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Finite Element Model for Prediction of Highway Pavement Deformation

Ezeokpube, Gregory Chukwuemeka

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Abstract

The determination of stresses developed in a pavement constitutes a basic prerequisite and is achieved mainly by implementation of various methods which is dependent on the number of distinct pavement layers. The need to predict the deformation of highway pavement with a precision that will aid optimal design cannot be oversized. Boussinesq?s work was foundational for the development of all subsequent elasticity theories, but Boussinesq assumed one layer of uniform subgrade material. In this research, a mechanistic elastic model for obtaining deformation in road pavement was derived using Finite Element Method (FEM). This model was found to be an improvement on the Boussinesq model owing to the closeness of its result to that obtained from Plaxis software. In addition to this, it has the capability of handling deformation in both flexible and rigid pavement utilizing the dimensional similarities between unit weight and modulus of subgrade reaction of soil. A MATLAB program was also written for easy computation using the new model.

Index terms— pavement deformation; finite element model; boussinesq?s model; MATLAB program.

1 I. Introduction a) Causes of Pavement Deformation in Highway

Pavement eformation of highway pavement can be occasioned by weak soils [1][2], frost action [3][4], expansive soils [5], Unbound aggregate material [6], seasonal drying and wetting [7]. Deformation can also result from thermal stresses [8], differential subgrade settlement [10], and aggregate morphology [11][12].

2 b) Methods of Analysis of Highway Pavement

Boussinesq's work was foundational for the development of all subsequent elasticity theories. Boussinesq's theory assumed one layer of uniform and homogenous subgrade material. According to [13], the stresses applied to an elastic homogenous and isotropic material extended to infinity at both directions, (horizontal and vertical) and the stress developed at any depth, z, below the surface of the pavement under the influence of a point load in Figure **??** can be calculated thus:

Vertical stress,? ?? = 3?? 2?? . ?? 3 ?? 5 (1)

After the pioneering work of Boussinesq, different methods of analysis have been used in obtaining stresses and the accompanying deformation in highway pavement. Behera (2013) [14] used linear elastic theory in analyzing the deformation behaviour of fly ash composite material in the subbase of surface coal mine haul road. Uzan (2004) [15] applied the mechanistic framework in determining the permanent deformation of flexible pavement. Du and Dai (2006) [16] utilized the dynamic stability evaluation index in analyzing permanent deformation. It was discovered that the method is not fit for evaluating permanent deformation of asphalt mixture. Tchemou et al. 2011 [17] and Qiao et al. 2015 [18] applied rutting mechanisms in predicting flexible pavement degradation, [19] used model simulation in determining permanent deformation in high-modulus asphalt having sloped and horizontally curved alignment. Du and Shen (2005) [20] applied grey modelling method, [21] used field cores, and [22] used ground-penetrating-ladar in predicting the development of irrecoverable deformation in road pavement.

Sawant (2009) [23] used dynamic analysis whereas [24] used the back-calculation of the transition probability approach. Each group of researchers demonstrated the merit of their method.

Many researchers have applied finite element method (FEM) in the analysis of deformation in highway pavement [25][26][27][28]. He et al. (2008) [29] used 3D viscoelastic finite element analysis (FEA) in determining asphalt pavement rutting deformation. Kim et. al. (2014) [30] used FEM in modelling the effect of environmental factors on rigid pavement deformation. In analyzing the influence of asphalt deformation under heterogeneous settlement of roadbed whereas [31] used elastic-plastic dynamic FEM to compute the differential settlement of the half-filled and half dug embankment under axle load. The latter succeeded in deriving a model for computing critical differential settlement. Each of the models is unique depending on the assumptions made by each group of researchers. **??**adek and Shahrour (2007) [32] compared Boussinesq's model with the occasional plastic nature of subgrade and pavement materials. The researchers model was shown to be an improvement on Boussinesq's model.

3 II. Purpose

This work involves the finite element method for predicting pavement deformation. Each model cited is derived either for rigid pavement and flexible pavement. However, this model is also unique owing to assumptions and approach was derived to handle both rigid and flexible pavement. Secondly, according to [33], many models used in the structural design of pavements are complex and/or difficult to use in the field, making its application in pavement analysis rather difficult. This model is devoid of such complexities.

