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Finite-Element Investigation of Vehicle Speed Effects on Jointed Concrete Pavement

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Abstract: Rigid pavements may suffer different types of damages such as longitudinal and transverse cracks, cracks in the joint resulting from dynamic traffic load and thermal stress during their lifetime. Understanding rigid pavement response under axial load is important in designing new pavement and implementation of measures to repair and modify existing pavement. In this study, JPCP slab response was studied under the axial loads. For three-dimensional modeling of concrete pavement, ABAQUS CAE Software package V.12 was used which is one of the most powerful software used in three-dimensional modeling.

Key words: Jointed concrete pavement, dynamic loading, finite element modeling, ABAQUS, implementation

INTRODUCTION

Jointed Plain Concrete Pavement (JPCPs) are mostly used for the roads due to their good performance. Inclusion of dowel bars at transverse joints in the JPCPs is necessary to transfer the traffic loads applied on a slab to an adjacent slab and it enhances the structural capacity at the joints, therefore all JPCPS must have contraction joints at definite intervals. Depending on the type of pavement, climate and experience, the distance between joints varies from 15-30 feet. Joints are also created in concrete pavements to relieve the tension caused by friction and changing weather conditions (temperature and humidity). These joints are in three forms: expansion joints, contraction joints and construction joints. In Fig. 1, the overall picture of the joint concrete pavement suture used in this research is presented (Fahmy, 2005).

To analyze and design this type of pavements laboratory, experimental, numerical analysis and finite element techniques can be used. One of the limitations of laboratory methods is that these methods cannot provide precise information on the effect of dowel and concrete at their joint and the created three-dimensional stress. To achieve a better understanding about the interaction of dowel bar and slabs and to study the effect of dowel and concrete friction reduction on the amount of axial force required to open joints, providing a good analytical model to predict the behavior appears necessary.

FEM is a numerical technique to solve problems with complex geometry, loading and material properties. This

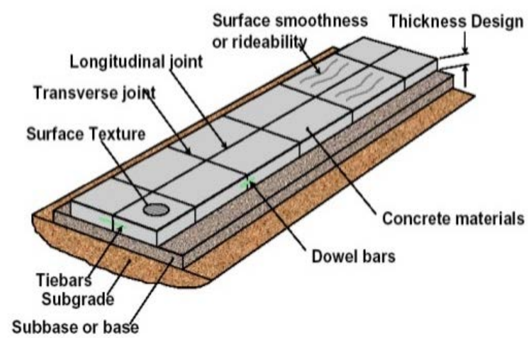

Fig. 1: The general form of jointed concrete pavement

is the solution for pavement problems more complicated than to be analyzed by numerical methods. In FEM methods, software forms equations for elements by solving which the balance for the elements, displacement points and stress are calculated. The aim of this study is to develop a D-FE3 Model to study the effect of dynamic axial loads on the response of joint concrete pavement. These studies can help design a correct and economic pavement. Achieving a computer model instead of using heavy, costly and time-consuming road construction testing could significantly reduce design, manufacture and repair costs.

Stresses and deformations in the concrete pavement can be calculated using three methods: Westergad's formulae, Ray and Picket impact curves and finite element computer programs. Formulae and impact curves can be

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expressed for unlimited slabs in Winkler foundation. In more complex cases such as loading in concrete slab joint on a liquid, solid or foundation the first two methods cannot be used and only FEM can be used. The most basic step in FEM method is to determine the overall structure classified as 2D or 3D. Increase in the computational capability of computers in recent years, by access to FF methods, has created a change in rigid pavement design and analysis (Fahmy, 2000).

Cheung and Zienkiewicz (1965) achieved the first algorithms for the analysis of rigid pavements. They solved problems related to Isotropic and non-isotropic slabs on two Winkler and semi-finite elastic foundations by using FEM. Huang and Wang (1973) continued their process to achieve the finite element method to calculate the concrete slab response due to transfer of load to joint, although the obtained model had no use in multilayer systems. From Chou (1984) obtained a computer program called WESLIQID for rigid pavement analysis which is modification of the program by Huang. Tabatabai and Barenberg (1978) developed a computer program called ILLISLAB. This program is based on the classic hypotheses for plates with an average thickness and Winkler foundation. Interlock between grains and joints are modeled using a spring element model that transfers load between two adjacent slabs using a cutting. Nasim found a method to study rigid pavement failure under dynamic load. Of other two-dimensional finite element programs KENELS, WESLAYER, J-SLAB, KENSLAB and ILSL97 can be named. In general, 2D-FE indicates significant potential in modeling methods and has made great progress compared to their traditional design. Many of these programs deal with elements of concrete slab slate and layers of foundation; they can analyze JPCCP with or without dowel loads and transmission of inter-grain interlock with spring elements. However, they are only able to perform static analysis and their application is limited. They cannot have enough precision in the following cases: (Fahmy, 2000):

