Malaysian Journal of Civil Engineering 28 Special Issue (3):267-278(2016)

SEPKA 2016

DETERMINATION OF U-SHAPED CONCRETE PANEL FOR LOW BEARING CAPACITY SUBGRADE

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Abstract: The concept of using U-shaped Concrete Panel (USCP) is expected to be a solution in strengthening low bearing capacity subgrade, used as foundation for rural road. The objective of this paper is to present the experimental feasibility in designing and testing of the USCP. The USCP has a shape of a panel with webs coupled at both end. The shape is designed to have optimum flexural strength as well as to overcome heaving of the ground. This USCP also should give an interlocking effect to the soil in contact with the USCP. The design of the shape is determined by the concept of U-shaped drain and shear failure of soil. This USCP further give advantage in providing strength to the low bearing capacity subgrade. Experimental tests included to determine the engineering properties of the USCP are the flexural strength test, drop-weight impact test, and dynamic load test. In this study, this USCP is aimed to be able to provide additional strength to the subgrade without disturbing the native soil.

Keywords: *Concrete panel, subgrade, peat soil, bearing capacity, subgrade strengthening*

1.0 Introduction

Road pavement structure consists of multiple layers of predetermined materials above the soil subgrade, which are either natural, imported, or stabilised soil. The primary function of a pavement is to distribute traffic loads to the subgrade. There are two general types of pavements to perform this role known as flexible pavement and rigid pavement. Regardless of the pavement types, the utmost important condition to meet before road construction is the soil condition. Soil type and moisture content are the major factors influencing subgrade performance. To satisfy the subgrade conditions, the study and knowledge of soil associated with pavement and highway design are crucially important where it has substantial differences with other geotechnical applications (Brown, 2003). Brown (2013) mentioned the important differences of transportation geotechnics with general geotechnics applications could be concluded in three important manners that is (a) subgrade layer and pavement structure materials should be above the water table level, where it should be sealed with a sealant right underneath. The drainage conditions and water table depth determined the saturated or partially saturated soils in that particular location. (b) Repeated applications of stress from wheel loading to the pavement structure can be analogically understand with earthquake and wave loading behaviour. Nevertheless, (c) a single application of moving wheel load directing to the essential resilient manner where it exists in elastic region. However, repeated wheel loading could lead to irrecoverable plastic and viscous strain to the pavement structure (Brown, 2003).

In Malaysia, the peat land covers a total of 143, 974 ha of its area (Jon *et al.*, 2010). It is inevitable to avoid any development or construction over it. In road network, traffic loading is transmitted to the lower layers. Subgrade which may in the form of undisturbed ground or imported soils, acted as the foundation of the pavement structure. A good subgrade is able to support loading without excessive deformation, but if construction on poor subgrade become unavoidable, it is necessary to improve the subgrade performance (Frost, 2003). Unfavourable California Bearing Ratio (CBR) value of subgrade layer defined by ASSHTO when it have a value of less than 3%. Bearing capacity can be defined as the ability of a soil to safely carry the pressure placed on the soil from any engineering structure without undergoing a shear failure with accompanying large settlements (Engineers, 1992).

Permanent pavement failure usually associated with a poor subgrade condition. Rutting is a major pavement failure, which requires full depth maintenance. Subgrade rutting may occur due to insufficient compaction during construction where secondary settlement takes place in the long period (Wibowo, 1989). Hence, U-shaped Concrete Panel (USCP) is design to have the ability to improve the subgrade strength without disturbing native soil of the construction area.

Constructions of road embankments, railway tracks, building foundations on peat soil require successful soil improvement. As in determination of subgrade layer, the bearing capacity and settlement of the soil is indispensable (Ibrahim *et al*., 2014). Construction on top of peat land is considered as a challenging engineering art. Usually, as much as possible, construction over peat land were opt out and replaced with either excavation or importing techniques (Scotland, 2010). These techniques, therefore, indirectly narrow the knowledge and problem solving when dealing with construction on peat soils.

Hashim and Islam (2008) concluded their study of peat soils in Peninsular Malaysia as having unfavourable potential for construction. This is due to high compressibility, high water content, high organic, and high fibre content of the sample. The aim of this paper is to present the design concept and experimental planning of the USCP which is being proposed to help subgrade strengthening for road construction on peat soils area.

2.0 Design of U-Shaped Concrete Panel (USCP)

2.1 Shape Design Concept

USCP came into concept to help with subgrade strengthening in the area where soft soil area could not be avoided such as organic soils and peat soils. The USCP were aimed to perform as a divider between undisturbed soil and the pavement structure above it. In a natural state, when loads applied on top of peat soils, it will undergo large settlement over a short period of time in primary consolidation stage (Yulindasari, 2006). Traffic loads induce repeated stress to each layer underneath.

