StormPav Green Pavement the environmentally friendly pavement

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Abstract. Growth of economy and population density, open space is being converted to roads or other infrastructures such as buildings or parking lots reducing green space. This paper demonstrates a new type of green pavement designed to replace flexible and rigid pavements which are water impermeable and have a short design life. This type of green pavement helps reduce runoff problems in urban areas. StormPav GP is an innovative Industrialised Building System (IBS) Green Pavement which has been shown to have structural, environmental and economic advantages. However, its susceptibility to distress has yet to be analyzed. This study addresses this gap by analyzing the mechanistic properties and evaluating distress of StormPav GP as compared to flexible and rigid pavements. WinJULEA, KenPave and Circly 6.0 were used for this analysis which also investigated the effects of different tire pressures on deflections. StormPav GP was found to have lower deflection due to a tandem axle dual wheel load on any pavement surface and provided a more uniform settlement with higher elastic modulus and shear modulus than flexible and rigid pavement.

1 Introduction

As more of the surface area in urban and rural areas becomes covered by roads and buildings green areas are reduced. This lack of filtering vegetation and absorbent soil surface disrupts absorption and increases runoff rates. This absence of vegetation is a considerable challenge for regions with heavy rainfall, such as in Indonesia. Moreover, impervious pavement surfaces such as rigid pavement and flexible pavement lead to problems associated with increased runoff volumes, river bank erosion and flash flooding. If no actions are taken to mitigate these risks sustainable development of particularly urban areas will be affected. One solution is to develop permeable pavement materials that allow the rainwater to pass through.

The ability of flexible pavement to maintain shape after repeated loading is affected by temperature and will decrease if the surface temperature exceeds 45°C [1] [2]. Bituminous pavements particularly are vulnerable to certain defects under high axle loading and braking force as well as to high temperatures.

StormPav GP is an innovative green pavement which has several structural, environmental and economic advantages over impervious asphalt and concrete pavements. While not designed for high-speed traffic above 80km/h, it is suitable for urban and university areas where traffic is generally slower. The chemically inert properties of the Grade 50 concrete it is made from results in low rates of surface distress.

In this research, software modelling is used to investigate surface distress on StormPav GP in response to different tire pressure and the allowable load repetition. It is assumed that StormPav GP has many of the same characteristics as rigid pavement because both produce monolithic solutions in response to the applied load.

2 Materials and Methodology

The evaluation of the pavement used analysis of technical and mechanistic aspects. Comparison of the contact pressure between a tire and this surface with that on rigid or flexible pavements was made. Tire contact area is dependent on the configuration and pressure of the tires which are both factors the critical tensile strain at the underside of the asphalt layer, the deflections of the surface and also the interface compressive strength [3].

The mechanistic analysis was conducted on the flexible, rigid and StormPav GP Pavement to analyze the response of the structure. Distress fatigue cracking was modelled using computer software.

A technical evaluation was conducted using mechanistic modelling of the StormPav GP compared to rigid and flexible pavements to gauge any technical advantages of StormPav GP. Sensitivity analysis using different parameters influencing the behaviour and response of the pavement structure was used.

To ensure comparison of results were valid some constant criteria were used throughout. Although, in real

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life, design procedures normally differ when constructing flexible and the rigid pavement, for the sake of consistency and comparison the experimental structures were constructed with the same input parameters. Table 1 shows these parameters.

Table 1. Pavement Design Parameters Properties

Parameters	Value		
	Rigid	Flexible	StormPav
Design life (years)	30		
Load	Tandem axle load		
Structural Number (SN)	-	3.0	-
Terminal Serviceability Index	3.0		

A single axle steer with single axle drive and dual tire rear tandem (a four-axle) 32-tonne gross vehicle weight and suited with 10R20 tires was used to provide the load. The configuration of the truck axle and the gross vehicle weight were chosen based on the investigation done by [4] and the tandem axle load (tandem axle dual wheel group: TADT) shown in Fig. 1 was chosen to be tested. The tested tire pressures are listed in Table 2.