4 III. Methodology a) Derivation of the New Model i. Model Assumption

In the derivation of the new model for deformation behaviour, the following assumptions were made;

1. Loading is symmetrical 2. Soil is elastic, homogenous and isotropic 3. The principle of superposition is valid 4. Constitutive law is valid 5. The idealized system of pavement structure is treated as a beam on elastic subgrade 6. The UDL from asphaltic concrete is converted to point load to produce the worst deformation needed for optimal design. 7. The problem is two-dimensional.

ii. Model Derivation A road of base course thickness ?? ?? , asphaltic concrete (AC) thickness as ?? ?? , and width l is subjected to a standard axle load ?? ?? as shown in Figure **??**0. To determine the total stricture stiffness matrix for a spring assemblage by using the force/displacement matrix relation of FEM, the model is discretized into nodes and element as shown in Figure 3. **??**3) is obtained.???? ?? 3 (1+? ??) ? 12 6?? ?12 6?? 6?? (4 + ? ??)?? 2 ?6?? (2 ? ? ??)?? 2 ?12 ?6?? 12 ?6?? 6?? (2 ? ?)?? 2 ?6?? (4 + ? ??)?? 2 ? ? ?? 1 ?? ? 1 ?? 2 ?? ? 2 = 0 ? = ? ? ? ?? 1 ?? 0 ???? +?? 2 ???? ?? 2 0 ? ? ? (6) K 2 1 2 3 (1) 0 K 1 ???? + ?? 2 ?? ?? ?**(2)**

(1) ???? + ?? 2 ?? ?? ? 2 2 L 1 1 l List of Abbreviations ? z = Vertical Stress Q = Vertical Load Z = Vertical Load R =

5 Highlights

? The need to predict the deformation of highway pavement with a precision that will aid optimal design cannot be overemphasized. Applying the boundary condition ?? 1 ?? = 0 = ? 2 ????????????????? using the 2 nd and 3 rd row of equation 13 whose rows are associated with the two unknowns, ? 1 and ?? 2 ?? and simplifying, we obtain; (7) ?? 2 ?? = (???? + ?? 2 ?? ?? ?)(4 + ? ??)?? 3 24???? For long slender beams with L about 10 times or more, the beam depth, shear correction term ? ?? is small and can be neglected [34]. For standard highway, L=7.

6 IV. Conclusion and Recommendation

Many roads fail even before their design lives, probably because of using conservative models in their design to save cost. The cost implication of early maintenance and/or rehabilitation implies that using conservative models is not economical in the real sense. This new model, being close with the result from plaxis software shows that it is an improvement on Boussinesq's model which is found to be conservative. Secondly, the dimensional uniformity between unit weight and modulus of subgrade reaction was utilized by the researchers in making it a flexible model that can handle deformation in both rigid and flexible road pavement unlike many existing models.

7 V. Declarations a) Ethical Approval and Consent to Participate

The research observed all ethical codes and done with the consent of all authors involved.

8 b) Consent for Publication

We give our Consent for the publication of the article.

9 c) Availability of Supporting Data Not applicable d) Code Availability

Not applicable e) Funding Not applicable [1]

[] , 10.1016/j.conbuildmat.2015.09.012. https://doi.org/10.1016/j.conbuildmat.2015.09.012

[Wang et al. ()] , G Wang , Y Wang , R Thompson , Y H Ahn . 2012.

[Peng et al. ()] , H Peng , W Ma , Y Mu , JinL . 2015. (Impact of)

[He et al. ()] '3D visco-elasto-plastic finite element analysis of the asphalt pavement rutting deformation'. Z He , T Lei , Chen H Wang , G Hou , YA . http://en.cnki.com.cn/Article_en/CJFDTotal-JIAN200806006.htm *Journal of Chogqing Jianzhu University* 2008.

[Tutumular and Pan ()] 'Aggregate morphology affecting strength and permanent deformation behavior of unbound aggregate materials'. E Tutumular , T Pan . 10.1061/(ASCE)0899-1561. *Journal of Materials in Civil Engineering* 2008. 200. 20 (9) p. 9.

[Tutumular and Pan ()] 'Aggregate morphology affecting strength and permanent deformation behavior of unbound aggregate materials'. E Tutumular , T Pan . 10.1061/(ASCE)0899-1561. *Journal of Materials in Civil Engineering* 2008. 200. 20 (9) p. 9.

[Tosti et al. ()] *An experimental-based model for the mechanical properties of rod pavements using ground-penetrating radar. Construction and Building Material*, F Tosti , L B Ciampoli , D 'amico , F Alani , A M Benedetto , A . 10.1016/j.conbuildmat.2018.01.179. https://doi.org/10.1016/j.conbuildmat.2018.01.179 2018. 165 p. .

