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## Experimental investigation of flexural behaviour of U-shaped concrete subgrade panel

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**Abstract.** In pavement design, subgrade condition is one of the criteria to be looked into. Poor subgrade made up of problematic soils could cause the soils to move upwards, known as heaving condition. The U-shaped subgrade concrete panel (USSP) is introduced in this study to help in reducing soil heave condition for low bearing capacity soils. This paper presents a description of the mechanical properties for the USSP flexural strength through experimental works. Flexural strength of USSP for 6 different sizes are compared with the control panel sizes of 150 x 150 x 50 mm, 300 x 300 x 50 mm and 600 x 600 x 70 mm. Modified supports of square-cross section steel blocks with the size of 45 x 45 mm were used in the 3-point flexural strength test to obtain the flexural strength of the control panel. The USSP sustained more flexural load compared to control panel ranging between 7 % to 88 %. The result of the flexural strength test shows that the introduction of the webs to USSP allows the USSP to sustain higher flexural load and induce lower modulus of rupture (MOR) compared to the control panel.

### 1. Introduction

A good pavement performance depends on the structure of the pavement itself. The structure bed starts from the bottom layer: the subgrade. As recommended by AASHTO [1], the subgrade layer should achieve 100% compaction or 95% compaction at optimum moisture content condition. Treatment to the top soils is essential in cases where the compaction does not meet the condition, and it is not feasible to import other suitable materials.

When constructing road structures for low volume traffic, especially rural roads, the costs allocated may not be as hefty as constructions of urban roads. However, when facing with problematic subgrade conditions, the limited budget would become a constraint in providing excellent riding quality to the road users. In this paper, the experimental works for U-Shaped Concrete Subgrade Panel (USSP) is presented. This USSP was introduced as an alternative to strengthen low bearing capacity subgrade [2].



According to Arahan Teknik Jalan 5/85 [3], a good subgrade layer should have a CBR value of 5% or more. Strengthening or stabilisation of soils should take place when the subgrade layer does not meet the required strength. The low CBR value associated with low bearing capacity soils crucially require strengthening works before any construction work can commence. Other than that, highly organic soils may also be subjected to treatment work. Atkins, H.N. [4] lists down several treatments when dealing with organic soils, one of it is by using geotextiles to separate the base material from the subgrade layer.

In a review by Amin, E. R. [5], soil reinforcement methods categorised as low cost are the use of geosynthetics, stabilisation using lime, cement and fly ash. Amin, E. R. [5] further mentioned that the common low cost soil stabilisation methods has the disadvantage for being ineffective or costly. Supposedly, a good subgrade material should be able to resist the accumulation of deformations under repeated load, which is related to shear strength failure [6].

This paper presents the determination of the shape performance by having relevant tests. The tests are conducted to determine the mechanical properties of the USSP. Among the tests conducted in the laboratory, the flexural strength test is the most prominent experiment to relate the USSP shape and the application on the subgrade. Hence, this paper focuses on the laboratory investigation on flexural strength of USSP shape and dimensions.

