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Sensitivity analysis of stormpav composite pavement

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Abstract. This study investigates the design and performance of modified composite pavement called StormPav. In this study, the sensitivity analysis is carried out by using available freeware to prove whether the StormPav composite pavement is able to provide long-life pavement and better levels of performance, both structural and functionally, than the traditional pavements. For this case, the sensitivity analysis is included data for fatigue behavior, rutting in the HMA (Hot Mix Asphalt) layer, and temperature gradient reduction of PCC slab with an HMA overlay. The StormPav composite pavement is actually an innovation IBS green pavement with structural, environmental and economic advantages. Inspired from Legos concept, the StormPav is made out of modular panels or "roadblocks" that are like enormous lego pieces that assemble and interlocking together forming a uniform settlement and at the same time acting as the monolithic character. The idea of StormPav is actually to minimize the usage of material in the composite pavement but provide the same strength and benefits as composite pavement.

1. Introduction

It is undeniable that pavements play an essential part of our daily life as we use them as roads, runways, parking lots and driveways. Like any other engineered structure, pavements are expected to be adequately strong and durable for their design life. Especially when it is related to highway, they are expected to function properly under heavy load and high speed as well as with smooth traveling experience under the various condition of the environment. Unfortunately, transportation agencies and the road building industry of worldwide have designed and used the same traditional pavement system over the years which are no longer competent to withstand the developing and increasing use of traffic nowadays. The two types of traditional pavements are flexible (asphalt) and rigid (concrete) pavement.

Conventional composite pavements generally consist of two parts: rigid base and asphalt surface. With their excellent pavement performance, composite pavements have shown great potential to become a promising alternative for sustainable pavement under heavy traffic [13]. Although there are two different types of pavement design systems which are conventionally used in the construction of roadways such as flexible and rigid pavement, the performances of both rigid and flexible pavements do not provide outstanding quality as composite pavements. There is another alternative pavement which is conventional composite pavements that have been proved to provide better levels of performance, both structurally and functionally, than the traditional pavement designs [3][11]. The conventional composite pavement is however considered expensive and is rarely used as new

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construction [2][4][12]. Hence, in this study, a new design concept of composite pavement will be introduced, and this new product is called StormPav composite pavement.

The StormPav composite pavement is an innovative IBS green product placed underneath hot mix asphalt (HMA) acting as a high stiff, rigid base with structural, environmental and economic advantages. Inspired from Legos concept, the StormPav is made out of modular panels or "roadblocks" that are like enormous Lego pieces that assemble and interlocking together forming a uniform settlement and at the same time acting as the monolithic character. The idea of StormPav is actually to minimize the usage of material in the composite pavement but provide the same strength and benefits as composite pavement.

2. Literature Review

Reflective cracks are cracks that occur in the asphalt surface course of the composite pavement system and that coincide with cracks of appreciable width or joints in the underlying layers; they are caused by relative horizontal and vertical movements of these cracks or joints caused by temperature cycles and/or traffic loading [6][9][14]. In general, a conventional composite pavement is a combination of flexible and rigid layer where a flexible layer (top-most layer) over a rigid layer. The flexible (asphalt) layer provides a smooth, safe, and quiet driving surface, whereas the rigid continuously reinforced concrete pavement provides a stiff and strong base [5].

StormPav composite pavement is an innovative IBS green product placed underneath hot mix asphalt (HMA) acting as a high stiff, rigid base with structural, environmental and economic advantages. Inspired by Legos concept, the StormPavmade out of modular panels or "roadblocks" that are like enormous Lego pieces that assemble and interlocking together forming a uniform settlement. Each unit of a "roadblock" structure is made up of 1 m^3 of concrete which consist of two components of precast concrete as shown in Figures 1 and Figure 2.