[Nahi et al. ()] 'Analysis of asphalt pavement under non-uniform tire pavement contact stress using finite element method'. M N Nahi , A Ismail , A K Ariffin . 10.3923/jas.2011.2562.2569. *Journal Applied Sciences* 2011. 11 (1) p. .

[Abaza ()] 'Back-calculation of transition probabilities for Markovian-based pavement performance prediction model'. K Abaza . 10.1080/10298436.2014.993185. https://doi.org/10.1080/10298436.2014.993185 *International Journal of Pavement Engineering* 2016. 17 (3) p. .

[Qiao et al. ()] 'Calculating rutting of some thin flexible pavements from repeated load triaxial test data'. Y Qiao , A Dawson , Huvstig , L Korkiala-Tunttu . 10.1080/10298436.2014.943127. https://doi.org/10.1080/10298436.2014.943127 *International Journal of Pavement Engineering* 2015. 16 (6) p. .

[Li et al. ()] *Cause analysis on permanent deformation for asphalt pavement using field core. Construction and Building Material*, Q Li , H Yang , F Ni , X Ma , LuoL . 2015. 2015. 100 p. .

[Du and Shen ()] 'Development of pavement permanent deformation model by grey modelling method'. J C Du , D Shen . 121doi:10. 1080/10286600500126348. *Civil Engineering and Environmental System* 2005. 2005. 22 (2) p. 109.

[Sawant ()] 'Dynamic analysis of rigid pavement with vehicle pavement interaction'. V Sawant . org/10.1080/10298430802342716. *International Journal of Pavement Engineering* 2009. 10 (1) p. .

[Pan et al. ()] 'Effects of coarse aggregate morphology on permanent deformation behavior of hot mix asphalt'. T Pan , E Tutumuluer , S H Carepenter . 10.1061/(ASCE)0733-947X(2006)132:7. *Journal of Transportation Engineering* 2006. 132 (7) .

[Hossain et al. ()] *Expansive subgrade behavior on a state highway in North Texas. Geotechnical and Structure Congress*, S Hossain , S Ahmed , M S Khan , AramoonA . 10.1061/9780784479742.099. https://ascelibrary.org/doi/abs/10.1061/9780784479742.099 2016. Phoenix Arizona.

[Behera ()] *Experimental and numerical investigation into behavior of fly ash composite material in the Subbase of surface coal mine haul road*, B Behera . https://pdfs.semanticscholar.org/3e02/eb9d00 2013. National Institute of Technology India (Ph.D Thesis)

[Helway et al. ()] 'Finite element analyses of flexible pavement'. S Helway , J Dyer , J Leidy . 0733-947X(1998)124:5(491. https://ascelibrary.org/doi/abs/10.1061/ *Journal of Transportation Engineering* 1998. ASCE.

[Kim et al. ()] 'Finite element modeling of environmental effects on rigid pavement deformation'. S Kim , H Ceylan , K Gopalakrishnan . 10.1007/s11709-014-0254-x. https://link.springer.com/article/10.1007/s11709-014-0254-x *Frontiers of Structure and Civil Engineering* 2014. 8 p. .

[Logan ()] 'First Course in the finite element method'. D L Logan . *Cengage Learning. ISBN* 2012. 13 p. 68251.

[Wen et al. ()] 'Ground temperature and deformation laws of highway embankments in degenerative permafrost regions'. Z Wen , W Sheng , W Ma , Q Wu , J H Fang . http://en.cnki.com.cn/Article_en/CJFDTotal-YSLX200907024.htm *Chinese Journal of Rock Mechanics and Engineering* 2009.

[Jegede ()] 'Highway pavement failure induced by poor soil geotechnical properties along the F209 Okitipupa-Igbokoda highway'. G Jegede . 10.4314/ijs.v6i1.32121. *Ife Journal of Science* 2004. 6 (1) .

[Kanitpong et al. ()] 'Investigation on the effects of gradation and aggregate type to moisture damage of warm mix asphalt modified with sasobit'. K Kanitpong , N Charoentham , S Likitlersuang . 10.1080/10298436.2011.565058. https://doi.org/10.1080/10298436.2011.565058 *International Journal of Pavement Engineering* 2012. 144 (1) p. .