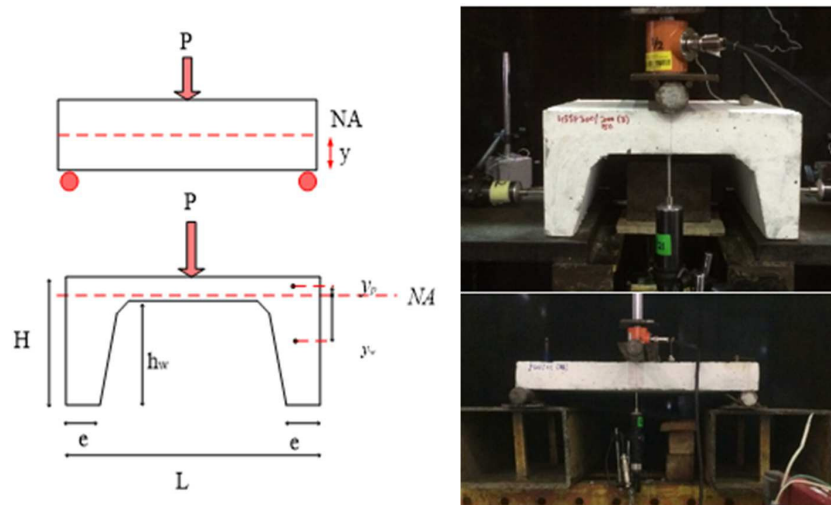
### *1.1. The shape of USSP*

The USSP designed in this study has adopted the shape of U-sectioned or U-shaped concrete drains. A study conducted by Azman et., al [7] mentioned that concrete block pavers that are laid on bedding sand are very much affected by the pavers' size, thickness, laying pattern, and shape. An individual concrete block paver should have good interaction with the jointing sand. The effectiveness of the interlocking system allow for load spreading and build up considerable resistance against applied load [7]. These properties are an important system in the introduction of USSP shape and dimension.

The USSP is divided into two parts, the panel section and webs section. The panel part is designed to receive loads transfer from the upper layer. The loads shall then be distributed to the webs section before it reaches the surrounding subgrade soils. Meanwhile, the web section is designed to cater to the soil heaving conditions when loads are applied onto the subgrade.

There are 6 sizes of USSP and 3 sizes of control panel being used in the experimental works as part of the USSP shape performance determinations. The control panel sizes are 150 x 150 x 50 mm (CP150), 300 x 300 x 50 mm (CP300) and 600 x 600 x 70 mm (CP600). Meanwhile, for the USSP, the nominal sizes are 150 x 150 x 100 mm (USSP150-100), 150 x 150 x 125 mm (USSP150-125), 300 x 300 x 150 mm (USSP300-150), 300 x 300 x 200 mm (USSP300-200), 600 x 600 x 270 mm (USSP600-270) and 600 x 600 x 370 mm (USSP600-370). Notice that the thickness of all the samples are kept to 50 mm and 70 mm in this study, because the thickness of the panel does not affect the flexural load under 3-point flexural strength test [8]. Moreover, this test also should conform with the study conducted by Bazant, Z.P., and Novak, D. [9] and Mohd Ahmed., et al, [10] where flexural tensile strength decreases with the increase of structural element size. The flexural behaviour of the USSP needs to be studied since it will be subjected to traffic loads with higher chances to break under bending failure compared to compressing pressure [11-13]. Additionally, by taking the load carrying capacity of concrete paver block under traffic loading as the analogy, the study on the geometrical shape of USSP is essential. The factors that may affect the results of concrete paver block load carrying capacity are the paver thickness, slenderness ratio, and the flexural strength [14].

Figure 1 (a) shows the 2D illustration of USSP and 1 (b) shows the actual samples prepared in the laboratory works.



**Figure 1.** (a) 2D Illustration of USSP and control panel (b) Actual USSP and control panel

### 1.2. Shape determination

In general, the USSP has adopted the shape of U-shaped drain. However, the panel part is designed according to BS EN1338 [15], the standard used in designing concrete flags. The limiting size of the flag shall be as in the equation (1).

$$\frac{L}{t_1} \leq 4 \quad (1)$$

Where L is the length of the concrete flag and  $t_1$  is the thickness of the concrete flag. However, as to reduce the weight of the sample, the thickness of the panel is limited to 50 mm for panel size 150 x 150 mm, 300 x 300 mm and 70 mm for panel size 600 x 600 mm, respectively. Meanwhile the web height for all USSPs is calculated based on half and one-third from the width of the respective panel.

Therefore, this paper presents the methodology and results for modified 3-point flexural strength on the USSP. The test is conducted to inspect the effectiveness of web sections as the stiffening part under USSP.

