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Numerical Simulation of Cracking in Asphalt Concrete Through Continuum and Discrete Damage Model

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Abstract: This study describes the development of Continuum and Discrete Damage Models in commercial finite element code Abaqus/Standard. The Concrete Damage Plasticity Model has been simulated, analysed, and compared the result with the experimental data. For verification, the Cohesive Zone Model has been simulated and analysed. Furthermore, the Extended Finite Element Model and concrete damage model are discussed and compared. The continuum damage model tends to simulate the complex fracture behaviour like crack initiation and propagation along with the invariance of the result, while the cohesive zone model can simulate and propagate the crack as well as the good agreement of the result. Further work in the proposed numerical models can better simulate the fracture behaviour of asphalt concrete in near future.
Keywords: Model, Concrete, Cohesive Zone, Finite element, Abaqus.

I. INTRODUCTION

As asphalt concrete has many distresses [1], [2], but the most significant distress is the cracking, which may cause to deteriorate the asphalt concrete pavement. Fatigue cracking is one of the major and common cracking in asphalt concrete pavement. To understand the cracking in asphalt concrete pavement, several experimental studies have been conducted. G.H.Paulino [3] conducted a lab test of asphalt concrete pavement which is a single-edge notched beam test and indirect tension test. Also describes the development of a Cohesive zone model for both homogeneous and non-homogeneous material systems to simulate crack initiation and propagation.

The concrete damage plasticity model (CDPM) is a continuum damage model and has been utilized in the analysis for the simulation of cracks propagation and initiation. The model is elastic, homogeneous, isotropic, and rate-independent. M.G.D. Geers [4] presented a higher-order continuum model and used it to establish a model that will examine the behavior of single-edge notched (SEN) concrete beams. Peter Grassl [5] presented a constitutive model for the description of the features of the process of destruction of the concrete which is subjected to multi-axis loading. Tomasz [6] described the requirements for the identification of material limitations for the CDPM and a three-point and four-point bending single edge notched (SEN) concrete beam sample has been analyzed. The cohesive zone model (CZM) is a discrete damage model and has been modeled in the paper for verification purposes. The model is a single-edge notched beam with elastic, homogenous, isotropic, and rate-independent. Seong Hyeok Song's [7] research consists of the study of the behavior of cracks in asphalt concrete and with the help of the intrinsic cohesive-zone model CZM. The parameters of the resulting material, the strength, and the cohesion of the failure can be carried out in conjunction with SENB. G.H. Paulino [8] defines the progress of a CZ fracture model with the use of intrinsic constitutive laws to simulate crack initiation and nucleation in asphalt concrete. The Extended finite element method (XFEM) has been studied in the paper for simulation of crack propagation in the SENB test of asphalt concrete. The model has material properties that are elastic, isotropic, homogenous, and rate-independent. Chengbin Du [9] presents the study on XFEM in which a significant benefit of the model is that in such complications the finite element mesh doesn't require to be updated to follow the crack path, which shows independent to mesh sizes. And specially designed to handle discontinuities without having to keep track of their geometries. RWAYDA KH. S. AL HAMD [10] studied the growth of the reinforced concrete beam cracks by using XFEM under dynamic tensile loading which is a typical crack problem. Kenny Ng [11] has researched a personalized XFEM to forecast crack propagation and fracture properties within perfect and numerical cementitious material samples.

II. TEST SETUP

For numerically analyzing the model for different numerical techniques we have a geometrical setup as illustrated in figure 1. a 2-D single-edge notched beam is employed with dimensions are the length and depth 376mm, 100mm respectively. A notched depth of 20mm is utilized. The rigid surface interacts with the SENB with two support are placed at 50mm from both ends. The bulk element type is A Four-node bilinear plane strain quadrilateral, reduced integration, hourglass control (CPER4). An exception to the models, a cohesive zone model has a material placed at the middle which has the cohesive properties. The bulk material is modeled as elastic, homogeneous, isotropic, and rate-independent.

The load is applied at the center of the top surface. and the quantity of displacement load is 10mm in the y-direction downward. There is a total of around 6500 elements and the size of element rages from 2mm to 0.6mm. Around 600 increments with a step time of 10 sec have been analyzed. The material properties are, Density 2.243e-9 kg/mm3, Young's modulus 14200 MPa, and Poisson's ratio 0.35.

