Saudi Journal of Engineering and Technology
Scholars Middle East Publishers
Dubai, United Arab Emirates
Website: http://scholarsmepub.com/

ISSN 2415-6272 (Print)
ISSN 2415-6264 (Online)

Research Article

Numerical Analysis of Roller Compacted Concrete Pavement

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Abstract: There has been various design methods for roller compacted concrete (RCC) pavement during a several decades. These design procedure are developed gradually. In this paper a 3D finite element (FE) model of RCC pavement has been developed. . In the validation step, the results of 3D modelling are compared with those obtained by theoretical approach. The comparison shows good correspondences. Due to the fact the theoretical approach uses 2D model in the formula, the 3D FE model results were slightly lower than the theoretical model. Using finite element software ABAQUS software, the paper investigated effects of changes speed in vertical displacement. In order to find the effect of speed in typical RCC pavement with the assumed properties in section 3, five partition for the applying load has created on the surface of slab. Vertical displacement at the bottom of the surface layer has been achieved for six different speed. Considering the obtained results of vertical displacement of the pavement for four assumed speed, the fitted curve is drawn with high accuracy.

Keywords: roller compacted concrete; finite element, vertical displacement, ABAQUS, speed.

INTRODUCTION

Roller Compacted Concrete is the commercial name used for concrete placed with conventional hot-mix asphalt paving equipment, then compacted with rollers [1]. Good performance of RCC is ensured by optimal concrete thickness, acceptable maximum displacement of pavement layers, and adequate transverse crack spacing, which are determined by design, material, construction, and environmental variables.

In 2008, Hmazah and Al-Shadeedi has evaluated the effect of cement content, water/cement W/C ratio and type of aggregate on the mechanical properties. In order to study the experimental and analytical behavior of various mixes of roller compacted concrete (RCC) using different materials, two groups of experiments has been selected, which the optimum mixes from the first group has been used in the second group. In this study they study the influence of admixtures and type of admixtures (steel filings, metakaolin, fly ash, lime, rice husk and concrete wastes) on the mechanical properties. The results showed that using steel filings improves the mechanical properties when replacing the sand by steel filings by weight. In addition, they concluded that Partial cement replacement by mineral admixtures like metakaolin decreases the strength and other properties at early age of 28 days when using metakaolin.

In 2003, Khunthongkeaw and Tangtermsirikul [3] developed correlations between the Vebe time and free water content of the mixes, which develops the vibration consistency prediction model for RCC. For this research, various parameters influencing the consistency of RCC has been applied, which are the ration of paste volume-to-void content of densely compacted aggregate phase, free water content, and physical properties of solid materials. The results could be used to predict the Vebe time of RCC with satisfactory accuracy.

Schrader [4] evaluated the effect of compaction methods, water content, and other variables on density, pore pressure, practical construction problems, and permeability. Due to the fact that developing air entrainment to satisfy freeze-thaw (FT) durability criteria and allowing RCC to fully complete with conventional concrete and asphalt in the marketplace is necessary, Dollen [5] summarized the results of testing before 1992 in the laboratory and in the field. The purpose of his study were related to reducing the need for conventional concrete facing and expand the application of RCC where FT durability is requirement.

Kajorncheapunngam and Stewart [6] made an experimental analysis of RCC mixes containing different proportions of Rise Husk Ash (RHA) with different water contents. Utilizing RHA could not only solve the cement shortage problem in developing countries but also help to conserve environment. The results show that using RHA will help to improve compressive strength of concrete up to 50 percent, which RHA could be considered as a replacement for cement. In addition, they showed that RCC mixes containing up to 50 percent RHA can produce an acceptable compressive strength of about 630 psi.

Vineela et.al [7] predicted the comparison of the stresses and displacements using different 2D models. The researchers showed that the edge loading case induces higher stresses than interior and corner loading cases and corner loading case induces high deformation than interior and edge loading cases.

Zdiri et.al [8] utilized a numerical 3D modelling for RCC. They have applied several methods of 2D modelling for determination of the stress and strain in RCC slab including Closed-form Formulas and the Portland Cement Association (PCA) method. They compared the results of 3D modeling with the other methods.

METHODOLOGY

In order to develop the pavement analysis system, an explicit approach of finite element analysis has been used Due to the fact that the displacement in each nodal point depends on forces in all the nodal points, solid function has been used in the model.