## 2. Methodology

### 2.1. Preparation of the mould

The mould used in the preparation of samples are made of 12 mm thick plywood. The plywood was custom-made in the Structural and Materials Laboratory at the Faculty of Civil Engineering, Universiti Teknologi Malaysia. Figure 2. shows the mould prepared for the samples.

### 2.2. Concreting works

The samples prepared in this study used the concrete grade C35/45 as described in Design of Normal Concrete Mixes, [16]. The concrete mix was designed according to British Research Establishment [17]. The materials used in the preparation works are the Ordinary Portland Cement (OPC), water, fine aggregate and coarse aggregate of maximum size 10 mm. The water-cement ratio of the concrete mix is 0.47 for every batch. There are 0.5% of superplasticiser added into the water.

There is also a BRC mesh installed in the mould according to the sizes designed. The BRC size is DA-6, which indicates the aperture is 100 x 100 mm and the diameter of the steel is 6 mm. The BRC yield strength,  $f_y$  is 250 N/mm<sup>2</sup>. This BRC mesh was installed into the USSP to give

additional strength when the USSP is subjected to destructive test. A study by Randhir, J. P., et al., [18] has shown that the addition of USSP gives additional strength to the ferrocement slab panels. However, in this study, the BRC installation is required as to ensure that the sample does not fail during handling works.

The targeted mean strength of the concrete is 41.56 N/mm<sup>2</sup> and the targeted fresh concrete slump is in between 30 – 60 mm. Figure 3 shows the concrete slump taken during concrete casting. The result shows that the concrete mix has the slump value as per designed, 60 mm.

The concrete was prepared in 3 different batches due to the volume limitation of the concrete mixer. The moulds were removed after 24 hours. The curing of every batch of the samples were made by covering the samples using wetted sacks for 28 days. After 28 days, white paint was applied to the samples to improve visibility of cracks on the samples later during flexural strength test.



**Figure 2.** Mould preparation for concrete casting



**Figure 3.** Fresh concrete slump

### 2.3. *Cube compressing strength test*

In determining the compressive strength of the concrete, there are 18 cubes that have been compressed with control load of 6 kN/s by using the Universal testing machine. The size of the concrete cubes is 100 x 100 x 100 mm. The average compressive strength of each batch of the concreting works are tabulated in Table 1. Note that the compressive strength of each batch differs from one another due to the addition of superplasticiser. However, the results show that the compressive concrete strength meets the targeted mean strength.

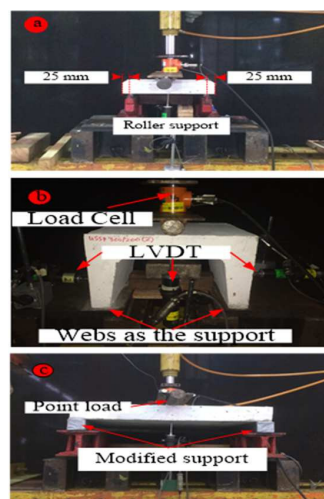
**Table 1.** Average Compressive Strength of Concrete Cubes

Day	Average Compressive Strength (Cube Test) (N/mm <sup>2</sup> )			Average (N/mm <sup>2</sup> )	SD	CV
	Batch 1	Batch 2	Batch 3			
7	48.26	40.98	40.75	43.33	4.27	9.86
28	54.00	52.13	50.68	52.27	1.66	3.18

#### 2.4. Flexural strength test

In determining the compressive strength of the concrete, there are 18 cubes that have been compressed with control load of 6 kN/s by using the Universal testing machine. The size of the concrete cubes is 100 x 100 x 100 mm. The average compressive strength of each batch of the concreting works are tabulated in Table 1. Note that the compressive strength of each batch differs from one another due to the addition of superplasticiser. However, the results show that the compressive concrete strength meets the targeted mean strength. The flexural strength test was conducted on a steel frame which was customised to fit the size of the samples. This test was also conducted in the same laboratory where the samples were prepared. The frame setup is shown in Figure 4. Before the samples were placed on the frame, the dimensions are recorded. Then the samples are marked with distance of support to support on the samples' front surface. A cross was marked on the centre-top surface of each sample to easily align the load cell.