- Dynamic loading
- Response to details such as stress at the interface of dowel bar and concrete
- Horizontal real friction force at the interface between different layers of pavement
- Vertical separation or gaps between the concrete slab and foundation
- Nonlinear thermal gradients in the slab
- Platform modeling as Winkler foundation does not let study the bed failure patterns

With the increase in computer time and memory capacity and the need to better understand reasons of some types of pavement failure, 3D-FEM method is used by many researchers. Many researchers decided to use three-dimensional software because the availability of inter-surface algorithms, thermal modules and material models make this approach the most appropriate way for the analysis of pavement structures. A set of software such as ABAQUS, DYNA-3D and NIKE-3D has been developed since 1970 and used in designing many problems. Chatti (1992) obtained a 3D-FEM Model called DYNA-SLAB that examined the effect of load transfer mechanism and the vehicle speed in rigid pavement response to dynamic loads. The model is the developed model of 2D-FE, called ILLI-SLAB. Shoukry and coauthors studied the dynamic response of rigid and composite pavements using FWD in LS-DYNA. The results show the reliability of LS-DYNA in predicting dynamic deformation that was measured and compared using FWD tests. Purdue and Ohio universities examined the effect of trucks load on rigid pavement. They used finite element software ABAQUS, in order to achieve a 3D-FE Model of multi-layer pavement structures. Single axle load of 80 kN on the wheel path is simulated (Chatti, 1992).

Hammons found a 3D-FE Model out of a rigid pavement with slab-joint-Foundation that was examining the charge transfer efficiency at doweled joints. This model is used in advanced pavement designing concepts by FAA. The model was developed using ABAQUS software and the effect of stabilized grained foundation in the target transverse joint response was studied. Seaman and coauthors developed the mechanistic airport pavement-design methods based on D-FE3 modeling. To simulate a landing runway for an aircraft at 161 kmh^{-1} (100 mph) speed on a PCC runway pavement, he used LS-DYNA. Tires path had been simulated rectangular and the runway was modeled as a PCC slab on the bed. The results show that the maximum horizontal stress in the direction of traffic on the lowest level of slab has directly occurred under the load. A D-FEM 3 Model was developed by Kennedy and his colleagues in 1995 and 1997 for modeling of pavement structures with the support of the Federal Highway Administration of America (FHWA) that funded it. This model is based on finite element equations that are solved with DYNA3D and NIKE3D and its beginning dates back to the mid-1970s at Livermore National Laboratory. FHWA computer program was experimentally compared with test lab results built in Ohio. The model is loaded by an experimental vehicle where each tire is simulated with a rectangular tire path having a steady pressure. In 1994, FAA started a 10 year research project aims to develop computer-aided design methods for airport pavements. As part of this project, FAA obtained a structural D-FE3

Model for pavement of PCC airport under airplane loads using NIKE3D Software. Many articles and theses have used three-dimensional finite element software to study the rigid and flexible pavements response whose results indicate the high capability of this model. With these models, one can study a variety of linear and nonlinear material properties, thermal properties and moisture-loading models, different types of interfaces and boundaries that give wide information to researchers (Chatti, 1992).

MATERIALS AND METHODS

FEM is a fully adaptive method capable of two-dimensional and three-dimensional geometric modeling and has the possibility of taking into account the linear and nonlinear characteristics of material, plastic behavior and many other complex traits. FEM Software used in this study for pavement modeling is ABAQUS Software. The most comprehensive environment of ABAQUS Software is ABAQUS/CAE which is also used in this study. Environmental ABAQUS/CAE easily provides the possibility to create appropriate models with different geometries, inserting different material properties, loads and boundary conditions, meshing and analysis to the user.

