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Multi-Scale and Multi-Physical Theoritical-Numerical Modelling of Tire-Pavement Interaction

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Abstract: In this review article the tire-pavement system is investigated from recent state-of-the-art theoretical-numerical researches. In particular, Using Finite Element Method (FEM) with the help of the Arbitrary Lagrangian-Eulerian (ALE) framework for tire and pavement and methods usage of tire pressure on pavements in Uzbekistan as well as time homogenization techniques are discussed in detail. Also, two dimensional tire-pavement ABAAQUS model is developed.

Keywords: Pavement; FEM; Simulation; Prediction; Interaction.

1. Introduction

The road network is main transportation and cargo in Uzbekistan so they are artirary in country's economy. Last decades, the transport flows are continuously increasing and new pavement structures need in order to increase life time of pavements. For this indeed new numerical methods are essential for understanding mechanical loading of the pavement and for prognosis. Main mechanical load is passing of vehicles in the short term and climate change.

For analysis by the finite element technique, the body to be analyzed, such as the cylinder shown in Figure 1, is divided into a set of elements connected at their joints or nodal points. On the basis of an assumed variation of displacements within elements together with the stress-strain characteristics of the element material, the stiffness of each nodal point of each element is computed. [1] For each nodal point in the system, two equilibrium equations may be written expressing the nodal point forces in terms of the nodal point displacements and stiffnesses.- These equations are then solved for the unknown displacements. With the displacements of all nodal points known, strains and For analysis withthis computer program, the structure to be analyzed is divided into a series of quadrilaterals and/ or triangles.stresses within each element are then computed. [2]

Displacements are assumed to vary linearly within each triangle; this assumption insures that no gaps will develop in the deformed structure and that displacements will be compatible throughout the structure as well as at the nodal points. Besides the finite element configuration to be used, additional items of input consist of specifying loads or displacements for each nodal point and material properties (Young's modulus and Poisson's ratio) for each element.[3]The amount of computer time required to solve a finite element problem depends on the number of nodal points (or elements) used to represent the system. For efficient operation, these should be kept to the minimum necessary for accurate representation of the system being studied. Although some judgment is inevitably required

in choosing a system of finite elements, the number of elements required is strongly dependent on the criteria for element sizes and shapes and on the size of the region which must be represented for valid simulation of the actual problem. Thus, it is desirable to establish criteria for boundary conditions by examining finite element solutions to problems for which other solutions are readily available. [4]

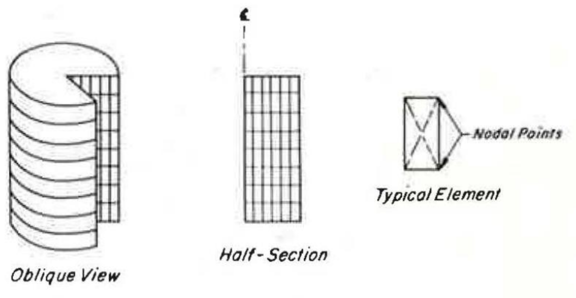

Figure 1. Finite element idealization of a cylinder [6]

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the bottom boundary were fixed, whereas those on the right boundary were constrained from moving in the radial direction. The nodal points on the centerline (left boundary) can only move vertically because of the symmetry of the problem. The nodal points beneath the loaded area are subjected to vertical forces which form the static equivalent of the pressure shown; the magnitudes of these forces are calculated by the computer program from the specified pressure. All other nodal points in the system are subjected to no forces or geometric constraints. [7]

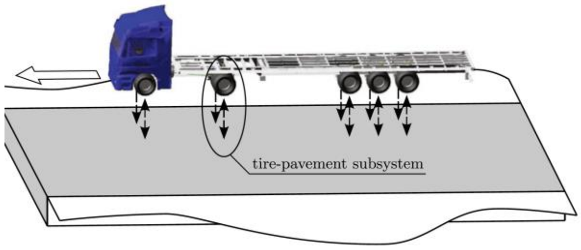

Figure 2. Vehicle-tire-pavement system with tire pavement subsystem [7]

2. Thermo-mechanical FE Tire Model.

While simplified rheological models with a reduced set of degrees of freedom (DOF) are mainly employed in analytical vehicle simulations,more detailed information on the tire response can be obtained by the belt-spring tire model used in multi-body simulations of vehicles driving on a flat or uneven surface. In order to obtain a detailed FE representation of the tire at low computational cost,an inelastic ALE FE approach has been developed and applied to the tire models used in this study. The ALE FE approach allows to reduce the DOF of the tire.