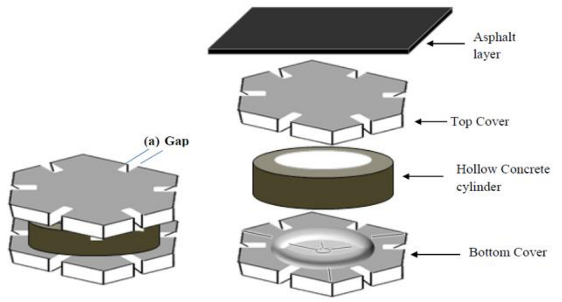

Figure 1. Illustrates main components of StormPav Composite pavement

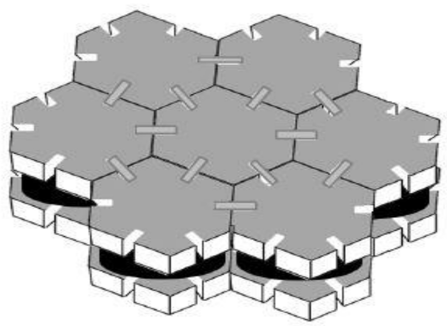

Figure 2. Illustrates A few units of StormPav Composite Pavement assembled together as a system (Lego-like system)

The first component is the cover concrete **(1);** reinforced precast hexagonal concrete panel. The cover concrete will be covering the hollow cylinder concrete top and bottom. Six intermediate rectangular gaps **(a)** at the edge of each side will provide the interlocking space. The gaps will be filled with cast in-situ concrete as interlocking concrete for the pavement. The second component is the body **(2);** The unreinforced precast hollow cylinder concrete to provide structural support to the reinforced top and bottom cover. This structure is actually acting as a rigid base. Then, a thin layer of asphalt is placed over a concrete surface to provide a smoother ride. Figure 3 shows the dimension of the StormPav composite pavement.

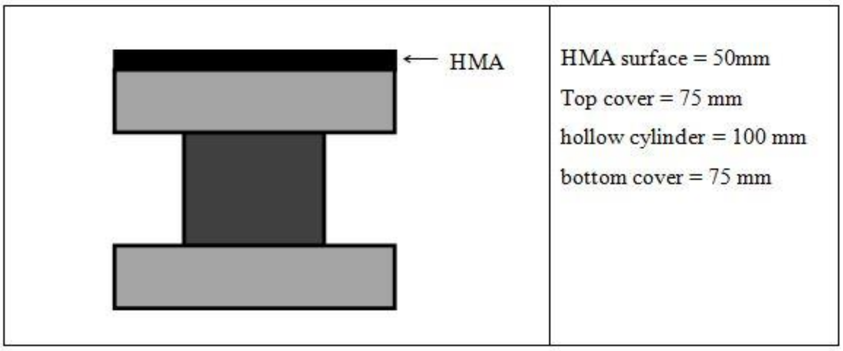

Figure 3. Illustrates the dimension of StormPav's component

The idea of StormPav is actually to minimize the usage of material in the composite pavement but provide the same strength and benefits as composite pavement. IBS StromPav composite pavement is combining the most desirable characteristic of both traditional pavements to act like concrete but to be easily maintained like asphalt concrete just like conventional composite pavement system.

The other benefits that IBS StormPav Composite pavement can provide are:

- Good levels of the rideability of the pavement and driver comfort by providing a smooth and quiet driving surface
- Strong support to the flexible layer provided by the rigid base layer
- Adequate pavement surface friction properties
- StrormPav that assembled as a rigid base having high stiffness provides strong to HMA overlay.
- Potential to provide both excellent surface properties (low noise, non-polishing aggregates, and durability) and long life structural capacity for any level of traffic.
- Prevention of the intrusion surface water to the rigid base due to the protection provided by the asphalt layer.
- Surfacing to be with high-quality and relatively thin HMA. The minimum thickness of HMA layer to be based on material with aggregate gradation and structure, binder types, etc.
- Reduction of the temperature gradient in the rigid layer because of the insulation provided by the overlying asphalt surface layer.
- Rapid and simple installation of StormPav as the structures is a precast product
- Development of traffic-load-induced critical tensile-stress at the bottom of rigid base thus providing compression mode in HMA.

3. Methodology

The sensitivity analyses included the variation of different parameters that were plotted against the results obtained for the various composite pavement systems [10]. In this case, the sensitivity analysis covered on the fatigue behavior, rutting in the HMA layer, reflective cracking, and temperature gradient reduction of a PCC slab with an HMA overlay.

