Analysis of hexagonal paving block as a better paving shape

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Abstract. Because of the raise of road infrastructure, the use of paving block pavement increases as well. One of the problems of using paving block is the shape of it which influences of its interlock. The soil deformation over pavement makes it defect easily causing the paving block surface becomes uneven and the soil settled. The aim of this research is to prove that hexagonal paving block is a better paving shape than the other shape of paving. Therefore, analysis comes to the advantage and disadvantage of the installation process and interlocking from any different shape of paving. In order to be able to analyse hexagonal paving shape as the most optimum shape, this research utilizes literature review as the methodology research, to analyse the calculation we used SAP2000, Plaxis, Interlocking and installation pattern. The conclusion from the analysed result of SAP2000 output, Plaxis output, Interlocking and pattern installation can be concluded that hexagonal paving block is the most optimum shape caused its best for lock the pavement and easy to install. Analysis results for moment of force of paving block 10 cm are obtained 201612.46 kg/cm for cube, 6764.09 kg/cm for hexagon, 67460.04 kg/cm for octagonal and 171363.84 kg/cm for rectangular. Therefore the deformation results are obtained -0.632 cm for cube, -0.097 cm for hexagon, -0.109 cm for octagon, -0.355 cm for rectangular. Deformation of soil deflection caused by paving block pavement is obtained 5.21 cm for cube, 3.38 cm for hexagon, 3.43 cm for octagon, 4.45 cm for rectangular. From the analyse of moment and deformation, soil deflection, interlocking and paving block installation can be concluded that hexagonal paving block is a better paving shape of paving block.

1. Introduction
Interlocking concrete block pavements are widely used, in many countries, to support traffic [1]. Concrete paver blocks are made with concrete basically consisting of cement, fine aggregates, coarse aggregates (10 mm and below), water, chemical pigments, etc. [2]. Concrete Block Pavement (CBP) is an alternative and effective pavement that can be used for a better pavement instead of flexible and rigid pavement in order to make a safety and comfortable road but CBP can be categorized as a flexible pavement due to units of the block can be easily removed (take out) if there is another installation needed under the pavement after complete construction [3]. Application of CBP is developing very fast for various reasons such as high resistance to deformation, durability, easy and rapid quality construction, ability to carry traffic immediately after construction, compatibility with the environment and aesthetic features [4]. Paving blocks have so many size and shape. The aim of this research is to prove that hexagonal is a better paving shape than the other shape by analyse the interlocking, moment of force, deformation and soil deflection. To analyse all the aspects, it used SAP2000 to calculated moment of force and deformation of the paving block, used Plaxis program to calculated the soil deflection Sketch
Up to control surface of paving lock’s surface movement and installation process in any shape of the paving block. The limitation used for this paper are:

i. Classification of quality paving block SNI 02-0691-1996.
ii. Load assumption due to Manual Road Pavement of Benkelman Beam Tool No. 01/MN/BM/83.
iii. Analyse used SAP2000 program with grid model.
iv. Soil data used the parameter of Semarang-Purwodadi soil design KM.16 - KM.27.
v. Analyse used Plaxis program, this program only for 2D and with plane strain model straight backward.
vi. Analyse of the surface of paving lock’s surface movement and installation process in any shape of paving block in the field.

2. Literature review
The base of concrete block pavement consists of subgrade and subbase. Figure 1 shows the typical cross section of concrete block pavement.

![Figure 1. Typical cross section of concrete block pavement.](image)

Subgrade soil was classified into four groups of bearing capacity, in the same way as in the Polish catalogue of typical bituminous pavements for roads [5], as shown in Table 1. The subgrade of the area to be paved should be inspected to know if it is formed by local natural soil or soil from another place. The soil should be non-expansive. Subgrade needed to be flattened before, in order to have the same slope level as drainage (water runoff) which the minimum is 1.5%. It needed to be compacted with a minimum 90% MDD (Modified Max Dry Density) before use the subgrade.

| Group of Bearing Capacity | CBR (%) |
|---------------------------|---------|
| G1                        | > 10    |
| G2                        | 5 – 10  |
| G3                        | 3 – 5   |
| G4                        | < 3     |

On the other hand, the subbase is included: natural aggregate, crushed aggregate, cement stabilised aggregate, lean concrete and a high quality cement concrete base for heavily loaded bus stops only [1]. Subbase should have 2% minimum slope level at the left and right. The slope level is important for the stability of paving block. Bedding sand is located below the concrete blocks to provide a smooth level running surface for placing the blocks [6]. The function of jointing and bedding sand is to lock the block in paving block pavement. Jointing as the filler of the joint space and bedding function is for flattened the paving block. The bedding sand layer is considered an essential component in a concrete block
pavement. Bedding sand layer provides uniform support for the blocks and to avoid stress concentrations which could cause damage to the blocks. Bedding sand gives a frictional force between concrete blocks to prevent the block moving towards. Thus, it fills the lower part of the joint space between adjacent blocks in order to develop interlock [7]. Paver is the upper layer in rigid pavement structure. Paver made of mix of Portland cement, water, fine aggregate, coarse aggregate and chemical components.