Figure 4(a) is the frame setup of flexural test according to ASTM C293 [19], where the distance of each support to the edge of sample is 25 mm minimum. In Figure 4(b), the frame setup for USSP is shown. The web section of the USSP acted as the support. Meanwhile, Figure 4(c) shows the frame setup for modified flexural strength test. This modified flexural strength test was performed to obtain the correction factor between control panel and USSP [20]. The steel blocks were placed at the bottom of the sample as replacement for the roller support. This modification was made to resemble the webs of the USSP. The base of the supports was anchored and tightened to the frame to avoid unnecessary movement during the test.

**Figure 4.** Flexural strength frame setup

The Linear Velocity Displacement Transducer (LVDT) and load cell are connected to a data logger model TML-530. The readings of the load and displacement were recorded into a connected computer. During the test, crack lines were marked on the samples and recorded. After the samples had failed, they were removed from the frame and kept for further visual inspection.

### 2.5. Determination of bending test in flexural

The bending stress of control panel and USSP was determined using the elastic flexural formula. Equation 2.1 is the basic formula used in determining the stress. The concept is used to determine the normal stress in a straight and symmetrical member, with respect to an axis. It is only true when the moment applied is perpendicular to the same axis.

$$\sigma = \frac{M_y}{I} \quad (2.1)$$

The stress,  $\sigma$  is proportional to the moment applied,  $M$ , which acted at the section  $y$  from the neutral axis, NA, and inversely proportional to the moment of inertia,  $I$ , of the samples cross section. For panel, the stress was calculated using Equation 2.2-2.5.

$$M_{cp} = \frac{PL}{4} \quad (2.2)$$

$$y = \frac{h_e}{2} \quad (2.3)$$

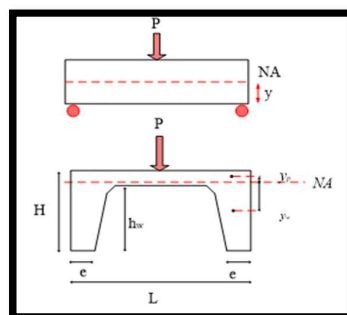
$$I_{cp} = \frac{b \cdot h_e^3}{12} \quad (2.4)$$

$$\sigma_{cp} = \frac{\left(\frac{PL}{4}\right)\left(\frac{h_e}{2}\right)}{\frac{bh_e^3}{12}} = \frac{3PL}{2bh_e^2} \quad (2.5)$$

The stress formula later modified for USSP, which is adopted from the study by Azman *et. al* [21] and Nur Aiza Shuhada, K., *et.al* [22]. The calculation of moment of inertia for USSP requires the USSP being divided into sections to get the distance of centroids of each section from the neutral axis. Hence, Equation 2.6-2.7 is used to find the centroid distance,  $\bar{y}$  and the moment of inertia,  $I_i$ . Figure 5 visualises the equations used in this study.