The freeware used to analyse the data is “AASHTO_Rigid spreadsheet" freeware, an excel tool developed by HMA Long-term pavement performance (LTTP) program to supplement the AASHTO pavement rigid design system, was used to model the performance of StromPav [1]

Table 1. Parameters used for the design of composite structure

Parameter		Typical Value
Design life		40 years
Reliability		95%
Traffic		50 000 000 ESALs
		58230 ADT
		12% trucks
Present Serviceability Index (PSI)		
	Initial	4.5
	Final	3.0
Note:		
ESAL = equivalent single-axel load		
ADT = annual daily traffic		

In order to compare the performance analysis or output using AASHTO_Rigid spreadsheet, it was very important to design the composite pavement systems so that some constant criteria were used throughout the analysis. Since StormPav (Tables A.1 to A.3 and Figures A.1 to A.5) is a new product of conventional composite pavement, the design procedures were followed to design composite pavement structures based on the same input parameters such as traffic and design life which is from various agencies as mention previously. The parameters used are as followed as Orlando Nunez (2007) recommended are shown in Table 1 and Table 2 shows the typical values used for the material properties of each layer used in composite pavement structures [4][7][10], as well as Table 3 shown the materials properties used for StormPav.

Table 2. Typical materials properties for the composite pavement layers

Layer No.	Materials	Elastic Modulus (psi)	Poisson's Ration	Modulus of Rupture (psi)
1	HMA	500000	0.35	-
2	PCC	4000000	0.15	650
	RCC	3500000	0.15	600
	Lean mix concrete	2000000	0.15	450
	CTB	1000000	0.20	200
	Soil Cement	500000	0.35	100
3	Subbase	20000	0.40	-
	Granular base	30000	0.35	-
4	Subgrade	7500	0.40	-

Table 3. The materials properties used for StormPav.

Layer. no	Materials	Elastic Modulus(psi)	Poisson's Ration	Modulus of Rupture(psi)
1	HMA	500000	0.35	-
2	Self-compacting concrete (Grade 50)	5366.4	0.15	884.7
3	Subgrade	7500	0.40	-

However, for analysis of temperature gradient reduction of a rigid slab with an HMA overlay, two equation is used which is obtained in the [8], the study were derived as a function of the thickness of the asphalt layer for both a dense asphalt concrete surface and a porous asphalt concrete surface.

High HMA layer: $\lambda = 1.43 - (0.114 \times h_p) + (0.00316 \times h_p^{2})$ (1)

Low HMA layer: $\lambda = 1.41 - (0.118 \times h_p) + (0.00339 \times h_p^{2})$ (2)

where,

λ = Reduction factor
h_p = thickness of asphalt surface course (cm)

Only StormPav and Conventional Composite Pavement are being compared for this part. Since the thickness of asphalt conventional composite pavement is greater than StromPav, thus to calculate the reduction factor for HMA layer for conventional composite pavement is using equations (1) and StormPav is using equation (2). The thickness of the asphalt surface course varies 4 cm to 10 cm is used in both equations. The calculation is as followed.

Conventional Composite Pavement:

(1). h_p= 4 cm $\lambda = 1.43 - (0.114 \times h_p) + (0.00316 \times h_p^{2})$
$\lambda = 1.43 - (0.114 \times 4) + (0.00316 \times 4^{2})$
$\lambda = 1.02$

(2). h_p= 6 cm $\lambda = 1.43 - (0.114 \times h_p) + (0.00316 \times h_p^{2})$
$\lambda = 1.43 - (0.114 \times 6) + (0.00316 \times 6^{2})$
$\lambda = 0.86$

(3). h_p= 8 cm $\lambda = 1.43 - (0.114 \times h_p) + (0.00316 \times h_p^{2})$
$\lambda = 1.43 - (0.114 \times 8) + (0.00316 \times 8^{2})$
$\lambda = 0.72$

(4). h_p= 10 cm $\lambda = 1.43 - (0.114 \times h_p) + (0.00316 \times h_p^{2})$
$\lambda = 1.43 - (0.114 \times 10) + (0.00316 \times 10^{2})$
$\lambda = 0.606$

StormPav Composite Pavement:

(1). h_p= 4 cm$\lambda = 1.41 - (0.118 \times h_p) + (0.00339 \times h_p^{2})$
$\lambda = 1.41 - (0.118 \times 4) + (0.00339 \times 4^{2})$
$\lambda = 0.99$

(2). h_p= 6 cm $\lambda = 1.41 - (0.118 \times h_p) + (0.00339 \times h_p^{2})$
$\lambda = 1.41 - (0.118 \times 6) + (0.00339 \times 6^{2})$
$\lambda = 0.82$

(3). h_p= 8 cm $\lambda = 1.41 - (0.118 \times h_p) + (0.00339 \times h_p^{2})$
$\lambda = 1.41 - (0.118 \times 8) + (0.00339 \times 8^{2})$
$\lambda = 0.68$

(4). h_p= 10 cm $\lambda = 1.41 - (0.118 \times h_p) + (0.00339 \times h_p^{2})$
$\lambda = 1.41 - (0.118 \times 10) + (0.00339 \times 10^{2})$
$\lambda = 0.569$

This part presents the result for sensitivity analysis of different pavement types which are StormPav Composite Pavement, flexible pavement, rigid pavement, and conventional composite pavement. It attempts to analyse the result obtained and reported them in the graphical and tabular format as shown below.