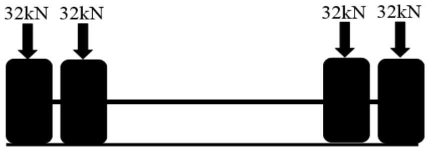

Fig. 1 Tandem Axle Dual Wheel Group

Table 2. Tire Pressure and Contact Radius of Truck Tire

Contact Pressure (kPa)	**Contact Radius**
875.63	104.0 mm = 10.4 cm
675.69	106.7 mm = 10.67 cm
475.74	108.5 mm = 10.85 cm

There are a few common depths of pavements used in construction and the ones used in this study were based on Austroad 2008 guidelines and are shown in Tables 3, 4 and 5 [5] which also lists typical property values of each layer of the pavement in these structures.

Table 3. Flexible Pavements Parameters

Materials	Poisson Ratio	Thickness (mm)	Elastic Modulus
14 mm Bituminous Pavement	0.40	50	2200
20 mm Bituminous Pavement	0.40	125	2500
Cemented Material	0.20	150	2000
Granular Material	0.35	200	210
Subgrade, CBR=5%	0.45	-	50

Source: Austroads, 2008[5]

Table 4. Rigid Pavements Parameters

Materials	Poisson Ratio	Thickness (mm)	Elastic Modulus (MPa)
Unreinforced concrete slab (Grade 30)	0.20	200	30,000
Concrete Base	0.20	150	3000
Lean Mixed Concrete	0.20	125	2000
Subgrade, CBR=5%	0.45	-	50

Source: Austroads, 2008 [5]

Table 5. Stormpav GP Parameters

Materials	Poisson Ratio	Thickness (mm)	Elastic Modulus (MPa)
Top Cover	0.20	75	34,500
Hollow Cylinder	0.20	300	34,500
Bottom Cover	0.20	75	34,500
Subgrade, CBR=5%	0.45	-	50

The elastic modulus for the StormPav GP used was sourced from Mechanical Properties of Concrete and Steel Reinforcement [6]. The front elevation and other details of StormPav GP are shown in Fig. 2 and Fig. 3.

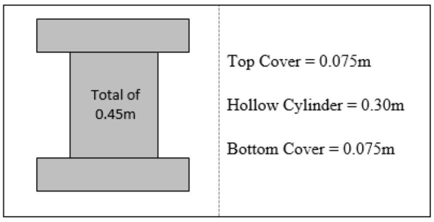

Fig. 2 The StormPav GP Components

The analysis of stress, strain or deflection was obtained by mechanistic analysis with WinJULEA, based on the theory of linear elastic analysis (LEA) that is used to model and determine the mechanistic response of the pavement.

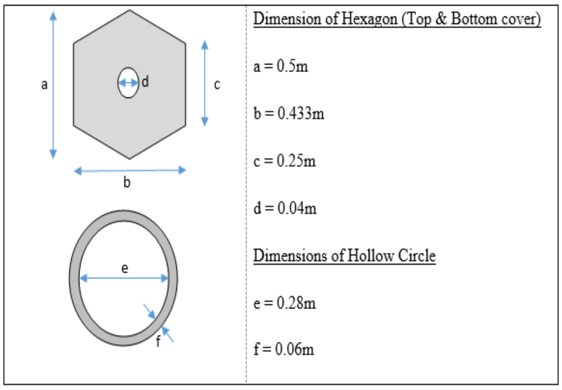

Fig. 3 Details of construction of StormPav GP

WinJULEA software was developed by the U.S. Army and Air Force Departments of Defense Engineering Research and Development Center (ERDC). The software has previously been successful in determining responses of flexible pavements in the new MEPDG suggesting it is a viable analysis tool for flexible pavements [7].

Although other measurements can be used to gauge the structural condition of pavement, surface deflection is the best method for providing information about a range of important characteristics. It can calculate load transfer to both flexible and rigid pavements and evaluates the magnitude and shape of the surface deflection caused by the load from traffic. Deflection measurements can also be used in back-calculations to determine the stiffness of a pavement structural layer and the subgrade resilient modulus [8].