To make the abovementioned points, software has different parts namely: part Module, Property Module, Assembly Module, Step Module, Interaction Module, Load Module, Mesh Module, Job Module. Part section is used to define and develop different parts required for the model with different geometrical characteristics used. In this study, it is possible to draw or modify the model geometry. In property section, one or more material properties are defined. Then for each material, a Section a section is created that has the desired properties of each material. Finally, according to the type of material, each Section is devoted to one or more pieces. The intended model may include one or more pieces each of which have been created in the part. In assembly section, these components enter the slate and then through imposing some restrictions, they are set in appropriate positions relative to each other. In step section, with regards to type of the problem, the necessary procedures for its analysis are defined. In addition, the kind of output and the quality of the output resulting from analysis are determined. In Interaction part, the behaviors of mechanical (such as friction) and thermal contact between the parts are defined and applied. I load section, boundary conditions and loadings of the component are defined. In mesh, the type and number of elements are specified and mesh. In Job, settings related to implementing the problem are applied and the created model is analyzed. In visualization the output results determined in step can be seen. The created model has dimensions of 9.2 m (in 360) in the direction of traffic and 3.660 m (in 144) in cross-section (one lane). Solid section for rigid pavement model is composed of a long concrete slab on a grained layer and a pavement bed. To eliminate the effect of boundary conditions and to ensure accurate and precise modeling of concrete slab, the middle slab at both ends with two other slabs using load dowel is transversely connected. The material properties of these layers are chosen similar to materials used in the experimental tests conducted by FWD in Virginia and the test results are also compared. To analyze the material, static analysis is used. Total load time is inserted in step stage. Assuming that the speed is fixed at the crossing point, total passing time can be obtained from the following equation where, t is loading time in seconds, l is the effective length in inches and is is speed calculated in terms of miles per speed:

$$t = \frac{l}{17.6^{*} vs} \quad (1)$$

In fact, the vehicle applies dynamic loads to the pavement structures. Thus, the traffic loading should be considered as a dynamic load FEM. In order to simulate accurately, the effect of dynamic load and to calculate non-linear changes in stiffness as the applied load in the transverse joint, especial finite element integrations are used. Tire loads move in a set of contact patches applied on the slab at a speed of 105 km h^{-1} (or 65 mph). Therefore, for 105 kmh^{-1} (65 mph) or 29058 mm sec^{-1} (1144 inches sec^{-1}) speed, 0.036 mm load per step will move. To simulate the traffic load, an area as the size of each wheel is gradually moved along the wheels at direction of traffic. For each area of the load, a load range is defined. Load application time on each area is obtained by dividing the length of the loading area to the assumed speed for traffic. Short time stages will allow small changes in pavement response. This method allows very smooth transition of load times from one node to another along the wheels direction. Loading model is shown in Fig. 2.

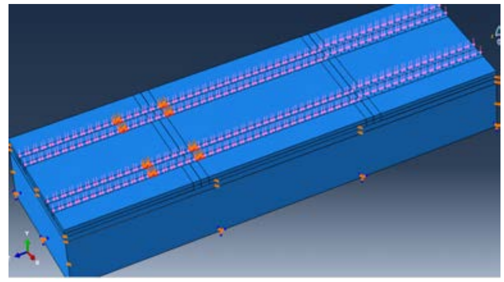

Fig. 2: The general form of jointed concrete pavement

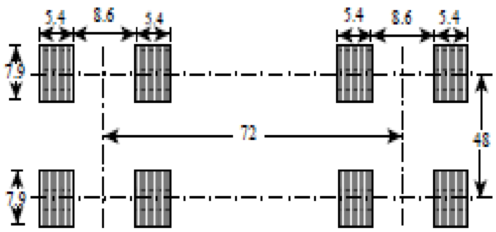

Fig. 3: Tandem axle configuration

The finite element model is loaded with combined axle shape. Reviewing previous studies indicates that the maximum combined axle load is between (28,000 and 40,000 pounds) 178 KN and 125. The distance between the compound axis is between 1 and 1.35 m (40 and 53 inch). The distance of the axis to axis between dual-wheels is about 0.35 m (14 inches). Based on a brief previous reviews, in this study, for the combined axis 16.3 tons (36,000 pounds) load with average 7.35 kg tire pressure per square centimeter was chosen. This even tire pressure was used on each tire trace. A schematic image of the axis used in shown in Fig. 3 (Tabatabaie *et al*., 1978).

After applying the loading and the introduction of the border, it is the turn for meshing model. This model is meshed by 8-node elements (C3D8R). In load applying areas, fine meshing is used and as it gets away from the load applied area, meshing becomes coarser. Full loading should be used in the implementation of the program because it raises the validity of the results.

RESULTS AND DISCUSSION

The most reliable method to evaluate the accuracy of the theoretical model is comparing its results with field measurements identical to the structure under loading conditions. Comparing the results obtained from the model with experimental measurements shows that the values are very close indicating the accuracy of the model. According to the model precision, the impact of speed on the response rate is investigated.