When the soft soil received loads exceeding the bearing capacity, it will tend to fail and major rehabilitation work will be needed (Brown, 2003). Therefore, layers of rectangular or square slab were proposed to be placed immediately on top of the subgrade layer. This proposed slab or panel may particularly design according to the concrete flags dimension. The initial idea of this USCP is to help with subgrade strengthening by providing a platform to receive load transferred from the upper layer of the pavement structure. However, with the proposed initial shape, it is predicted to induce other issues such as uneven settlement and rutting. Hence, this USCP need to have a couple of web at the bottom end of the panel.

2.2 *Bending Stress*

The bending stress of the USCP is determined using the elastic flexure formula. It is used to determine the normal stress in a straight member, having cross section that is symmetrical with respect to an axis, where moment is applied perpendicular to this axis. The flexural formula is based on the requirement that the resultant internal moment on the cross section is equal to the moment produced by the normal stress distribution about the neutral axis. Basic formula uses to calculate the bending stress is:

$$\sigma = \frac{My}{I} \tag{1}$$

From the formula, the stress are proportional to the bending moment, *M* at the section *y* from the neutral axis, *NA*, and inversely proportional to the moment of Inertia, *I*, of the cross section. When the USCP being loaded with centre-point loading, the maximum bending moment induces at the centre, which can be control with the effective depths of the USCP. For this USCP, the moment of inertia, *I*, acting depends on the shape, width, *b*, and effective depth, h_e, of the USCP. In flexural formula, *M*, is measured in Newton-meters, *y* is in meters, *I* in meters^4 and bending stress, σ is expressed in Pascal, Pa. In contact with USCP shape, Equation (1) can be further expanded as in Equation (2), (3), (4), and (5).

Equation (2) is representing the equation for moment about the USCP. The moment, *M*, is equal to load multiply by the length and further divided by 4.

$$M = \frac{pL_b}{4} \tag{2}$$

The neutral axis where the flexural strength is equal to zero can be calculated through Equation (3):

$$y = \frac{h_e}{2} \tag{3}$$

The moment of inertia, *I*, acting on the neutral axis involves a continuous distribution of mass along the *y*-axis and mathematically defined as:

$$I = \frac{bh_e^3}{12} \tag{4}$$

Therefore, the stress of the USCP can be simplified as in Equation (5):

$$\sigma = \frac{\left(\frac{PL_b}{4}\right)\left(\frac{h_e}{2}\right)}{\frac{bh_e^3}{12}} = \frac{3}{2}\frac{PL_b}{bh_e^2} \tag{5}$$

For USCP, where the webs takes the stresses, as illustrated in Figure 1, the central axis, $\bar{y}$, of the areas is represented in Equation (6).

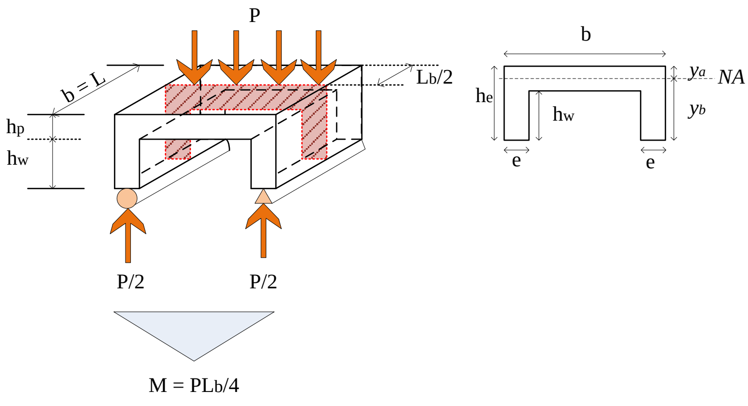


Figure 1: Bending stress in flexure for USCP

$$\bar{y} = \frac{\sum A_i \overline{y_i}}{\sum A_i} \quad (6)$$

Since the central axis has change, the moment of inertia, *I*, also changes and calculated as in Equation (7).

$$I_x = \sum \left(\frac{bh^3}{12} + A_{\bar{y}}^2 \right) \quad (7)$$

2.3 *The Concept of Compressible Soil*

The USCP shape is divided into two parts where it is consisted of panel and webs coupled at both end of the panel's width. Figure 2shows the basic shape of USCP. The idea of using this shape is to cater the shear failure of compressible soil under traffic loading. It has the shape of inverted U-drain or box culvert. The USCP later will be placed on the surface of the subgrade layer; under sub-base/base layer of pavement structure.