The pavement response to traffic loading was modelled mechanistically using computation of the stresses and strains in each layer. A single load causes minimal stresses and strains resulting in little damage [9]. However, a load repeated applied results in successive deterioration resulting in an unacceptable condition. Thus, the performance and service life of a pavement depends on the magnitude and the number of repetitions of loadings [10] and this can be modelled using pavement stress-strain analysis which has become an integral part of pavement design and performance evaluation [9]. As trucks become larger and carry heavier loads, tire loadings and inflation pressures tend to increase making a deeper understanding of stress-strain behaviour of pavement options imperative in designing distress resistant roads [9].

Determining allowable repetitions of load for flexible pavements is generally calculated as follows. Values for Modulus of elasticity, thickness, Poisson's ratio and the contact pressure of a selected flexible pavement are inputted into Circly 6.0. The maximum compressive and horizontal tensile strains and the critical location of the load are determined. From this, the allowable number of loads can be obtained. Assumptions in this method are that the pavement materials used, in all but unbound granular base layer and subgrade, are homogeneous, isotropic and elastic.

Equation 1, 2, and 3 are fatigue and rutting models were used to calculate strain of the pavement due to load repetition [11].

$$N_f = f1\ \varepsilon t^{-f2} E1^{-f3} \tag{1}$$

$$N_r = f4\ \varepsilon v^{-f5} \tag{2}$$

$$N = [\frac{9300}{\mu\epsilon}]^{-7} \tag{3}$$

where;

N_f is allowable number of load repetitions to prevent fatigue cracking from reaching a certain limit (10 – 20% of the pavement surface area)

N_r is allowable number of load repetitions to prevent rutting from reaching a certain limit (0.5in.)

εt is tensile strain on the bottom of the asphalt layer

εv is compressive vertical strain on the surface of the subgrade

E_1 is elastic modulus of the asphalt layer

f_1, f_2, f_3, f_4 is the regression coefficients.

$\mu\epsilon$ is vertical strain (in units microstrain) at the top of the subgrade

N is allowable number of repetitions of a Standard Axle at this strain before an unacceptable level of permanent deformation develops

To determine the allowable load repetition for StormPav GP the design subgrade and selected subbase were used to evaluate effective strength of the subgrade. Then selection was made of the desired values for concrete base flexural strength after 28 days [12], the load safety factor and project reliability. From this, load repetitions resulting in the allowed fatigue from each type of axle were calculated using Eq. 4 and Eq. 5.

Equations (1) and (2) enable calculation of allowable load repetitions (N_f) for selected axle loads [11]:

$$log(N_f) = [\frac{0.9719 - S_r}{0.0828}] \text{ when } S_r > 0.55 \tag{4}$$

$$(N_f) = \left[\frac{4.258}{S_r - 0.4325}\right]^{3.268}$$

$$\text{when } 0.45 \le S_r \le \quad 0.55 \tag{5}$$

Where:

$S_r = (S_e/0.944 f_{cf})(\frac{PL_{SF}}{4.45\ F1})^{-0.94}$

S_e is equivalent stress (MPa)

L_{SF} is load safety factor

f_{cf} is design characteristics flexural strength at 28 days (MPa)

P is axle group load (kN)

F_1 is load adjustment for fatigue (based on axle group)

- single axle single wheel (SAST) = 9
- single axle dual wheel (SADT) = 18
- tandem axle single wheel (TAST) = 18
- tandem axle dual wheel (TADT) = 36
- triaxle with dual wheel (TRDT) = 54

3 Results and Discussions

3.1 Equivalent Single Axle Load (ESAL)

ESAL is determined by referring to the AASTHO 1993; Guide for the Design of Pavement Structure. A two-axle trailer truck was used with a drive axle (single axle) and a pole trailer axle (tandem axle). The load of the single axle was 64kN and the tandem axle 128kN. Results of the axle load equivalency factors used are shown in Table 6.

