A R and Mat Said K N 2017 The Deep Mixing Method: Bearing Capacity Studies *Geotech. Geol. Eng.* **35(4)** 1271–1298
[8] Black J A, Sivakumar V, Madhav M R and Hamill G A 2007 Reinforced Stone Columns in Weak Deposits: Laboratory Model Study *J. Geotech. Geoenvironmental Eng* **133(9)** 1154–1161
[9] Cicek E, Guler E and Yetimoglu T 2015 Effect of reinforcement length for different geosynthetic reinforcements on strip footing on sand soil *Soils Found.*, **55(4)** 661–677
[10] Boiko I L and Alhassan M 2013 Effect of vertical cross-sectional shape of foundation on settlement and bearing capacity of soils *Procedia Eng.* **57** 207–212
[11] Jha J N and Shukla S K 2015 Bearing Capacity and Settlement Characteristics of Sand Subgrades with Vertical Reinforcement Supporting a Square Footing *Int. J. Geosynth. Gr. Eng.* **1(6)** 1–13
[12] Shukla S K and Yin J H 2006 *Fundamental of Geosynthetic Engineering*. London, United Kingdom: Taylor & Francis Group
[13] Azman M, Nor H M, Hainin M R, Yaacob H, Ismail C R, Hafizah N A K 2013 The Effect of Groove-Underside Shaped Concrete Block on Pavement Permanent Deformation *Jurnal Teknologi (Sciences & Engineering)* **61(3)** 7-14
[14] Knapton J and Barber S D 1979 The Behaviour of a Concrete Block Pavement *Proc. Inst. Civil Engrs* **66** 227-292
[15] Azman M , Nor H M, Hainin M R, Hafizah N A K 2014 Effective Thickness of Bedding Sand Layer for Shell Groove-Underside Shaped Concrete Blocks for Pavement *Jurnal Teknologi*

(Sciences & Engineering) **70 (4)** 143–147
[16] Elwakil A Z and Azzam W R 2016 Soil improvement using grout walls *Alexandria Eng. J.* **55(3)** 2741–2748

Acknowledgements
This study was conducted under the financial support from Universiti Teknologi Malaysia under Research University Grant (GUP) Q.J130000.2522.13H03 and High Impact Research Grant (HIR) Q.J130000.2451.04G54.