[Kanitpong et al. ()] ‘Investigation on the effects of gradation and aggregate type to moisture damage of warm mix asphalt modified with sasobit’. K Kanitpong , N Charoentham , S Likitlersuang . 10.1080/10298436.2011.565058. https://doi.org/10.1080/10298436.2011.565058 *International Journal of Pavement Engineering* 2012. 144 (1) p. .

[Ling et al. ()] ‘Laboratory performance of crumb rubber concrete block pavement’. T Ling , H Nor , M Hainin , A Chik . 10.1080/10298430802342740. https://doi.org/10.1080/10298430802342740 *International Journal of Pavement Engineering* 2009. 10 (5) p. .

[Long-life pavement design and construction-a case study The 9 th Asia Pasific Transportation Development Conference] ‘Long-life pavement design and construction-a case study’. *The 9 th Asia Pasific Transportation Development Conference*, p. .

[Weng and Zhang ()] ‘Nonlinear FEM analysis of influence of asphalt pavement under non-homogenous settlement of roadbed’. W Weng , X Zhang , ChenB , YanS . http://en.cnki.com.cn/Article_en/CJFDTotal-ZGGL200401003.htm *China Journal of Highway* 2004.

[Leiva-Villacorta et al. ()] ‘Permanent deformation and deflection relationship from pavement condition assessment’. F Leiva-Villacorta , A Vargas-Nordcbeck , J Agular-Moya . 10.1016/j.ijprt.2017.03.005. https://doi.org/10.1016/j.ijprt.2017.03.005 *International Journal of Pavement Research and Technology* 2017. 10 (4) p. .

[Du and Dai ()] ‘Permanent deformation evaluation index of asphalt mixture’. S Du , J Dai . http://en.cnki.com.cn/Article_en/CJFDTotal-ZGGL200605004.htm *China Journal of Highway and Transport* 2006. 19 (5) p. .

[Uzan ()] ‘Permanent deformation in flexible pavements’. J Uzan . 10.1061/(ASCE)0733-947X(2004. *Journal of Transportation Engineering* 2004. 130 (1) p. 1.

[Rahman and Erlingsson ()] ‘Predicting permanent deformation behavior of unbound granular materials’. M Rahman , S Erlingsson . 10.1080/10298436.2014.943209. https://doi.org/10.1080/10298436.2014.943209 *International Journal of Pavement Engineering* 2015. 16 (7) p. .

[Tchemou et al. ()] ‘Prediction of flexible pavement degradation: application to rutting in Cameroonian highway’. G Tchemou , L S Minsili , Mototemapa A M Eko , R Manguelle , JH . https://pdfs.semanticscholar.org/ba5c/2464c5782149d2864af8c5ac9f6261f172ea.pdf *Electronic Journal of Geotechnical Engineering* 2011. 16 p. .

[Zheng et al. ()] ‘Simulation of permanent deformation in high-modulus asphalt pavement with sloped and horizontally curved alignment’. M Zheng , L Han , C Wang , Z Xu , H Li , Q Ma . 10.3390/app7040331. https://doi.org/10.3390/app7040331 *Applied Sciences* 2017. 131 (1) p. .

[Garg ()] *Soil mechanics and foundation engineering*, S K Garg . 2013. New Delhi: Khanna Publishers. (ISBN 9788174091048)

[Jiang and Qiu ()] ‘The influence of asphalt pavement deformation due to the differential subgrade settlement’. X Jiang , Y T Qiu . http://en.cnki.com.cn/Journal_en/A-A011-SWDG-2006-04.htm *Hydrogeology and Engineering Geology* 2004. p. 4.

[Jiang and Qiu ()] ‘The influence of asphalt pavement deformation due to the differential subgrade settlement’. X Jiang , Y T Qiu . http://en.cnki.com.cn/Journal_en/A-A011-SWDG-2006-04.htm *Hydrogeology and Engineering Geology* 2004.

[Sadek and Shahrour ()] ‘Use of Boussinesq’s solution in geotechnical and road engineering: Influences on plasticity’. M Sadek , I Shahrour . 10.1016/j.crme.2007.08.007. *Comptes Rendus Mecanique* 2017. 335 (9) p. .

[Collop et al. ()] ‘Use of the distinct element method to model the deformation behavior of an idealized asphalt’. A Collop , G Mcdowell , Y Lee . 10.1080/10298430410001709164. https://doi.org/10.1080/10298430410001709164 *International Journal of Pavement Engineering* 2004. 5 (1) p. .