Figure 2: Basic shape of USCP

The rational of having webs at the bottom side of the plain concrete block is to control the shearing of soil under loading. According to Terzaghi's basic principles for bearing capacity theory, there are three modes of failure in soil. The modes generally are general shear failures, local shear failures, and punching shear failures (Gofar and Kassim, 2007). An analysis for the failure pattern of soft soils under loading was done using analysis software, Limit State: Geo 3.2. Illustration of peat soils under loading failure pattern analysed using Limit State: Geo is presented in Figure 3.

In the case of analysis using the software, the soil parameters set by using previous study information by Kazemian *et al*. (2011). The average undrained shear strength of peat soil in Malaysia is between 3 to 15 kPa. Critical condition used for the purpose of the analysis. Hence, in the analysis, the value of undrained shear strength used was set to 3 kPa. The average value of unit weight of peat soil in Malaysia lie between 8 kN/m^3 to

11 kN/m^3 (Kazemian *et al.*, 2011; Yulindasari, 2006), where the value used for the analysis is 10 kN/m^3. The unit weight of the concrete is set at 24 kN/m^3.

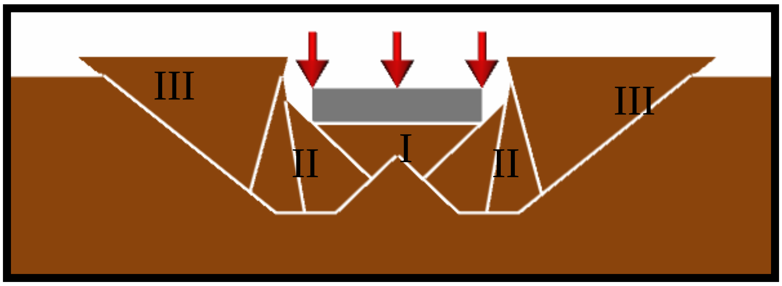


Figure 3: Shear failure pattern of analysed peat soil under loading

From the analysis ran in Limit State: Geo, the shear failure shows the local shear failure behaviour. According to Terzaghi's bearing capacity theory, local shear failure happens when there is a significant compression of the soil under the footing. Moreover, the local shear failure associated with high compressibility soils where large settlement occurs.

To define the shear plane after loading has been applied to the footing, the area divided into three zones. Zone I under the footing is the Triangular Rankine active zone. When the weight of the footing and the soil in this area pushes zone II or Prandtl radial shear zones to the sides and zone III or the Triangular Rankine Passive zones to the surface of the soil resulting in the bulge of the soil surface.

2.4 USCP Dimension Determination

The panel part is designed according to concrete paving dimensions.BS EN 1338:2003 stated that concrete paving block unit shall not have less than 50 mm horizontal distance from any edge. If it is to satisfy concrete paving size, then the overall length divided by its thickness should be less than four as expressed in Equation 8.

$$\frac{L}{t_1} \ll 4 \quad (8)$$

From this expression, the proposed size of the panels was set to 150 x 150 mm, 300 x 300 mm, and 600 x 600 mm for the purpose of this study. By using Equation 1, the minimum thickness that could be designed for the panel is tabulated in Table 1. Considering the minimum thickness from expression in Equation1, which is adopted from design code for unreinforced concrete block, then the minimum thickness should adhere to BS EN 1338:2003. This is to avoid the failure in flexural when the concrete panel is subjected to loads.

Table 1: Proposed thickness of USCP

Length, L (mm)	Proposed minimum thickness, t_1 (mm), BS EN 1338:2003	Proposed thickness, t_1 based on U-shaped drain standard size (mm)
150	37.50	-
300	75.00	65.00
600	150	70.00

Meanwhile, for the thickness of web, it is designed to be equal as the thickness of the panel section, $t_{1,}$ as adopted from the dimension of precast U-shaped drain. Further design concept taken into the USCP shape is based on the standard dimension of U-shaped drain or box culvert. Table 2 shows the standard size of commercial U-drains available on Malaysia's market.

When pavement subjected to wheel load, the element in or under the pavement will experience general stress regime. Brown (2003) shows the existing normal stress and shear stress acting on the material particle under the pavement as illustrated in Figure 4.

