Scientific Journal of Impact Factor (SJIF): 5.71
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 5, Issue 10, October -2018

NUMERICAL MODELING OF NONLINEAR BEHAVIOR OF ASPHALT CONCRETE

Muhammad Asim[1], Rawid Khan[1], Awais Ahmed[1], Qaisar Ali[1]

[1]*Department of Civil Engineering, University of Engineering and Technology, Peshawar, Pakistan*

Abstract: *The paper aims to model the nonlinear behavior of asphalt concrete numerically. The major constituents of asphalt concrete are aggregates, air voids and asphalt binders which shows variation in properties depending on various factors. Therefore understanding the behavior and performance of asphalt concrete is quite complex. The behavior of asphalt concrete has been treated as pure elastic traditionally. This assumption subjected to high speed traffic loading and low temperature. Therefore, the behavior will not remained same when asphalt concrete exposed to low speed traffic loading during high temperature. The research focuses on simulating the viscoelastic behavior of asphalt concrete by incorporating the laboratory determined properties into finite element model. The mechanical model and three dimensional finite element models developed numerically in this study help to simulate the behavior and response of asphalt concrete under any traffic loading conditions.*

Keywords: *Asphalt concrete, Mechanical model, Finite element model.*

I. INTRODUCTION AND BACKGROUNG

Asphalt concrete pavements considered as one of the principal component of transportation system being used throughout in the world. Asphalt concrete is also used for surfacing of parking lots, airports runways and core of embankment dams. It comprised of mineral aggregates that are bounded with asphalt laid in layers form and compacted properly. The properties of each component and the way it react with each other affect the general characteristics of asphalt concrete [2]. Asphalt concrete pavements are complex system that involves multiple layers of various materials, varying environmental conditions and different combinations of irregular traffic loading. Therefore reasonable assessment for the behavior and performance of asphalt concrete pavements are important for pavement engineers. The performance of asphalt concrete pavements depends on the behavior of asphalt concrete. Therefore different mechanical and performance models are developed to simulate the response and behavior of asphalt concrete. Most materials show both elastic and viscous behavior that is viscoelastic materials that exhibit time dependent and history dependent properties. Their mechanical response varies under different loading histories. The problem of mechanical modeling is that at finite deformation, viscoelastic materials often show nonlinear behavior. Many models with different success have been proposed to describe the time dependent nonlinear behavior of viscoelastic materials [3]. Theoretical viscoelastic models are very important for prediction, simulation, description and design in different disciplines of sciences such as engineering research, medical sciences and biology. Most successful predictive models are shown to be founded on extension of the classical linear rheological models to finite deformation [4-5].

II. SCOPE OF RESEARCH

The development of mechanical and finite element models for asphalt concrete provides important information to pavement material engineers regarding the response and behavior of asphalt concrete under different traffic loading conditions. Therefore the significance of this research work intended to develop best fitted mechanical model and finite element model for asphalt concrete to simulate its response under any dynamic truck loading conditions.

III. OBJECTIVES

The research aimed at finding out the following prime objectives:

1. To numerically simulate the response of asphalt concrete under time dependent loading.
2. To develop finite element model for asphalt concrete and validation of material property.
3. To review the theory of viscoelasticity for asphalt concrete.

IV. METHODOLOGY

1. Material Specimen and Experimental Results

Continuously dense graded bitumen macadam was selected for experiment. Aggregates of granite and bitumen were used to prepare asphalt concrete mix. The binder contents and air contents were 5.5 % and 6 % correspondingly. The diameter and height of sample used for testing was 100 mm and 100 mm respectively which were arranged by using Gyratory compactor [1]. In laboratory Uniaxial stress relaxation test was performed on asphalt concrete specimen, in which instantaneous strain applied to the specimen which was held constant for particular period of time [1]. The time period is known as relaxation time, during which the stress response was recorded as shown in Figure 1 and Figure 2 respectively.