Dual axis speed in three speeds 72, 105 and 160 km h^{-1} is examined to study the chorus effect on the stress and strain of the concrete slab. The results are shown in Fig. 4 and 5.

In general, changing speed from 72, 160 km h^{-1} does not have a significant impact on the strain and tension in the slab along wheels.

In the transverse joint, the average tensile stress at the bottom of slab indicates the average speed of 62.5 kg cm^{-2} as shown in the figure, except for 160 km h^{-1} where tensile stress in approximately 20% higher. The average tensile stress obtained in the lower middle of the slab is greater than the average tensile stress at the joints. Similar results are observed for the strain that does not

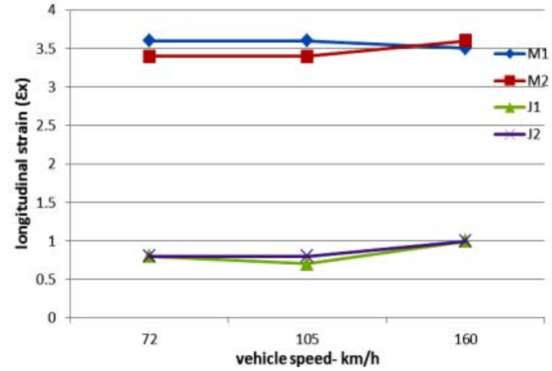

Fig. 4: Effect of traffic speed on ex in the concrete slab

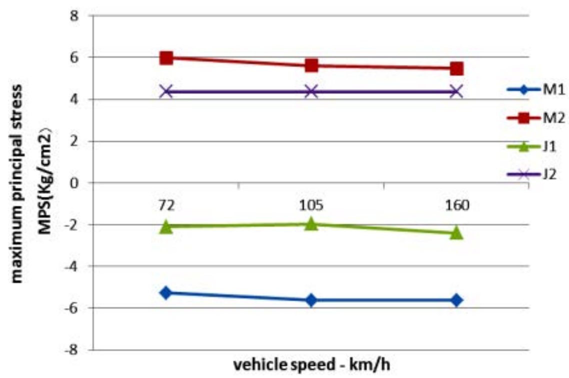

Fig. 5: Effect of traffic speed on MPS in the concrete slab

show a significant effect on the speed of traffic on pavement response. Low speeds expose each point of slab to strain fluctuations as the amount in a very short period. The larger the number, the number of oscillations of the tension that comes on each pint of the slab is greater, so the number of fatigue cycles affecting that region is larger. The large number of fatigue cycles affecting the pavement in a short period of time can weaken the pavement and reduce its life cycle.

CONCLUSION

FEM model obtained can get a rigid pavement response with a high level of accuracy that is not obtained very often by previous studies and research in the field of modeling pavement. The proposed research shows that the theoretical model is capable of producing the same results obtained from field studies and thereby increases the confidence about the results. When compared with field measurements, regarding collecting any data, the theoretical model is more economical, faster, easier to change and had the most capability of producing accurate local reaction at any point in the pavement structure. Traffic speed does not have a significant impact on the response of rigid pavement slab but higher speed will have higher number of passes that increases the amount of fatigue damage that causes major damage in concrete slab that has high costs.

Due to loading and unloading cycle, concrete slab gets fatigue cracks. In the upcoming models, the effect of repetitive loads on concrete slab response can be studied. consequently, pavement is demolished soon but a viscoelastic model is the best choice for effective asphalt pavement analysis.

REFERENCES

Chatti, K., 1992. Dynamic analysis of jointed concrete pavements subjected to moving transient load. Ph.D. Thesis, University of California at Berkeley, California.

Cheung, Y.K. and O.C. Zienkiewicz, 1965. Plates and tanks on elastic foundations: An application of finite element method. Int. J. Solds. Struct., 1: 451-461.

Chou, Y.T., 1984. Stress analysis of small concrete slabs on grade. J. Transp. Eng., 110: 481-492.

Fahmy, M.R., 2000. Finite element modeling of dowel jointed plain concrete pavement response to thermal and moving traffic loads. https://oatd.org/oatd/record?record=oai%5C%3Awvuscholar.wvu.edu%5C%3A4955.

Huang, Y.H. and S.T. Wang, 1973. Finite-element analysis of concrete slabs and its implications for rigid pavement design. Highway Research Record No. 466, Washington, DC., pp: 55-69.

Tabatabaie, A.M. and E.J. Barenberg, 1978. Finite element analysis of jointed or cracked concrete pavements. Transportation Research Record No. 671, TRB, National Research Council, Washington, DC., pp: 11-19.