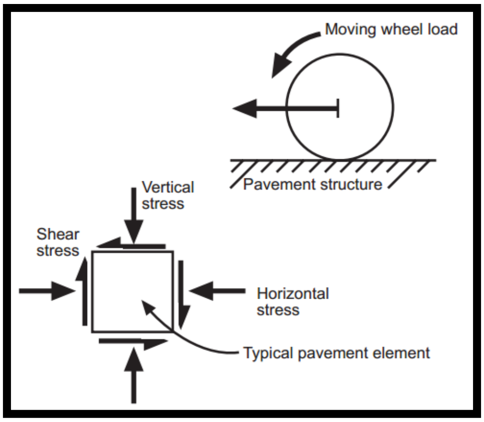


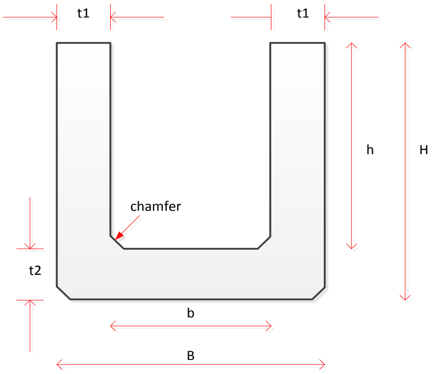
Figure 4: Stress regime under moving wheel load (Brown, 2003)

An analogy to justify the relevance of having the webs is also can be explained through the design concept of raft foundation. Raft foundation is suitable to solve differential settlement or to cover wide areas. The raft foundation has a thickened thickness at the edge to act as the beam supporting the external wall of the structure above it. It also helps to transfer loads to the surface immediately underneath (Lopes, 2000). According to Azman *et al*. (2015), the web section designed for their underside shape concrete block is important because it takes the stresses applied on it.

Table 2: Standard size of U-shaped drain

Suppliers	**Dimensions**						
	Nominal size (mm)	B (mm)	b (mm)	t_1 (mm)	t_2 (mm)	h (mm)	H (mm)
TEKUN Concrete	300 x 300	430	300	65	65	300	365
	450 x 450	590	450	70	70	450	525
	600 x 600	750	600	75	75	600	680
OKA	300 x 300	430	300	65	65	300	365
	450 x 450	580	450	65	65	450	515
	600 x 600	730	600	65	65	600	665
SCIB Concrete	300 x 300	-	-	-	-	-	-
	450 x 450	-	-	-	-	-	-
	600 x 600	740	600	70	70	600	670
HUMES	300 x 300	-	-	-	-	-	-
	450 x 450	-	-	-	-	-	-
	600 x 600	740	600	70	70	600	670
UTAMA Concrete	300 x 300	-	-	-	-	-	-
	450 x 450	-	-	-	-	-	-
	600 x 600	740	600	70	70	600	670

Detailing



Chamfer:-

TEKUN : 45 degree
OKA : 25 x 25 mm
SCIB : 70 x 70 mm
HUMES : 70 x 70 mm
UTAMA : 70 mm x 45 degree

3.0 Research Methodology

The design of the USCP is divided into two parts that are the panel and the webs. Six proposed size for USCP are 150 x 150 x 37.5 mm, 150 x 150 x 50 mm, 300 x 300 x 75 mm, 300 x 300 x 100 mm, 600 x 600 x 150 mm, and 600 x 600 x 175 mm. The length to thickness ratio of the panel is aimed to be able to cater the flexural strength without having failure.

The web section was equally designed with the same dimension as the panel, which adopted from the typical precast U-shaped drain dimension. Denoting the typical size of precast U-shaped drain, the dimension of the flange and the base section is always the same. Hence, for the design of USCP shape, the same concept is adopted. Figure 5 illustrate the isotropic view shape of the USCP. Chamfer of 45 degree in between panel and web section is to be adopted. This chamfer is determined to be necessary to minimise cracking before failure strength achieved.