The basic methodology of FEM is to divide a complex domain into simple subdomains (finite elements), as triangles and quadrilaterals [9]. The displacements within each finite element are interpolated using the nodal displacements. On the other hand, the strain vector is obtained from the nodal displacements using appropriate cinematic relations [9, 10]. Chen et al [2] performed an extensive study of pavement analysis program and showed that ABAQUS results are comparable with other software. In this paper, using ABAQUS 6.10, the model has been validated with exact methods including Westergard. After validating the model, semi-static analysis has been applied using moving load method. This method could clarify the effect of vehicle speed on the maximum vertical displacement.

MODEL VALIDATION

Theoretical solution

The first theoretical solution for 2D-model of RCC analysis was proposed by Westergard [12]. For the interior loading Westergard proposed equation 1 and 2 for the tensile stress and vertical displacement at the bottom of the surface layer. The equations 3 and 4 are related to the tensile stress and vertical displacement where the load is at the corner. In addition, equations 5 and 6 are the theoretical results for the tensile stress and vertical displacement where the surface is under the edge loading.

$$\sigma = \frac{3(1+\nu)P}{2\pi h^2}(\ln\frac{l}{b}+0.6159) \tag{1}$$

$$\Delta = \frac{P}{8kl^2}\left\{1+\frac{1}{2\pi}\left[\ln\left(\frac{a}{2l}\right)-0.673\right]\left(\frac{a}{l}\right)^2\right\} \tag{2}$$

With b=a if $a \geq 1.724h$

$b = \sqrt{1.6a^2+h^2}-0.675h$ If $a \leq 1.724h$

$$\sigma = \frac{3P}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right] \tag{3}$$

$$\Delta = \frac{P}{kl^2}\left[1.1-0.88\left(\frac{a\sqrt{2}}{l}\right)\right] \tag{4}$$

$$\sigma = \frac{3(1+\nu)P}{\pi(3+\nu)h^2}\left[\ln\left(\frac{Eh^3}{100ka^4}\right)+1.84-\frac{4\nu}{3}+\frac{1-\nu}{2}+\frac{1.18(1+2\nu)a}{l}\right] \tag{5}$$

$$\Delta = \frac{\sqrt{2+1.2\nu P}}{\sqrt{Eh^3k}}\left[1-\frac{(0.76+0.4\nu)a}{l}\right] \tag{6}$$

Where

σ : The tensile stress at the bottom of surface slab.

Δ : The displacement at the bottom of the surface slab.

l : Radius of relative stiffness (m) and can be calculated by equation 7.

a: the contact radius (m)

P: concentrated load (N)

h: the thickness of RCC slab (m)

k: the modulus of subgrade reaction (MPa/m)

E: elastic modulus of the RCC slab

ν : poisson's ration

$$l = \left[\frac{Eh^3}{12(1-\nu^2)k}\right]^{0.25} \tag{7}$$

According to the equations, the vertical displacement for the interior case shows the lower results than those from corner loading and edge loading cases. In addition the stresses results in edge loading case is higher than the other loading cases.

Finite Element Geometry

In finite element modeling, two RCC slab separated by a joint, were modelled. Both rest on a gravel sub-base suitably compacted. The whole also rests on a ground support. The geometries and the mechanical properties of material were introduced in table 1.

Table 1. The material properties of 3D FE model

	Thickness (m)	Elasticity modulus (MPa)	Poisson ratio	Dimension (m)
Two RCC slabs	0.2	31000	0.22	4.00*7.00
Gravel foundation layer	0.3	155	0.35	4.00*14.00
Subgrade	1.3	50	0.45	4.00*14.00

In finite element modeling, two RCC slab separated by a joint, were modelled. Both rest on a gravel sub-base suitably compacted. The whole also rests on a ground support. The geometries and the mechanical properties of material were introduced in table 1.

The parameters were used in the model are: the elastic modulus E, the Poisson's ratio n and the admissible stresses of tensile and compression. All dimensions are finite in 3D; the diagrams of the model are presented in Figures 1. According to the previous models [13], a solid foundation was used, which is more realistic. The Friction ratio Slab/Foundation was assumed equal to 1.5 and the Friction ratio Foundation/ground were assumed to 1.1. Three cases of loading of the RCC slab were used in the validation section; an interior loading (load in the center), a load in the corner and a load at the edge of the slab; but the applied load were a static loading. The applied load was of 65000 N/tire which is equal to 740000 Pa.