$$\bar{y} = \frac{\sum A_i \bar{y}_i}{\sum A_i} \quad (2.6)$$

$$I_i = \sum \left( \frac{bh^3}{12} + A_i d_i^2 \right) \quad (2.7)$$



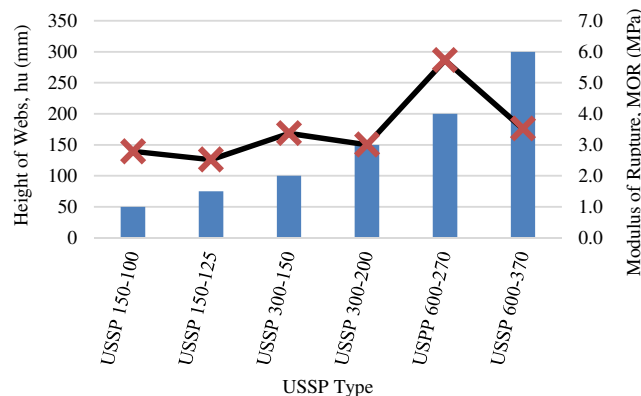
**Figure 5.** Bending stress in flexure

### 3. Result and discussion

#### 3.1. Effects of USSP web height on flexural load and modulus of rupture

There are 36 samples tested for the flexural strength. The samples were tested using standard 3-point flexural strength test [19] and modified 3-point flexural strength test [20]. Figure 6 illustrated the value of flexural load against the modulus of rupture (MOR) value for the samples tested. Generally, MOR is related to the bending stress. The comparing USSP150-100 and USSP150-125 shows a decrease of MOR value with increase of web height.

The same pattern can be found when comparing USSP300-150 with USSP300-200 and, USSP600-270 with USSP600-370. This is because with higher web height beneath the center of the USSP, a higher moment will be created during the flexural load and increases its probability to fail. The difference between MOR value for USSP150-100 and USSP150-125 is 9.7% with height difference of 25 mm. The MOR decrease as much as 2.4% for USSP300-150 and USSP300-200 with height difference of 50 mm. Meanwhile for USSP600-270 and USSP600-370, the difference between the MOR value is 38.7%, with height difference of 100 mm.



**Figure 6.** Relationship between USSP web's height and MOR

#### 3.2. Relationship between flexural load and modulus of rupture

The relationship between flexural load and modulus of rupture (MOR) is shown in Figure 7. The trend noted that with the introduction of webs to the USSPs had increased the ultimate flexural load for each control panel (CP). There is only subtle difference in the flexural load sustained by USSPs compared to the CP. The flexural load of CP150, USSP150-100, and USSP150-125 is 20.11 kN, 21.54 kN, and 26.45 kN respectively. Comparison of MOR value in between USSP150-100 and USSP150-125 shows a decrement value, from 2.79 MPa to 2.52 MPa. However, the MOR value for both USSPs is higher than the MOR value for CP150, 0.54 MPa.

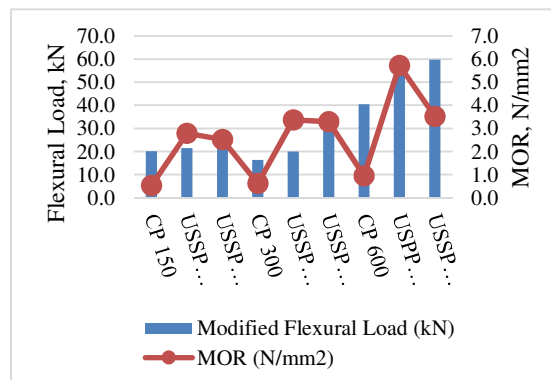
For CP300, USSP300-150, and USSP300-200, the flexural load sustained is 16.33 kN, 20.07 kN, and 30.72 kN respectively. The MOR value in between CP300 and associated USSPs increased from 0.63 MPa to 3.37 MPa, but with decrement shown from 3.37 MPa to 3.29 MPa in between USSP300-150 and USSP300-200.

The same trend experienced by CP600, USSP600-270 and USSP600-370. As the flexural load increased among the samples, the MOR value decreased. CP600 reached ultimate flexural load at 40.55 kN with MOR value of 0.95 MPa. USSP600-270 and USSP600-370 sustained up to 55.95 kN and 59.73 kN when flexural loads applied, causing decrement of MOR value, from 5.73 MPa to 3.52 MPa respectively.