3.1. Fatigue Behaviour

The reduction in stresses at the bottom of the rigid layer is apparent as shown in Figure 4. The use of a thicker layer thickness would significantly increase the fatigue life of the base. A stress-ratio plot,

Figure 5 was created to show how the stress ratio would change as the thickness of the rigid base layer increases. From the graph, it is shown that the StromPav has the longest fatigue life than rigid and conventional composite pavement. Although StormPav has fewer layers and thinnest PCC base, compare to these two pavements, but yet the StormPav produce less stress at the bottom layer. This is the advantage monolithic characteristic of StormPav where it is able to develop of traffic-load-induced critical tensile-stress at the bottom of rigid base thus providing compression made in HMA. Preservation of the structural integrity of rigid base ensuring long-life of the pavement.

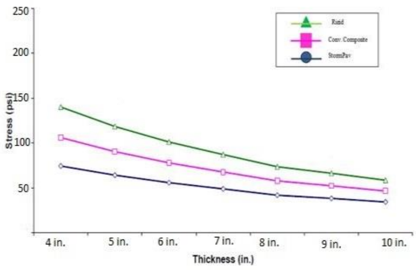

Figure 4. Tensile stresses at the bottom of various rigid layer thicknesses

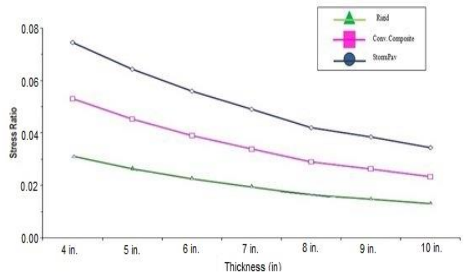

Figure 5. Stress ratio of the rigid pavement at various thicknesse

3.2 Rutting

Figure 6 shows that how severe the rut depth for each pavement under certain ESALs value. As the number of load repetitions increased, greater rut depths were computed in the HMA layer. It is found that the rut depth of StormPav is still under 0.5 inch although it reaches 70,000,000 ESALs, whereby conventional composite and flexible pavement are already under the critical value of rut depth even before they even reach 50,000,000 ESALs. This was an expected outcome because the high rigidity of the base does not allow any significant vertical deformation to occur. Thus, the HMA layer absorbs all the vertical strains and deforms itself. Since StorrmPav is made of Self-compacting concrete (grade 50), therefore StormPav has better rigidity compared to those two pavements.

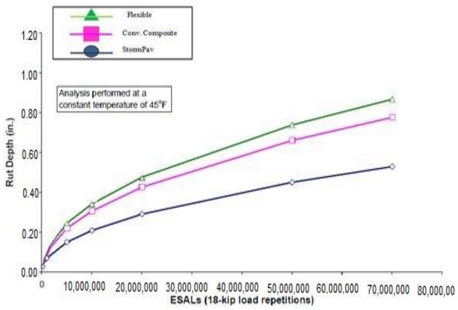

Figure 6. - Rut depth in HMA layer using various pavement at different load repetitions

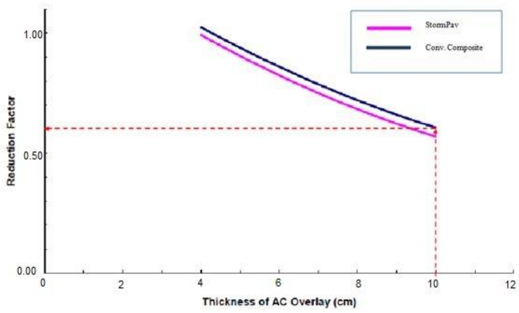

Figure 7. Reduction factor of temperature gradient using various overlay thicknesses

3.3 Temperature Gradient reduction

Figure 7 shows a sensitivity analysis involving the increment of the thickness of the HMA layer and the reduction factor magnitude for the temperature gradient of a concrete slab. This shows that the reduction factor for StromPav is smaller than conventional composite pavement. The hollow cylinder of StromPav provides ventilation and cooling system within the StromPav make it able to withstand the high temperature.