Table 6. Axle Load Equivalency Factor

	Load (kN)	Flexible	Rigid	StormPav
Tandem Axle Load (128kN)	124.6	0.643	0.850	0.849
	133.4	0.788	1.140	1.140
Single Axle Load (64kN)	62.3	0.468	0.340	0.336
	71.2	0.695	0.603	0.599

Source: AASHTO (1993) [12]

Table 7. Calculation of ESAL for each Pavement Type

	Flexible	Rigid	StormPav
Single Axle Load	$\frac{71.2-64}{0.695-x_1}=\frac{71.2-62.}{0.695-0.4}$ X₁ = 0.486	$\frac{71.2-64}{0.603-x_2}=\frac{71.2-62.}{0.603-0.3}$ X₂ = 0.390	$\frac{71.2-64}{0.599\quad x_3}=\frac{71.2-62.}{0.599\quad 0.3}$ X₃ = 0.386
Tandem Axle load	$\frac{133.4-128}{0.788-y_1}=\frac{133.4-12}{0.788-0.6}$ y₁ = 0.699	$\frac{133.4\quad 128}{1.140-y_2}=\frac{133.4\quad 124.}{1.140-0.85}$ y₂ = 0.962	$\frac{133.4-128}{1.140-y_3}=\frac{133.4-124.}{1.140-0.84}$ y₁ = 0.961
Total ESAL	0.486 + 0.699 = 1.185	0.390 + 0.962 = 1.352	0.386 + 0.961 = 1.34

The assumptions in calculating distress were that 100 trucks per day, 6 days per week, use the road over a design life of 30 years. These results in the calculations for the total ESAL shown below. These values were then used as input in Circly 6.0 to calculate distress.

i. StormPav Green Pavements

$$^6/_7 \times 365 \times 30 \times 100 \times 1.347 = \mathbf{1{,}264{,}255}\ \mathbf{\mathit{ESAL}}$$

ii. Rigid Pavements

$$^6/_7 \times 365 \times 30 \times 100 \times 1.352 = \mathbf{1{,}268{,}949}\ \mathbf{\mathit{ESAL}}$$

iii. Flexible Pavements

$$^6/_7 \times 365 \times 30 \times 100 \times 1.185 = \mathbf{1{,}112{,}207}\ \mathbf{\mathit{ESAL}}$$

3.2 Maximum Deflections

The excessive load from heavy vehicles which cause the pavement to deflect may produce a distress. Maximum deflection was determined using a model of the tandem axle dual wheel load of a trailer as shown in Fig. 4. This is greater than a drive single axle single wheel load and is 128kN per axle. Details of tire characteristics are listed in Table 8. WinJULEA software was used to obtain the amount of pavement surface deflection due to the loads and different tire pressures inputted from this data. These values are shown in Figs. 5, 6 and 7.

Table 8. Detail of Tandem Axle Load Tire

Tyre Size	254mm
Dual Tyre Spacing (centre-to-centre)	330mm
Tandem Axle Spacing	155cm

Source: Haron, Arshad & Rahman [2]

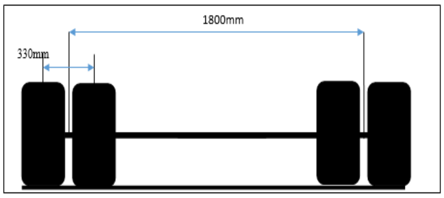

Fig. 4 Dual Wheel Tandem Axle Used in the Analysis

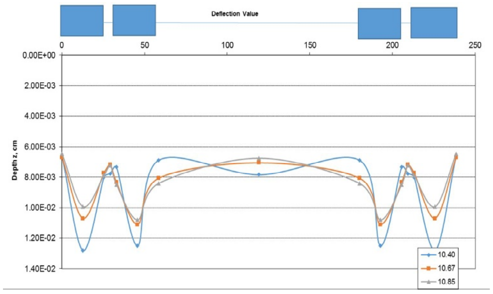

Fig. 5 Surface deflection with different tyre pressure (Flexible Pavement)

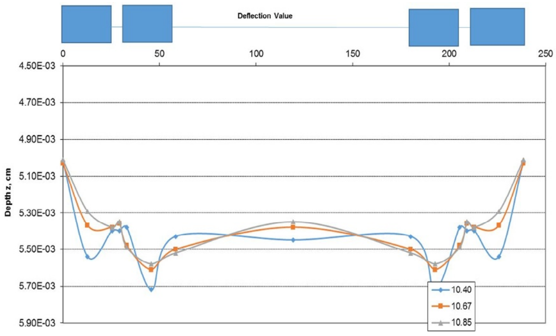

Fig. 6 Surface deflection with different tire pressure (Rigid Pavement)