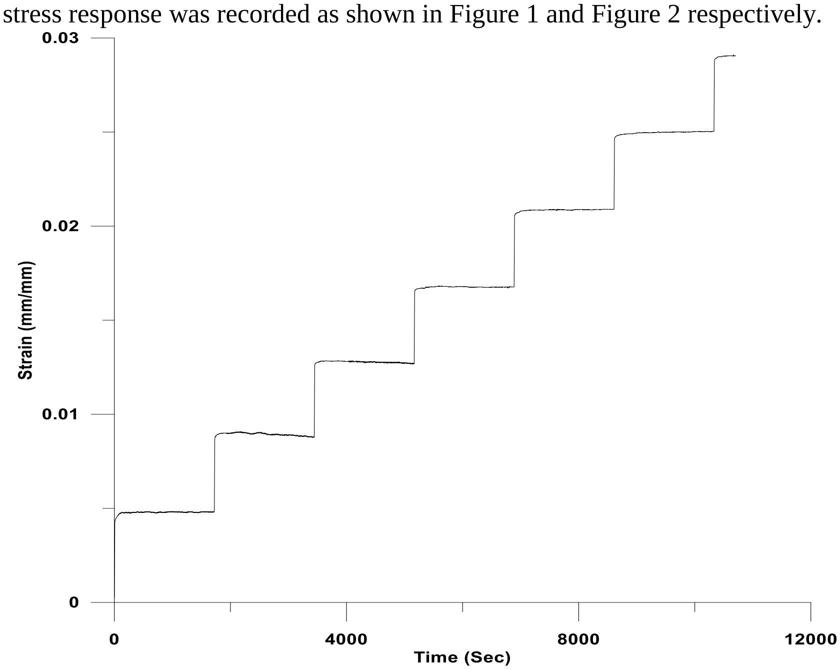

Figure 1: Applied strain during relaxation test

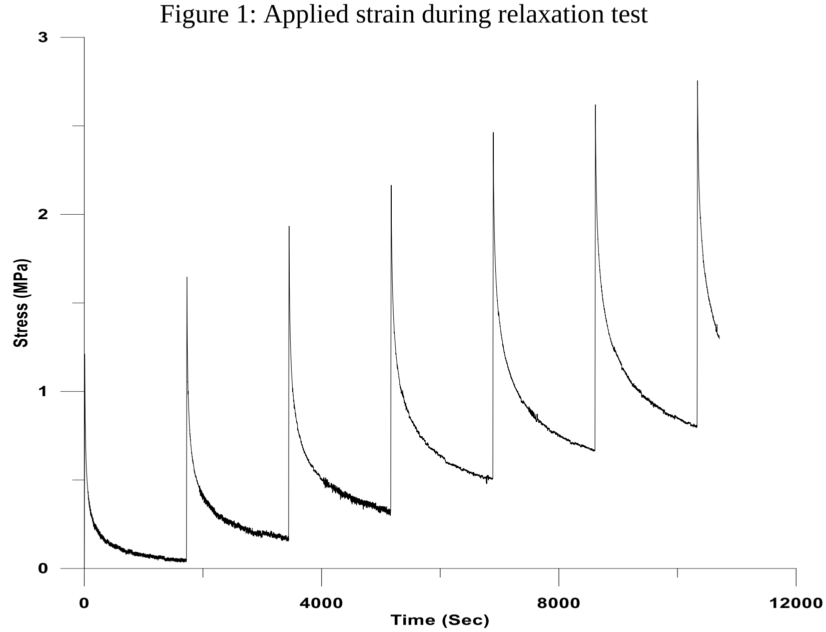

Figure 2: Resulting stress relaxation under applied strain

2. Mechanical Model

In this part we describe the Maxwell model and derive the governing constitutive equation as well as the model response equation. To numerically simulate the response of Maxwell model for the behavior of asphalt concrete, the mechanical properties of material is divided into two parts: Elastic spring (E) which capture the elastic response while dashpot (η) capture the viscous response of asphalt concrete. The connection of spring and dashpot in series represent Maxwell model for which following equations obtained.

$$\begin{cases} \varepsilon_1 = \frac{1}{E}\sigma \\ \varepsilon'_2 = \frac{1}{\eta}\sigma \\ \sigma = \sigma_1 = \sigma_2 \\ \varepsilon = \varepsilon_1 + \varepsilon_2 \end{cases} \quad (1)$$