3.4 Summary

From the result, the summary is made as shown in Table 4. The StormPav has the best resistance to rutting/deformation followed by rigid and conventional composite pavement then lastly flexible pavement. For lifespan, StormPav has the greater lifespan followed by conventional composite, rigid and flexible pavements. Therefore, in term of maintenance and cost, StromPav is able to provide the easiest and low maintenance cost followed by both rigid and conventional composite which are provided easy maintenance with low cost, lastly flexible pavement provides the difficult and high maintenance cost. Whereby, the reduction factor of the temperature gradient between conventional composite and StormPav composite pavement, it is shown that StromPav is able to provide a lower temperature gradient reduction than conventional composite pavement.

Table 4. Summary of result analysis

Compared Properties	Flexible Pavement	Rigid Pavement (PCC)	Conventional Composite Pavement	StormPav Composite Pavement
Resistance to rutting/ deformation	-	Poor	Good	Very good
Lifespan	Lower	High	Higher	Highest
Maintenance and cost	Difficult and high maintenance cost	Easy and low maintenance cost	Easy and low maintenance cost	Easiest and lowest maintenance cost
Reduction Factor at 10 cm Thickness	-	-	Low	Lowest

4. Conclusions

Based on the result presented previously, the conclusions of the sensitivity analysis of the StormPav Composite pavement are drawn as followed:

- From fatigue behaviour analysis, it was found that the StormPav composite pavement has the longest fatigue life compared to traditional pavements which are rigid and conventional composite pavement.
- For resistance to rutting or deformation analysis, StormPav has the best resistance behaviour among other pavements; the unique structure and monolithic characteristic of StormPav are the main contributions.
- The temperature gradient reduction of StormPav with HMA layer is smaller than conventional composite pavement with HMA layer, which means that StormPav has bigger resilience toward heat or high temperature compared to conventional composite pavement. In other words, StormPav indeed has more advantages than typical composite pavement.

Therefore, from these outstanding performance and result of sensitivity analysis, the StormPav composite pavement system has proven to have the potential to become a cost-effective pavement. Nevertheless, this new technology is still under research and adapting to industry standard. There are limitations to this technology, and it should only be used in appropriate situations. For example, StormPav composite pavement is not suitable for installation on the hilly road. The benefits, however, are clear. This technology allows for strong performance, provides the smoothness and sound control that a full HMA pavement has as well as still contribute to the same benefit as composite pavement and strength but able to minimize the usage of materials in the composite pavement. It is also easier to maintain and allows for the more recycled product to be used in the PCC base. It will likely be a technology that society will see implemented more and more in the future

Acknowledgment

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5. References

[1] AASHTO. (1993). ASSHTO Guideline for Design of Pavement Structures, American Association of State Highway and Transporation Officials, Washington, D.C

[2] Dong Qing Wu, Daud, Yanli Zhang (2011). Semi-rigid pavement with higher performances for road and parking aprons. Chemilink Technologies Group, Singapore

[3] Hein, D. K., Olidis, C., Magni, E., and MacRae, D. (2002). "A method for the investigation and validation of composite pavement performance including the use of the falling weight deflectometer." *Pavement Evaluation 2002--A Joint Conference of the FWD and RoadProfilers User Groups*, Roanoke.

[4] Huang, Y. H. (2004). *Pavement Analysis and Design*, Pearson Prentice Hall, Upper Saddle.

[5] Kumar, Paveen, Sachin Dass, Ankit Sharma (2013). Guidelines on Composite Pavement- Design and Evaluation of Composite pavements, Department of Civil Engineering, Deenbandhu Chhotu Ram University of Science and Technology, India.

[6] Mukhtar, M. T., and Dempsey, B. J. (1996). "Interlayer stress absorbing composite (ISAC) for mitigating reflection cracking in asphalt concrete overlays." *UILU-ENG-96-2006*, Illinois Cooperative Highway Research Program Series 260.

[7] NCHRP. (2004). *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures - NCHRP 1-37A*, National Cooperative Highway Research Program(NCHRP), Champaign, Illinois.

[8] Nishizawa, T., Shimeo, S., Komatsubara, A., and Koyanagawa, M. (2000). "Temperature gradient of concrete pavement slab overlaid with asphalt surface course." *Transportation Research Record*, 1730.