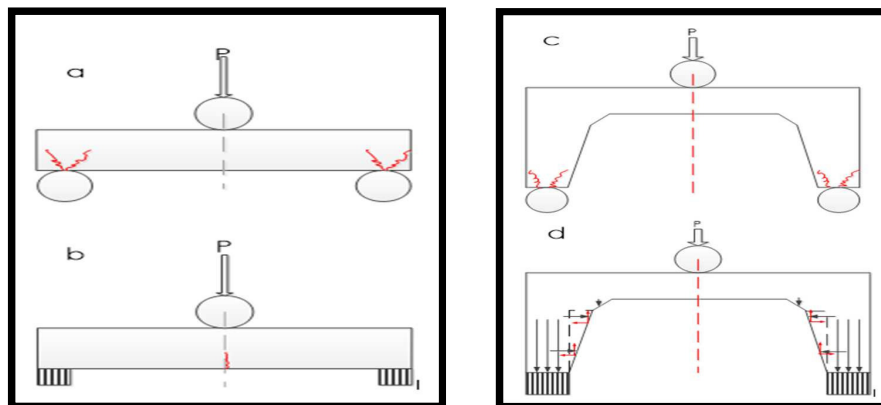
The flexural load increment in between each sample is affected by the height of the samples. Higher webs' height caused lower flexural stress. As discussed in section 3.1, the height of the webs induces higher moment to the sample, hence increasing the probability to fail.



From the flexural load result, it clearly shows that the load sustained by each sample is influenced by the shape and the size. Figures 8(a) until 8(d) show the effect of having webs and how the modified support change the cracking point on the tested sample.



**Figure 7.** Relationship between flexural load against modulus of rupture



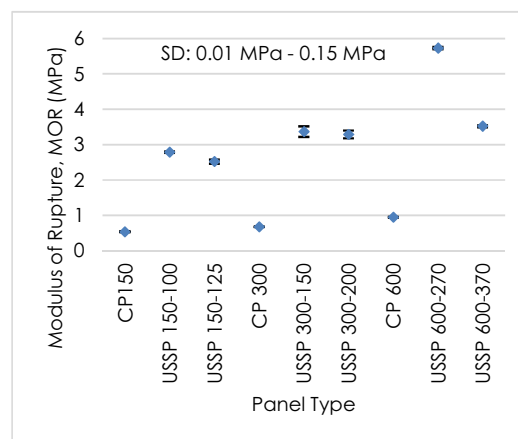
**Figure 8.**(a) Standard flexural load, critical point at the roller support (b) Modified flexural support, critical at mid span, tension area (c) USSP with standard roller support, and critical point (d) Triangle shape of webs stiffening effect

Figures 9(a) and (b) show the actual conditions of USSP after the sample has failed under flexural load. Note that the inside section of the webs had failed, without disturbing the rectangular part of the web. Hence, it proves that the triangle shape, gives the USSP stiffening effect, resulting in higher load retained before failure occurred.

The effectiveness of the USSP webs further proves that by having low value of standard deviation as illustrated in Figure 10. The small range of MOR value in between 0.01 MPa to 0.15 MPa shows that the ultimate load sustained by each sample is consistent. The difference in between control panel (CP) and USSP with associated size ranging in between 73% and 83%. Referring to section 1.2, the consistent range of MOR value in between CP with USSP and among the USSPs itself proves that height of the web plays an important factor in retaining the load.



**Figure 9.** (a) Crack at inner part of USSP web (b) Crack only occurred in triangle area



**Figure 10.** Modulus of rupture of control panel and USSP

#### 4. Conclusions

Based on the experimental test results, the conclusions are as follows:

1. The geometry of the USSP, especially the height of the webs, gives significant effect on the flexural load sustained by the sample.
2. The consistency in geometry dimensions of the sample is essential to obtain good results, with preferred small value of standard deviations.
3. The modulus of rupture is highly influenced by the height of tested sample. Higher USSP induces greater probability to fail.
4. The stiffening section of USSP webs gives an extra advantage when dealing with failure; the stiffening section failed when ultimate loads reached. Meanwhile, the rectangular part of the webs remained intact.

#### 5. Acknowledgements

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