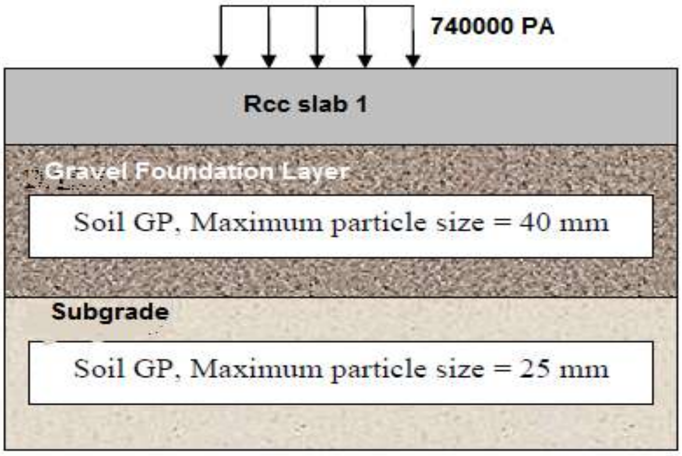

Fig-1: Transverse section of modeling

Meshes based on hexahedrons with eight nodes were chosen. Mesh dimensions are chosen through test and trial analysis in a way that boundaries have no effect on analysis results. Figure 2 shows the 3D meshed model of RCC. The boundary conditions were selected in order to approach to the real boundary conditions. The two RCC slabs were fixed on one face in directions x and y. In addition, the gravel sub-base and ground support layers were fixed in the two directions x and y.

In order to consider the behavior of RCC more realistic in compression, an experimental behavior has been defined. This compression behavior of RCC has been presented in figure 3. In addition the tension RCC behavior was assumed to be linear until the crack occurs. After this situation, RCC tends to have linear loss of resistance [14].

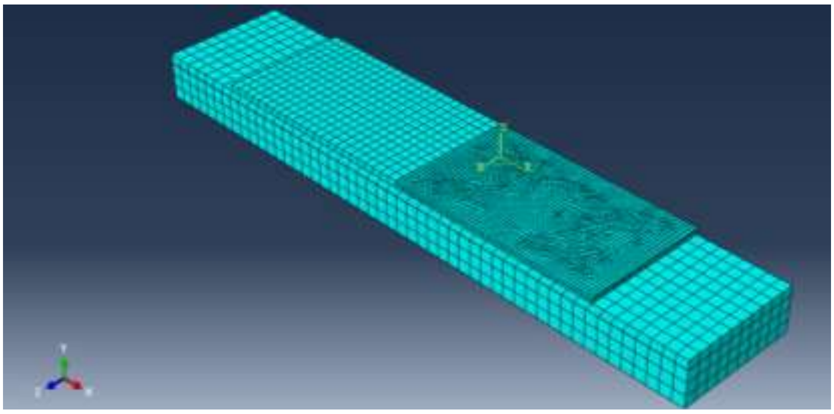

Fig-2: **3D meshed model of RCC**

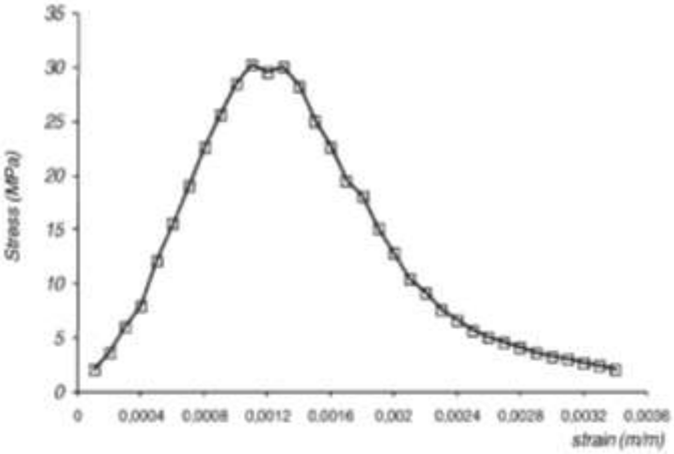

Fig-3:Stress-strain behavior of RCC [8]

The results obtained from model analysis are compared with the results of experimental Westergard calculation formula, as shown in table 2. There is a good occurrence between FE model and experimental results.