The constitutive equation for the model based on above relation

$$\varepsilon' = \varepsilon'_1 + \varepsilon'_2 = \frac{\sigma'}{E} + \frac{\sigma}{\eta} \quad (2)$$

Multiplying by E and using $\tau = \frac{\eta}{K}$ in equation (2)

$$E\,\varepsilon' = \sigma' + \frac{\sigma}{\eta} \quad (3)$$

Since in stress relaxation $\varepsilon' = 0$, equation (3) becomes

$$\frac{d\sigma}{dt} = -\frac{1}{\tau}\sigma$$

Separating variables and integrating

$$\int_{\sigma_o}^{\sigma} \frac{d\sigma}{\sigma} = -\frac{1}{\tau}\int_0^t dt$$

$$\ln\sigma - ln\sigma_o = -\frac{t}{\tau}$$

$$\sigma(t) = \sigma_o \exp(-\frac{t}{\tau}) \quad (4)$$

Equation (4) shows the effects of material parameters on time-stress response. The effects of these parameters are studied by varying the time while keeping the other two constants. For single increment stress relaxation when we fit equation (4) on the experimental text data to simulate the asphalt concrete response under time dependent loading, then the following results obtained as shown in Figure 3.

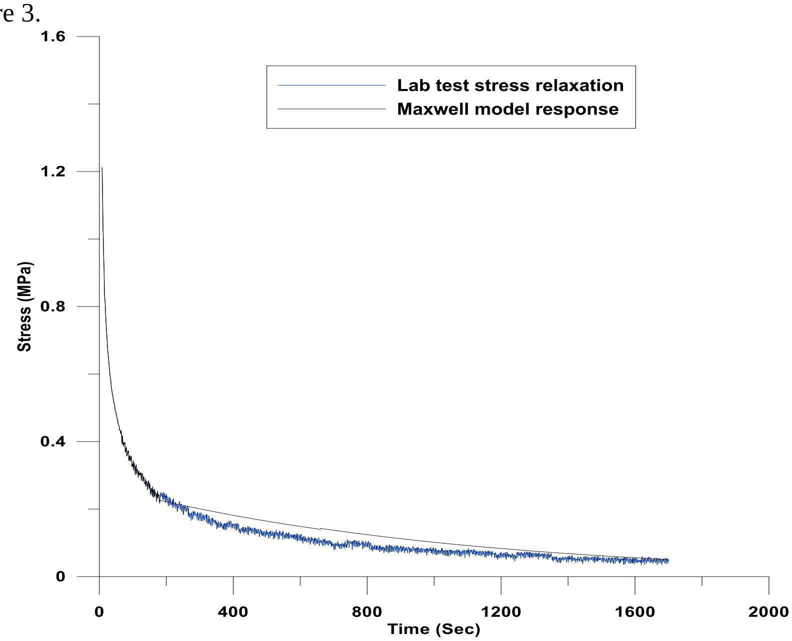

Figure 3: Maxwell model response to simulate asphalt concrete response

3. Finite Element Model

Abaqus three dimensional finite element software used in this study to simulate the response of asphalt concrete. A three dimensional modeling space and deformable type model was selected in this work. The geometry of model was defined as 100 mm diameter and 100 mm height. An elastic modulus of 2759 MPa, density of 22.1 kN/ m^3 and Poisson ratio of 0.35 were selected. Since Abaqus assumed that viscoelastic materials are defined by Prony series expansion of dimensionless relaxation modulus. The Prony series coefficients were defined in such a way that the resultant data can fit to the curves obtained from the laboratory testing [1]. The values of the shear relaxation modulus ratio and relaxation time [1] used to define viscoelastic properties of asphalt concrete are given in Table 1.

Table 1:Prony series coefficients

S. No	Shear relaxation modulus ratio (g_i^{-P})	Relaxation time (τ_i^G)
1	0.4532	1.9472
2	0.3214	30.2541
2	0.1187	125.4102

The model was considered fixed at the base, with confinement of 200 kPa and the top of model was exposed to displacement of magnitude 0.00004 m. Explicit dynamics analysis was selected and C3D8R (An 8-node linear brick, reduced integration, hourglass control) element type were used. Analysis at three different time increments were performed, the incremental time was decided based on guidelines in Abaqus manual [6]. The results of the analysis obtained at different time increments were compared with the stress relaxation curve obtained from the laboratory test as shown in Figure 4 (a, b, c, d).