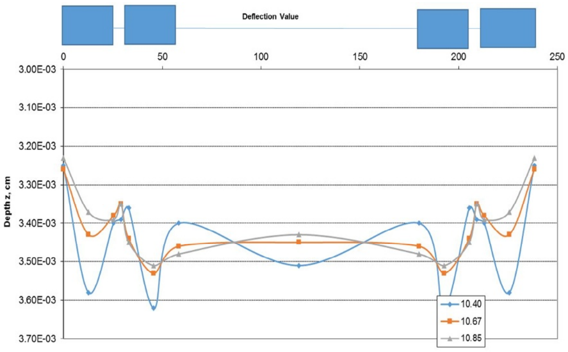

Fig. 7 Surface deflection with different tire pressure (StormPav GP)

On all three pavements, the lowest deflection occurs with larger contact radius (10.85 cm). It appears that elastic modulus of the pavement is a large influence on deflection. As StormPav GP base layer has the largest elastic modulus, it showed less deflection than the other two pavements. Table 9 shows the maximum deflection of each type of pavement with a contact radius of 10.40 cm and the reduction of deflections compared to the flexible pavement.

Table 9. Maximum Deflections of Pavement (For Contact Radius 104.0 mm)

Type of Pavements	Percent reduction (%)	Max. Deflections. (mm)
Flexible Pavement	0	0.1280
Rigid Pavement	55.3	0.0572
StormPav GP	71.7	0.0362

3.3 Allowable number of repetitions for fatigue failure

The allowable load repetitions for different types of pavement were calculated using Eq.1, Eq.2 and Eq. 3 for flexible pavement and Eq. 4 and Eq. 5 for rigid pavement and StormPav GP. A summary of the results is shown in Table 10.

The number of load repetitions to fatigue failure is more than an order of magnitude higher in the StormPav GP than in the other pavement types. The high elastic modulus of the pavement layer results in a decrease in the strain so significantly reducing the fatigue in the pavement. Thickness also affects fatigue, pavement with a thicker base or subbase also reduces stress due to the larger pavement layer area [13].

Table 10. Allowable Number of Repetitions to Rigid Fatigue

Structure	Repetitions to Rigid Fatigue
Flexible Pavement	1.67×10^6
Rigid Pavement	7.62×10^6
StormPav Green Pavement	4.17×10^8

3.4 WinJULEA, KenPave and Circly 6.0 Results

The findings from the use of this software modeling are as follows:

a. Distress modeling using WinJULEA demonstrates that deflection of the surface pavement is a function of tire pressure and contact radius. Lower pressure and large contact radius produce fewer deflection and thus a decrease in distress occurrence. StormPav GP surface showed the least deflection due to the material used having a higher elastic modulus. KenPave analysis shows that the stresses and strain initiated by the loads acting on the pavement are affected by the depth of the pavement. Stress and strain decrease with increasing the depth and increasing with a higher elastic modulus.
b. The repetition of loads acting on the surface affects the performance of each pavement to different degrees. StormPav GP shows the least stress, strain and has a far higher number of allowable repetition loads than the other two pavements. This indicates a higher ability to withstand damage.
c. Less time required to install StormPav GP than tradition pavements. The components may be produced on a large scale in a factory or construction site ensuring strict quality control. This prefabrication means that StormPav installation is fast and independent of weather conditions.

Thus, it can be concluded that Stormpav GP pavement is an innovative and environmentally friendly pavement because it still maintains the process of absorbing rainwater into the ground.

4 Conclusions

This research has compared the performance of the StormPav GP with both rigid and flexible pavement, thus can be concluded as follows,

1. The deflection of the surface pavement is influenced by the tire pressure and contact radius.
2. The interlocking joints and monolithic modules of StormPav GP construction ensure uniform settlement, that results in the pavement responding as one platform.
3. The concrete used in StormPav GP has a higher elastic modulus and shear modulus than the materials used in rigid pavement or the bitumen used in flexible pavement.

These features indicate StormPav GP is a superior type of pavement for urban roading infrastructure.

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