Nowadays there are so many software programs that can be used in civil engineering. SAP2000 is one of the programs to analyse and design structure. Steps to use SAP2000 in order to analyse and design a structure:

1. Set the unit
   The unit is kg-m, t-m, kg-cm, etc. To set the unit first is so important cause its influence on the design and on structure loading. When input the grid take attention on the unit first. The unit can be changed every time but to change it again click ‘running’.

2. Definition
   The definition is in define toolbar. Before design, the structure the definition that should be used are material definition, the cross-section, load type, analysis type, load combination. The material definition is the material that will be used in the structure component (column, beam, plate) whether the material is concrete, steel or the other material. After the material definition is to make the cross-section, load type (dead loads, live loads, wind load, earthquake load, etc.). For the analysis, the type is whether it is linear or nonlinear, static or dynamic. For the combination can use SNI Standard.

3. Modelling the structure
   Set the grid, draw the structure component (column, beam, and plate) and the position, give the load to the structure.

4. Analysis
   After modelling the structure, then analyses the structure to know the force (M, D, N) the reaction and the structural deformation. To start the analysis, click Set Option Analysis choose 2D or 3D and then click Run Analysis.

5. Design
   Design the cross-section from all the data.

6. Interpretation
   From all the data of analysis and also the design has it same with the theory or not.

   Plane Strain assumes the problem in analysis is of infinite length normal to the plane section of the analysis. By definition, the out-of-plane displacement (strain) is zero in a Plane Strain analysis. The Axisymmetric analysis allows you to analyses a 3D problem which is rotationally symmetric about an axis. The input is 2-dimensional, but because of the rotational symmetry, you are in fact analysing a symmetric 3-dimensional problem. Axisymmetric analysis is commonly applied to circular tunnels.

3. Research Method

3.1. Manual pavement road used Benkelman Beam Tool No.01/MN/BM/83
   This research used primer and secondary data. Secondary data is an archives data from an institution and from plan/design data. Data of the distribution load of transportation from “Manual Pavement Road used Benkelman Beam Tool No.01/MN/BM/83” shown in Table 2.
Table 2. Manual Pavement Road used by Benkelman Beam Tool No.01/MN/BM/83.

| Configuration axle & type | Curb weight (ton) | Weight load maximum (ton) | Total maximum weight | UE 18 KSAL curb | UE 18 KSAL maximum |
|--------------------------|-------------------|---------------------------|----------------------|----------------|-------------------|
| 1.1                      | 1.5               | 0.5                       | 2.0                  | 0.0001         | 0.0005            |
| 1.2 Bus                  | 3                 | 6                         | 9                    | 0.0037         | 0.3006            |
| 1.2 L Truck              | 2.3               | 6                         | 8.3                  | 0.0013         | 0.2174            |
| 1.2 H Truck              | 4.2               | 14                        | 18.2                 | 0.0143         | 5.0264            |

3.2. Compressive Strength
The paving usually used in application for Road Pavement, Car Parks, Footpaths and Garden Parks for the compressive strength, wear resistance and average minimum infiltration shown in Table 3.

Table 3. Compressive strength and wear resistance for application.

| Type | Application       | Compressive strength (kg/cm³) | Wear resistance | Average of maximum infiltration (%) |
|------|-------------------|-------------------------------|-----------------|-------------------------------------|
|      |                   | Average | Minimum | Average | Minimum |                          |
| A    | Road pavement     | 400     | 350     | 0.0090 | 0.103   | 3                            |
| B    | Car parks         | 200     | 170     | 0.1300 | 1.149   | 6                            |
| C    | Footpaths         | 150     | 125     | 0.1600 | 1.184   | 6                            |
| D    | Garden/Parks      | 100     | 85      | 0.2190 | 0.251   | 10                           |

3.3 Size of paving block shape (cube, rectangle/holland, hexagon and octagon).
The shape and size of paving blocks which used usually in pavement are cube/rectangular, rectangle, hexagon and octagon, while Table 4 shows the detail of the paving.