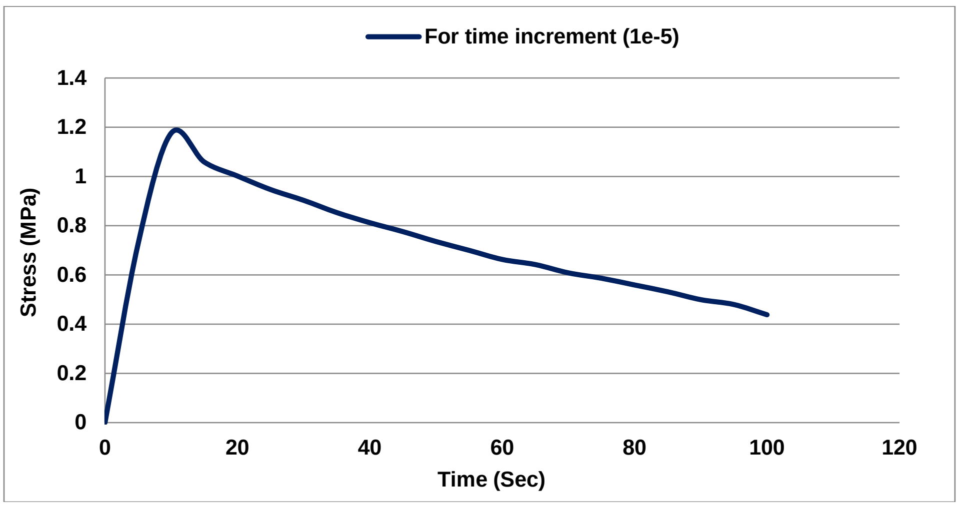

Figure 4 (a): Stress relaxation for time increment $1\ x\ 10^{-5}$ Sec

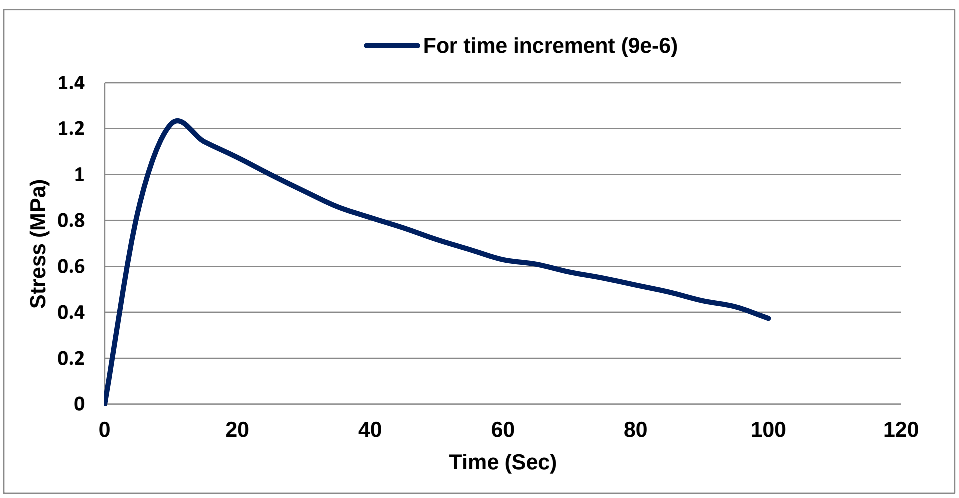

Figure 4 (b): Stress relaxation for time increment $9\ x\ 10^{-6}$ Sec

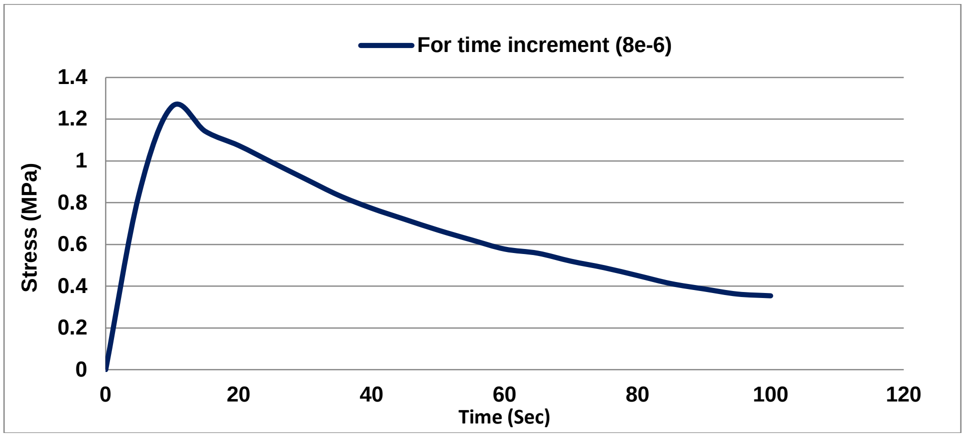

Figure 4 (c): Stress relaxation for time increment $8\ x\ 10^{-6}$ Sec

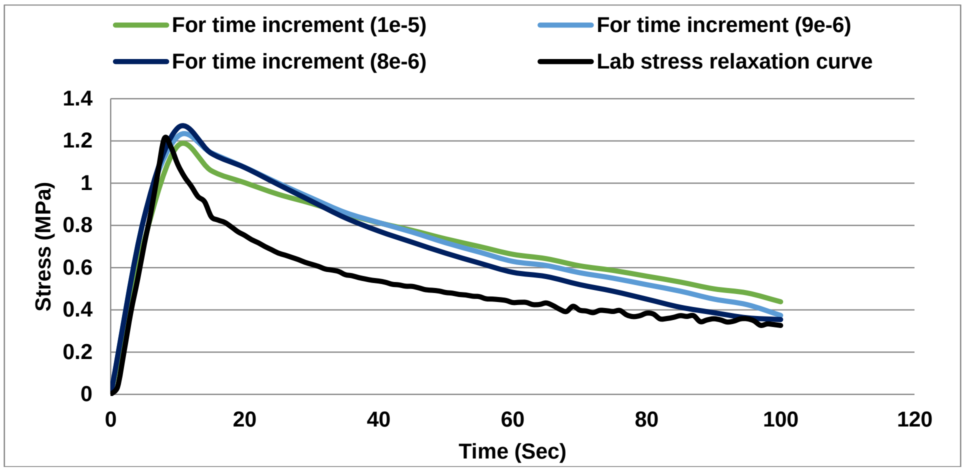

Figure 4(d): Comparison of stress relaxation results from lab test data and Abaqus

V. CONCLUSIONS

The numerical modeling of Maxwell model conclude that the model response results show good agreement with stress relaxation test results and both have better accuracy in predicting the response of asphalt concrete under time dependent loading. The finite element model results are also matching with test results and helpful in investigating the response of asphalt concrete. The finite element modeling in Abaqus at three different time increments shows that as the incremental time keep on decreasing, then the material response covered more equilibrium points and the material behavior come close to its actual behavior.

VI. REFERENCES

[1] Khan, Rawid, James Grenfell, and Andrew Collop. "Micromechanical modelling of typical Dense Bitumen Macadam (DBM) from laboratory testing and X-ray Computed Tomography (CT)." *Construction and Building Materials* 77 (2015): 1-6.

[2] Karki, Pravat. "Computational and experimental characterization of bituminous composites based on experimentally determined properties of constituents." (2010).

[3] Chotard-Ghodsnia, Roxana, and Claude Verdier. "Rheology of living materials." *Modeling of biological Materials*. Birkhäuser Boston, 2007. 1-31.

[4] D. T. Corr, M. J. Starr, R. Vanderby, Jr and T. M. Best, “A Nonlinear Generalized Maxwell Fluid Model for Viscoelastic Materials”, *Journal of Applied Mechanics*, 68 (2001), 787-790.

[5] Monsia, Marc Delphin. "A Simplified nonlinear generalized Maxwell model for predicting the time dependent behavior of viscoelastic materials." (2011).

[6] ABAQUS, A. S. (2011). User’s manual, Version 6.11. 1. *Dassaults Systemes Inc*.