Table-2: The comparison between experimental and numerical results

Stress and displacement	Interior Loading		Corner Loading		Edge Loading	
	Experimental results	Numerical results	Experimental results	Numerical results	Experimental results	Numerical results
Tensile stress (Ma)	1.94	1.47	2.26	1.406	3.3	1.06
Vertical Displacement (mm)	0.187	0.57	1.162	1.07	0.702	0.577

RESULTS AND DISCUSSION

In order to find the effect of speed in typical RCC pavement with the assumed properties in previous section, five partition for the applying load has created on the surface of slab (figure 3). Vertical displacement at the bottom of the surface layer has been achieved for six different speed (figure 4). Considering the obtained results of vertical displacement of the pavement for four assumed speed, the fitted curve is drawn with high accuracy. Equation 8 shows the relation between speed and the vertical displacement for the assumed typical RCC model.

$$d = 0.1128*\exp(-0.134*S) \tag{8}$$

Where:
d: displacement (mm)
S: speed (m/s)

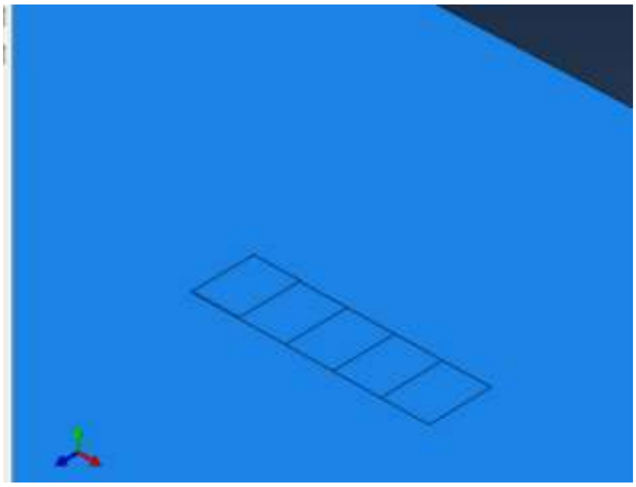

Fig-3: The partitions for applied load

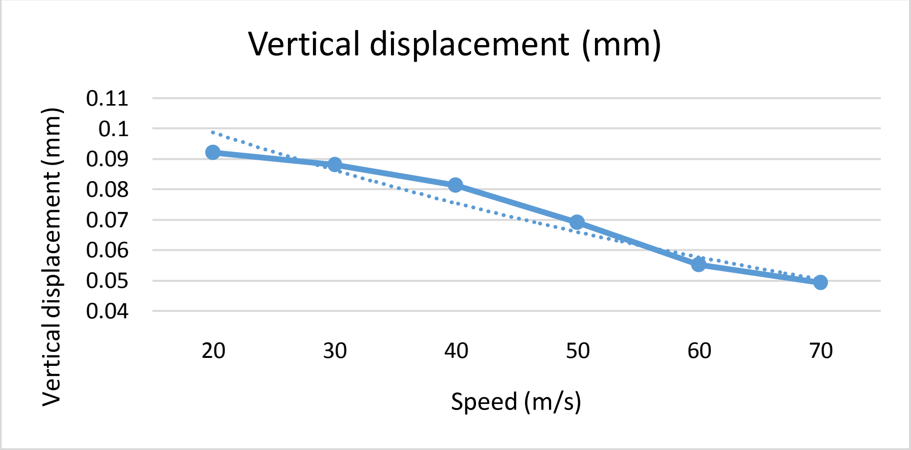

Fig-4:Vertical displacement for different speed

CONCLUSION

In order to develop the pavement analysis system, an explicit approach of finite element analysis has been used Due to the fact that the displacement in each nodal point depends on forces in all the nodal points, solid function has been used in the model. In this paper, using ABAQUS 6.10, the model has been validated with exact methods including Westergard. The comparisons of the stresses and displacements predicted by Westergard with those obtained by ABAQUS code 6.1 show good correspondences although the present 3D modelling gives results slightly lower than those given by the other methods in stresses. After validating the model, semi-static analysis has been applied using moving load method. This method could clarify the effect of vehicle speed on the maximum vertical displacement. The results showed lower values in comparison with the static model. In addition, with increasing the speed, the vertical displacement decrease. The fitted curve has been achieved for the typical RCC pavements. This curve only can be used for the properties which has been assumed in this paper.

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