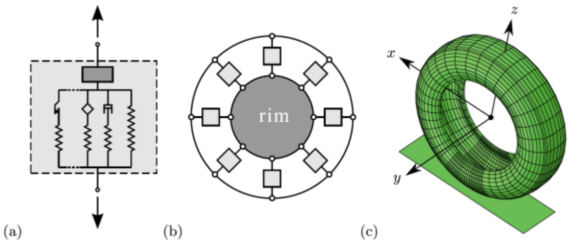

Figure. 3 Different approaches for the numerical representation of the tire within the tire-pavementsystem: a 1-mass model with reduced rheology, b belt-spring models with simplified rubber ring, tread stiffness and rigid rim, c full 3D FE model of the tire, [8]

In this contribution, a numerical framework for the efficient thermo-mechanical analysis of fully 3D tire structures (axisymmetric geometry) in steady state motion is presented. The modular simulation approach consists of a sequentially coupled mechanical and thermal simulation module. In the mechanical module, the Arbitrary Lagrangian Eulerian (ALE) framework is used together with a 3D finite element model of the tire structure to represent its temperature-dependent viscoelastic behavior at steady state rolling and finite deformations. Physically computed heat source terms (energy dissipation from the material and friction in the tire–road contact zone) are used as input quantities for the thermal module. In the thermal module, a representative cross-sectional part of the tire is employed to evaluate the temperature evolution due to internal and external heat sources in a transient thermal simulation. Special emphasis is given to an adequate material test program to identify the model parameters. The parameter identification is discussed in detail. Numerical results for three different types of special performance tires at free rolling conditions are compared to experimental measurements from the test rig, focusing especially on rolling resistance and surface temperature distribution.[9].

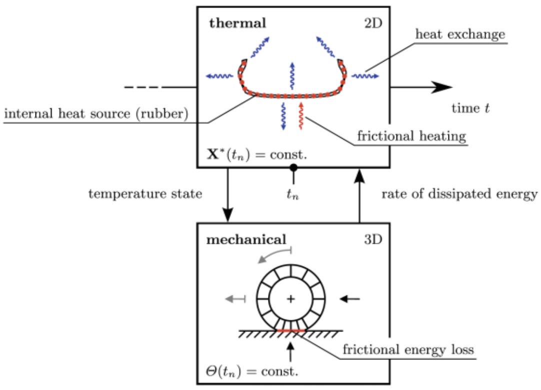

Figure 4. Sequentially coupled thermo-mechanical simulation approach for the thermo-mechanical investigation of steady state rolling inelastic tires. [9]

3. Friction

Unlike cohesion, adhesion primarily refers to the molecular connections that exist between two distinct surfaces. Decohesion between two distinct materials is another term for the debonding process [10]. For example, a nonlinear traction-separation-law with the adhesional stress vector can be used to describe adhesion friction in the FEM. Normal adhesion, which occurs without touch, and tangential adhesion, which occurs with contact, are distinguished by the adhesion model. Thus, to describe transmitted stresses, a single damage value is needed. As soon as the fracture energy is attained in a normal direction, the damage value specified is reset to zero (healing). Damage may develop repeatedly as a result of increased tangential or normal separation after the points re-establish contact (bonding). It is appropriate to guarantee minimal friction following tangential debonding in certain situations (such as continuing stress transmission after D = 1). Thus, using hyperbolic tangent regularisation, a classical Coulomb law (expressed by μadh,0) is introduced to the adhesion model [11]

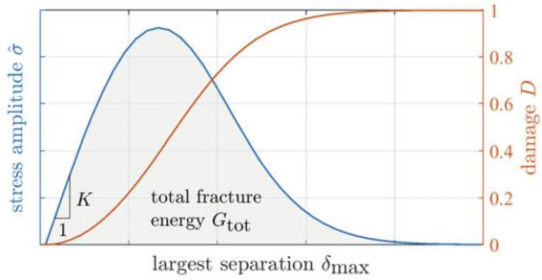

Figure 5. Traction-separation-law of adhesion model [10]

Conclusion

The increasing transport flows in Uzbekistan necessitate the development of new pavement structures to enhance their lifespan. Numerical methods, particularly finite element analysis (FEA), are crucial for understanding mechanical loading on pavements and making accurate prognoses. This study highlights the significance of FEA in simulating vehicle-induced mechanical loads and climate effects on pavements. The finite element technique involves discretizing the pavement structure into smaller elements, allowing for precise calculation of nodal displacements, strains, and stresses under various loading conditions.

Furthermore, the study explores the thermo-mechanical behavior of tires using the Arbitrary Lagrangian Eulerian (ALE) approach, which reduces computational complexity while accurately capturing the viscoelastic and temperature-dependent properties of rolling tires. A sequentially coupled mechanical and thermal simulation framework enables the prediction of heat dissipation and rolling resistance in different tire models, enhancing the understanding of tire-pavement interaction.

Additionally, the research examines frictional behavior in pavement modeling, particularly adhesion and decohesion mechanisms. The traction-separation law is used to model adhesion, with a damage-healing mechanism accounting for repeated bonding and debonding under stress. This approach provides a more realistic representation of tire-road contact behavior, essential for improving pavement durability and performance.

In conclusion, the integration of advanced numerical techniques such as finite element analysis, thermo-mechanical tire modeling, and adhesion friction modeling contributes significantly to optimizing pavement design and performance. These methods help in addressing real-world challenges in road infrastructure by enhancing structural resilience, predicting long-term pavement behavior, and improving vehicle-pavement interactions.

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