[9] Oowusu-Antwi, E. B., Khazanovich, L., and Titus-Glover, L. (1998). "Mechanistic-based model for predicting reflective cracking in asphalt concrete-overlaid pavements." *Transportation Research Record*, 1629, 234-241.

[10] Orlando Nunez, 2007, Composite Pavements: A Technical and Economic Analysis During the Pavement Type Selection Process Thesis. Graduate Research AssistantCenter for Safe and Sustainable Infrastructure Virginia Tech Transportation Institute

[11] Parry, A. R., Phillips, S. J., Potter, J. F., and Nunn, M. E. (1999). "Design and performance of flexible composite road pavements." *The Proceedings of the Institution of Civil Engineersand Transportation*, 135, Crowthorne, England, U.K.

[12] River, NJ.Russel W. Lenz (2011). *Pavement Design Guide. Retrieved from* http://onlinemanuals.txdot.gov/txdotmanuals/pdm/introduction

[13] Sheng Li, You Huang, Zhao-hui (2015). "Experimental Evaluation of asphalt material for interlayer in the rigid-flexible composite pavement, Changsha University of Science and Technology, Changsha, Hunan, China.

[14] Von Quintus, H. L., Finn, F. N., Hudson, W. R., and Roberts, F. L. (1979). "Flexible and composite structures for premium pavements--Volume 1 and 2. Federal Highway Administration (FHWA), U.S. Department of Transportation, Washington, D.C

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Appendix A:

	Description	Features
1	Number of the unit made using $1m^3$ of 50MPa concrete (Grade50)	34 units
2	Area coverage with 34 units	$5.7m^2$ pavement area
3	Units required for $1m^2$ pavement area	6 units
4	Total pavement thickness including 50mm HMA	300mm thick
5	Crushing load of StormPav	100 to 130 kN/unit, more than 40kN/single wheel of 80kN standard axle load
6	StormPav is an IBS green product placed underneath hot-mix asphalt (HMA) acting as a rigid base with structural, environmental and economic advantages	
7	Providing uniform load distribution through interlocking and monolithic characters	
8	StormPav as precast made with fiber reinforced concrete, HMA as cast in-situ	
9	Reduction of the temperature gradient in the rigid base due to overlaying with HMA layer	
10	Development of traffic-load-induced critical tensile-stress at the bottom of rigid base thus providing compression mode in HMA	
11	Earning LEEDS and GBI for Township credit points	
12	StormPavInstallation: Rapid and simple	
13	Suitable for any road construction	

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Table A.2. Technical features of StormPav composite pavement

Description	Conventional Flexible Pavement	StormPav Composite Pavement
Type of Fabrication	Made in-situ with solid form	Precast solid and hollow blocks
Machine production	No	Yes
Material Type	Granular materials	Fibre reinforced concrete
Flexural Strength	Low or Negligible	High flexural strength
Wheel Load Transfer	Grain to Grain contact	Beam action
Excessive Loading	Local depression resulting in rutting etc	Failure if load more than 100kN/unit
Load-induced Stress	Transmit vertical & compressive stresses to lower layers	Tensile stress only
Thermal stress development	No	No
Strength of Road	Highly dependent on Subgrade strength	Less dependent on the strength of subgrade
Load-induced Subgrade Deformation	Yes, transfer to the upper layer	No
Pavement Settlement	Differential	Uniform
The initial investment for the heavy loaded road from sub base to wearing course	[800mm thick=RM240/m^2 area]	[Material cost = RM120/m^2 area]
Repair cost	Very frequent repair	Minimum
Material consumption for heavy loaded road	[800mm thick=1,560kg/m^2 area]	[420 kg concrete/m^2 area, HMA excluded]
Speed of construction	Slow [several layers]	Rapid [precast system]
Machinery involvement in the construction	Several heavy types of machinery	Light equipment for lifting & installation
Skilled workers involved in the construction	Yes	10m^2 pavement area/hour by three workers
Opening to Traffic	Few hours	1-hour [excluding HMA]
Pavement Repair	Slow	Rapid [precast system]
Cost and Time Effective	No	Yes

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Table A.3. Green building features of StormPav composite pavement