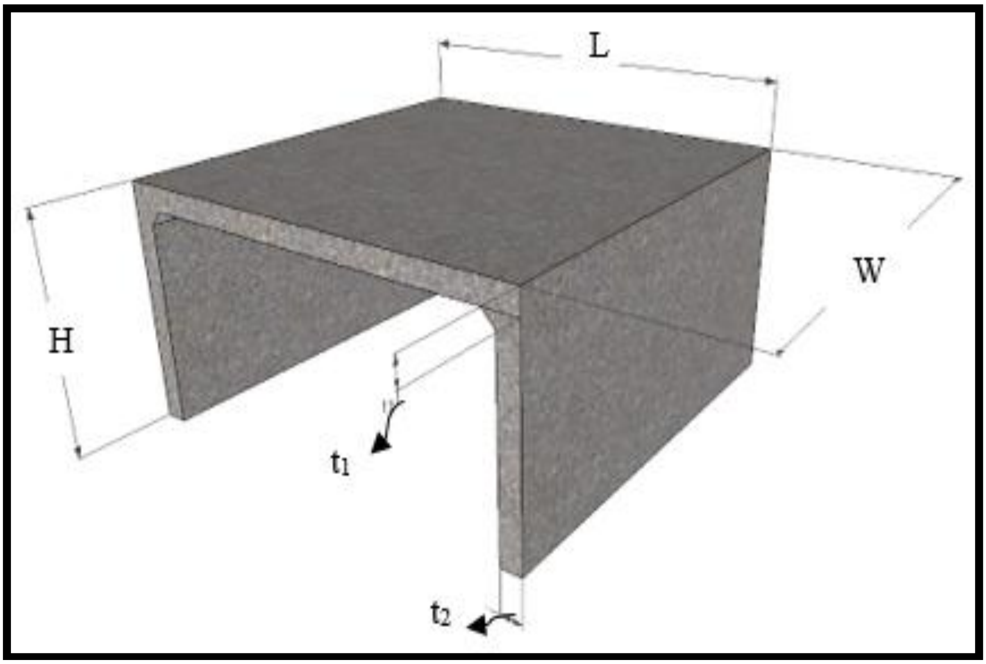


Figure 5: Isotropic view of USCP

The number of samples and proposed dimension of the USCP to be tested with destructive test is present in Table 3. The designated tests to determine the engineering properties of the USCP are (a) flexural strength test, (b) drop-weight impact test and (c) dynamic load test. Each test will have 3 number of samples from each shape. The limited number of samples being proposed here is due to the time frame constraint and budget constraint.

Table 3: USCP dimension and number of samples

Dimensions				Number of sample (unit)
L x W (mm)	H (mm)	t_1 (mm)	t_2 (mm)	
150 x 150	150	37.5	37.5	9
150 x 150	150	50.0	50.0	9
300 x 300	300	75.0	75.0	9
300 x 300	300	100.0	100.0	9
600 x 600	600	150.0	150.0	9
600 x 600	600	175.0	175.0	9

The concrete grade to be used for the USCP is accordance to standard normal grade of concrete having direct contact with soil, i.e. in between grade 25 or grade 30. In order to determine the load carrying capacity of USCP, three-point loading flexural strength test will be conducted to all 54 units of samples. The flexural strength test methodology will be conducted according to ASTM C78 (American Society for Testing and Materials, 2016) .

For drop-weight impact test, existing test methods will be used in this study. Drop weight impact test use a weight of 3.76 kg to be dropped from 0.5 m height, directly on the USCP sample. The USCP should be laid on a horizontal plate and surface to avoid unnecessary errors. Dimension of the steel weight is 44.6 mm. The steel weight is to be dropped from centre of the USCP panel surface until panel section break apart (Ling, 2008). A rather complicated impact load test also has been done by (Andersson, 2014). However, test set up by (Ling, 2008) is selected for this study due to availability of equipment. From the drop-weight impact test, visual observations are to be conducted to observe the cracking pattern, length and depth.

Another test to determine the engineering properties of the USCP is the dynamic load test. The test method follows the ASTM D4945, the standard test method for dynamic load test (American Society for Testing and Materials, 2012). The aim for the test is to determine the bearing capacity of USCP under loading, as well as collecting the acceleration and strain of the USCP.

Another assessments included in this study are the USCP dimensions check, water absorption test, USCP density, crack assessment and observation of failure modes under loading. As mentioned in (Scotland, 2010) report paper, construction of floating road on top of peat land, require minimal load rating being applied during construction to avoid excessive primary settlement and compressibility behaviour. Peat soils settlement and consolidation is favoured to be in slow settlement instead of rapid settlement to avoid shear overstress which can affect the structure on top of it (Munro, 2004)

4.0 Conclusion

At the end of the testing, with the proposed shape and dimension adopted into designing USCP, it should be able to provide additional strength to the subgrade consisted of low bearing capacity soils. With panel section acting as a platform receiving the loads, the webs are supposed to be able to minimise the soil heaving. Furthermore, the flexural strength of the USCP is very much depending on the effective depth of the USCP. To ensure the USCP would meet the objectives of the study, proper laboratory planning and research work shall be conducted. As mentioned in section 1.0, peat soils have the lowest bearing capacity compared to other types of soils. The USCP, however, is aimed to be an alternative solution for the strengthening of the subgrade without disturbing the native soil where construction is located.

5.0 Acknowledgements

We are grateful for the support from Research University Grant (GUP) Q. J130000.2522.13H03 and collaboration with Southern Premix Sdn Bhd.

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