Table 4. Size of paving block shape.

| Shape          | Size               |
|----------------|--------------------|
| Cube (21x21)   | t : 6, 8, 10 cm    |
| Rectangle (21x10.5) | t : 6, 8, 10 cm |
| Hexagon (10x10) | t : 6, 8, 10 cm    |
| Octagon (8x8)  | t : 6, 8, 10 cm    |
3.4. Soil data from parameter of soil design of Semarang-Purwodadi KM.16 - KM.27

Table 5. Soil data from parameter of soil design of Semarang-Purwodadi KM.16 - KM.27.

| Material Model | Name       | Material properties KM 16 – KM 27 Semarang – Purwodadi | Unit       |
|----------------|------------|---------------------------------------------------------|------------|
|                | Thickness  | Subbase       | Bedding sand | Paver | cm |
| Unsaturated Unit Weight | γ\text{unsat} | 15 | 22 | 22 | kN/m³ |
| Saturated Unit Weight | γ\text{sat} | 18 | 23 | 22 | kN/m³ |
| Horizontal Permeability | k_x | 0.8 | 1 | 1 | m/day |
| Vertical Permeability | k_y | 0.8 | 1 | 1 | m/day |
| Modulus Young | E_{\text{ref}} | 1800 | 2900 | 307322 | Psi |
| Poisson Ratio | ν | 0.35 | 0.35 | 0.35 | - |
| Cohesion | C_{\text{rej (cu)}} | 3.05 | 1.82 | 1 | kN/m² |
| Friction | θ | 29 | 29 | 30 | - |
| Dilatation | ϑ | 0 | 0 | 0 | 0 |

Then the primer data information collected by survey and interview to resource in the field. The data is collected for knowing the advantage and disadvantage of installation process and interlocking.

4. Results and analysis

4.1. Interlocking aspect

For the interlocking aspect in this research Sketch up used for design the interlocking of paving. In Sketch up the design based on real size that used for pavement. The data got from field survey. The interlocking of different shape shown in Table 6.
Table 6. Interlocking of paving shape.

| No | Paving Shape |
|----|--------------|
| 1  | ![Image](image1.png) |
| 2  | ![Image](image2.png) |
| 3  | ![Image](image3.png) |
| 4  | ![Image](image4.png) |

4.2. Deformation of paving block

From the secondary data, SAP2000 used in order to analyse the data. And the output from the analysis shown in Table 7 and Figure 2.

Table 7. Deformation of paving block.

| Size                  | 6 cm thickness | 8 cm thickness | 10 cm thickness |
|-----------------------|----------------|----------------|-----------------|
| 21x21x6 (Rectangular) | -2.93          | -1.2344        | -0.632          |
| 6x10x10 (Hexagonal)   | -0.45206       | -0.1907        | -0.097          |
| 6x8x8 (octagonal)     | -0.50846       | -0.21451       | -0.10988        |
| 6x10.5x21 (Rectangle) | -1.6456        | -0.6942        | -0.3554         |
From Table 7 and Figure 2 shown the results of the deformation of paving block at three different thickness. Figure 2 show that Hexagonal has the most minimum deformation number which can be concluded that hexagonal is the most optimum paving shape.

4.3. Moment of paving block
Table 8 and Figure 3 show the moment of paving block. The most minimum number of the moment is in hexagonal shape which has 67983.6 in 6 cm thickness, 67586.33 in 8 cm thickness and 67464.09 in 10 cm thickness.

Table 8. Moment of paving block.

| Size      | 6 cm thickness | 8 cm thickness | 10 cm thickness |
|-----------|----------------|----------------|-----------------|
| 21x21x6   | 202732.63      | 202226.87      | 201612.46       |
| 6x10x10   | 67983.6        | 67586.33       | 67464.09        |
| 6x8x8     | 67459.95       | 67449.95       | 67460.04        |
| 6x10.5x21 | 171943.57      | 172097.24      | 171363.84       |
4.4. Analysis of subgrade settlement used Plaxis
The output result of deformation calculation of paving blocks with load 36.03KN/m² and thickness 10 cm shown in Table 9.

| Shape    | Soil Settlement |
|----------|-----------------|
| Hexagonal| 3.38 cm         |
| Octagonal| 3.43 cm         |
| Rectangle| 4.45 cm         |
| Cube     | 5.21 cm         |

5. Conclusions
From the analysis of strength, interlocking and installation process of the paving block can be concluded as:

i. From interlocking aspect and installation process due to advantage and disadvantage from the field survey, hexagonal is the most optimum shape.

ii. For calculation of the moment (strength aspect) of paving block size of 10 cm calculated by SAP2000, the results are 201612.46 kg/cm for rectangular, 6764.09 kg/cm for hexagon, 67460.04 kg/cm for octagonal and 171363.84 kg/cm for the rectangle. Therefore, the deformation results are obtained -0.632 cm for rectangular, -0.097 cm for hexagon, -0.10988 cm for the octagon, -0.3554 cm for the rectangle. Based on the calculation the minimum number of deformation is hexagon -0.097 cm.

iii. Deformation of soil deflection caused by paving block pavement is obtained 5.21 cm for rectangular, 3.38 cm for hexagon, 3.43 cm for the octagon, 4.45 cm for the rectangle. From the analyse of strength, soil deflection, interlocking and paving block installation can be concluded that hexagonal paving block is the most optimum shape of paving block.
6. References

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