Description	Conventional Flexible Pavement	StormPav Composite Pavement
U.S. Green Building Council's Leadership in Energy & Environmental Design (LEED)		
- Sustainable Sites (Credit 6.1)	No	Yes
IBS concrete products for otherenvironmental benefits, such as reducing heat island effects (Sustainable Site Credit 7.1)	No	Yes
- Regional materials (Materials & Resources Credit 5)	Yes	Yes
Green Building Index, GBI, for Township		
- Heat Island design principles (CEW1, 4)	No	Yes
- Health design (CPD6, 2)	No	Yes
- Low impact material (BDR1, 1)	No	Yes
- Regional material (BDR3, 1)	No	Yes
- Quality in construction (BDR4, 2)	No	Yes
- Sustainable construction practice (BDR7, 2)	No	Yes
- Innovation (BSI2, 6)	No	Yes

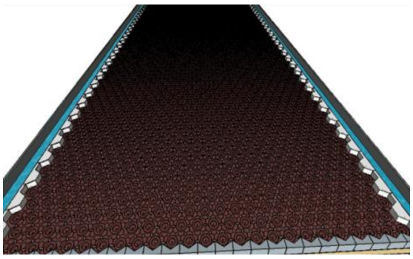

Figure A.1. Base blocks installation (conceptual)

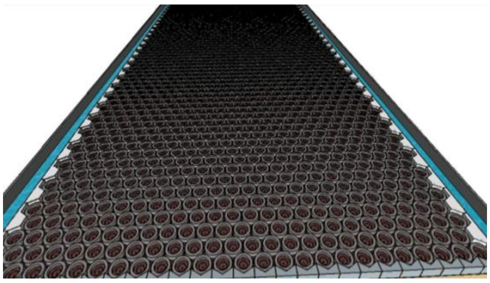

Figure A.2. Hollow cylinder installation (conceptual)

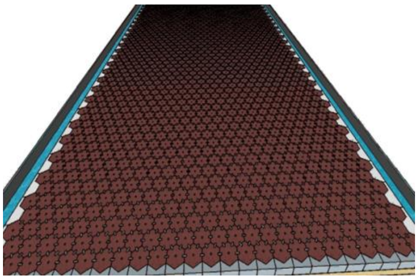

Figure A.3. Top blocks installation (conceptual)

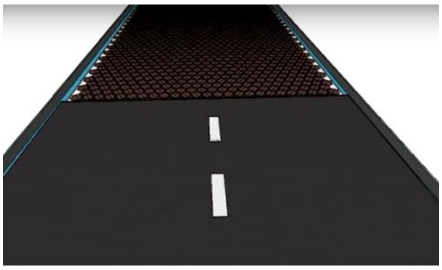

Figure A.4. HMA as cast in-situ for the top layer (conceptual)

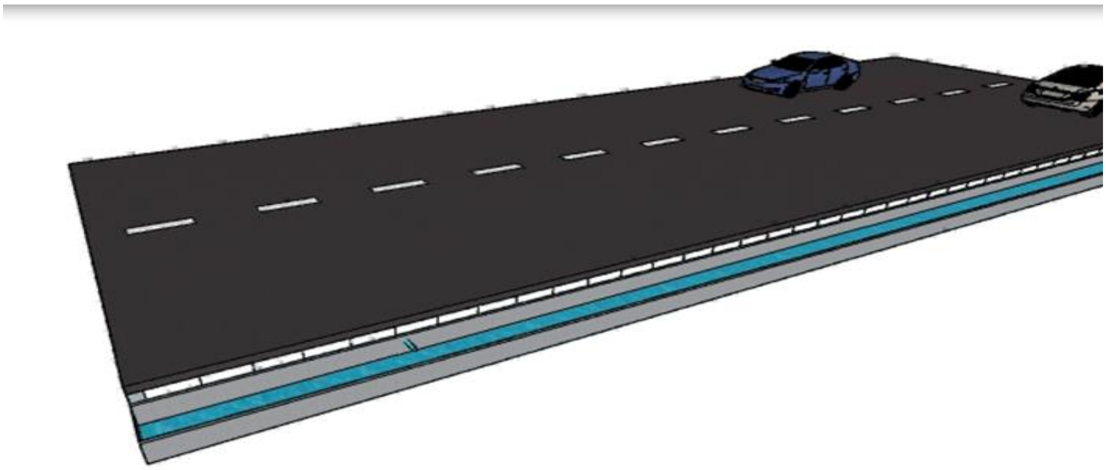

Figure A.5. Finished road (conceptual)