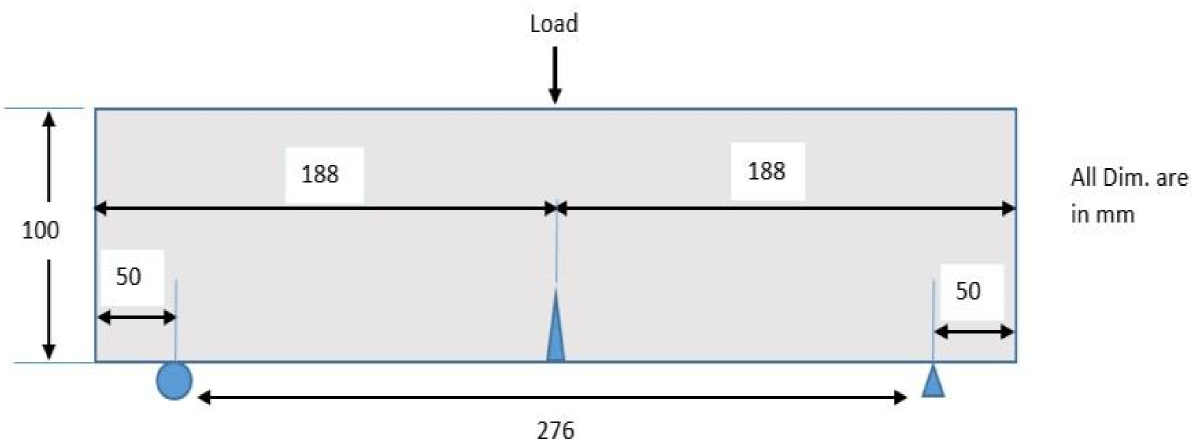

Fig. 1. Test setup of SENB model.

III.NUMERICAL SIMULATION OF MODELS:

The figure shows the comparison of the three numerical models with the experimental data. The models predict the initiation of crack at the notched tip and propagate to the top until damage occurred. The cohesive zone model shows the same profile and full damage occurred with 8mm opening displacement of crack mouth. Another numerical simulation was done on the extended finite element model which shows some agreement till the elastic limit then damage increases with the same rate of loading, it also predicts the crack initiation and propagation. In addition to that, a concrete damage model has numerically simulated a single edge notched beam and the results show the same profile till the yield limit after that it shows some increase in both load and cracks mouth opening displacement, and the damage occurred when crack mouth opening displacement reaches to 20mm, it also shows that the crack neither generating nor propagating. More work is needed to predict the enhancement of CDPM and EXFEM models to simulate asphalt concrete. Other models extension like viscoelastic material modeling, damage in the bulk material model, and rate dependency are also expected to close the gap between predicted and experimental results.

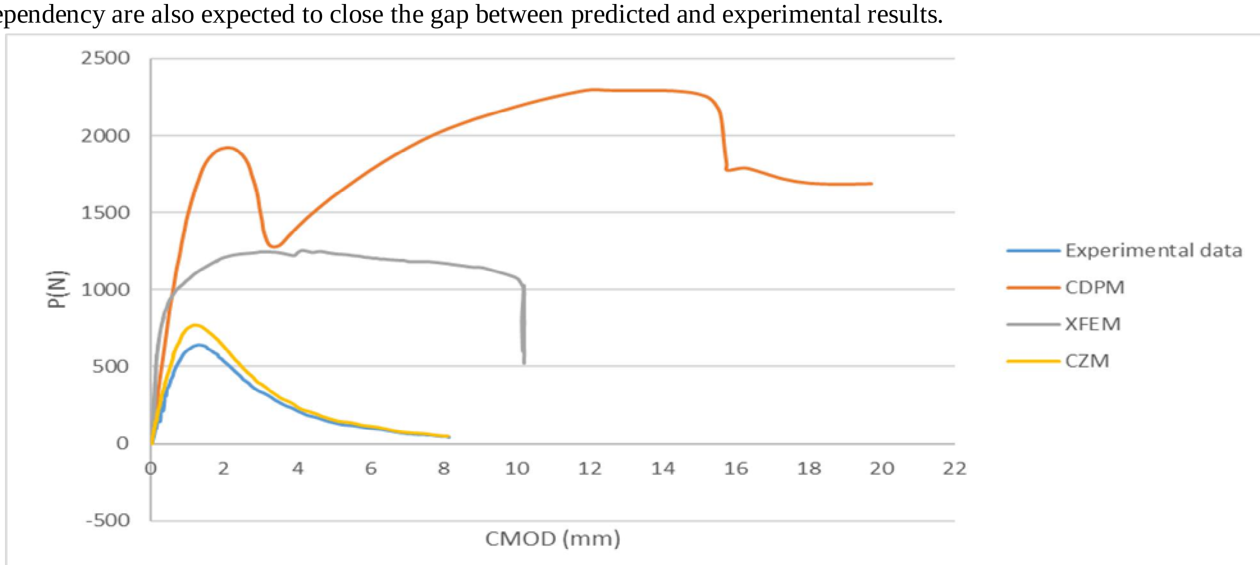

Fig. 2. Load vs CMOD of the numerical models and experimental result.

IV. SUMMARY AND CONCLUSION

The Continuum and Discrete Damage Models were developed in the Finite element code commercially available software ABAQUS and implemented through built-in models i.e. Concrete Damage Model, Cohesive Zone Model, and Extended Finite Element Model, to simulate the crack initiation and propagation in the three-point bend test of a Single Edge Notched Beam. To verify the correct implementation of the models, A cohesive zone model is analyzed, as shown in the graph, the cohesive zone model and Experimental data show a good agreement and follow the same profile. The brittleness has been shown by the XFEM, while the CDPM follows the same profile up to some limit, then increases to the fracture point and shows some inconsistency in agreement. All the models have the advantage of being capable of capturing the crack nucleation, initiation, and propagation. Further work in the proposed numerical models can better simulate the fracture behavior of asphalt concrete in near future.

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