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The finite element analysis between tire and road

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Abstract: This paper conducted analysis on the stress and deformation between tire and road by abaqus software. Firstly, tire was set as rigid body in 2D model to study the deformation and stress of road.Secondly, Then, the road was set as the rigid body in 2D model to research the deformation and stress of the tire. Finally, 3D analysis was presented to analyze the deformation and stress of three-dimensional pneumatic tire and the tire grounding mark on different load.
Keywords: Tire;Road; Finite element analysis

I. Introduction

As the tire model is more complex, the constitutive relations of the road has many types.So,we selected the linear elastic constitutive relations model and simplified the model analyzing road stress and deformation under different boundary and load conditions and establishing the tire structure model the same as the actual model.The finite element analysis of the interaction between tire and road should include the geometric,material,boundary nonlinearity conditions,but it will make analysis time increase greatly.So we simplify the tire model and the simplified model can meet the content to study.

1. The nonlinear finite element analysis theory

The nonlinear finite element analysis of tire is a relatively difficult work.This is mainly due to tire has a triple nonlinear structure: (1) nonlinear of tire material,tire material is extremely complex,it mainly include the incompressibility, nonlinear hyperelastic materials, rubber materials,anisotropic rubber-cord composite materials, etc. (2) Large deformation of the rubber material lead to the geometric nonlinear of tire structure. (3) Contact nonlinear of tire and road.Therefore it is necessary to consider tire structure nonlinear problem when study the nonlinear problem of meridian tire.Next, nonlinear theory in the application of finite element are discussed

1.1The basic theory of material nonlinear

Material nonlinearity is the material constitutive relations nonlinearity, the so-called nonlinearity is a function of stress and strain nonlinearity.According to the basic equations of finite element:

$$[K]\{u\}=\{R\} \qquad (1\text{-}1)$$

$\{R\}$is node external load vector; $\{u\}$is the nodal displacement vector; $[K]$istotal stiffness matrix,it Can be represented as:

$$[K]=\sum_{1}^{n}[K]_e \qquad (1\text{-}2)$$

$[K]$is unit stiffness matrix and n is in total cell number. $[K]_e$ can be represented as:

$$[K]_e = \int_{v_e} [B]^T [D][B] dV \tag{1-3}$$

$[B]$ is geometric matrix, $[D]$ is constitutive matrix, v_e is unit volume.

When linear elastic material appear small displacement or strain, $[D]$ is constant matrix. For the nonlinear material deformation problem, $[D]$ is no longer a constant matrix and the finite element basic equations of nonlinear material is:

$$[K(u)]\{u\} = \{R\} \tag{1-4}$$

The formula has become nonlinear equations, then according to the solution of nonlinear equations to solve. Finite element analysis of material nonlinear problems must establish $[D]$ matrix of various kinds of material model. Now,a variety of ideal material model is used to describe the actual material properties in the process of research material nonlinear constitutive equation.Finite element model of materials commonly used cable elastic material model, the nonlinear elastic model, elastic material model and hyperelastic material model, the viscoelastic material model, elastic-plastic material model, sticky elastic-plastic material model, this paper applied to linear elastic material.

Linear elastic material: when the stress and strain present a linear relationship in ε_{mn} loading and unloading cases, and after the material unloading without residual strain, the materials be called linear elastic materials. The constitutive equation is:

$$\sigma = E\varepsilon \tag{1-5}$$

1.2 The analysis theory of geometric nonlinear the structure occurs small deformation, the relationship of strain and displacement is linear.At this time,it is not to consider the change of the object shape and position to list balance equation. In many cases,it is no problem for small deformation to meet the accuracy requirement. However, when the structure occurs large structure deformation problem, we need to consider the effect of deformation on the balance, to meet the accuracy requirement.Large deformation problems is the geometric nonlinear problem, because at this time the geometric equations include the quadratic term of displacement.

Geometric nonlinear structure can be summarized as two aspects: (1) the structure occurs large displacement and little strain.When a large structure displacement and little strain occurs we can think that the structure belongs to the geometric nonlinear structure, At this time we can set up balance conditions after the deformation on the configuration, that is to say, we should consider the effect of deformation on the balance, at the same time the quadratic term of displacement shall be included in the geometric equations.As a result, the balance equations and geometric equations are nonlinear equations.(2)The structure occurs large displacement or large strain, belongs to the geometrical and material dual nonlinear.Geometric nonlinearity of tire structure is determined by the tire work of large deformation.If the tire deformation become more large after the loading ,it belongs to the geometric nonlinearity.

In the finite element method,if involving geometric nonlinear problem, generally we uses the incremental analysis method to solve.we can adopt two kinds of format to represent this method.A format of the reference configuration selected as the no deformation initial configuration called completely Lagrange(T.L.) method.Another reference configurations chosen as a neighboring configuration,called modified Lagrange(T.L.) method.Generally in dealing with large deformation incremental, two methods listed in theory of equivalent balance equation due to the tire nonlinear very obvious on the load , T.L. method is used in the finite element analysis for this kind of large deformation problems.

1.3 Contact nonlinear theory of finite element analysis

Contact nonlinear refers to the change of part boundary conditions according to the loading process, the reason for this phenomenon is in contact with body deformation and friction contact boundary effect.At the beginning of the contact problem, we do not know the contact state and contact interface, the changing in the process of object motion and deformation.And the contact problem of general geometry nonlinear and material nonlinear problems.So,contact problem analysis is a difficult problem.Two objects in contact must meet no penetration constraints.Tire contact nonlinear mainly embodied in the tire contact with the road and tire contact with the rim, etc.In the nonlinear finite element analysis of contact,the node load and the unknown node displacement exist the function relation, as the change of external load, contact area and contact pressure distribution is also changing, and also is associated with the stiffness of the contact body.

Contact nonlinear finite element equation can be represented as:

$$[K]\{q\} = \{F(q)\} \qquad (1\text{-}6)$$

$[K]$is total matrix, $\{q\}$is nodal displacement matrix, $\{F(q)\}$is outer load matrix.The contact boundary conditions must be known, if we want to solve the finite element equations.In order to deal with contact boundary,usually we use penalty function method, the hybrid element method and direct constraints method and hybrid method, etc.

II. The finite element model of tire and road

2.1 Tire model

As a result of the research is only the distribution of the stress and deformation of tire, When we study the stress and deformation of the two-dimensional and three-dimensional tire distribution, set the road for the rigid body, the tire is simplified and just keep the structure of tread rubber.When analyzing the deformation and stress of the ground, the tire is treated as a rigid body, the road is treated as the variable form.

2.2Road model

We choose the asphalt road and the constitutive relationship of asphalt road include linear elastic model, the non linear elastic model and elastic-plastic model.Linear elastic constitutive model is the most simple model, this paper choose the constitutive relations for finite element analysis.

III. The interaction of two-dimensional finite element analysis between tire and road

3.1 Rigid body of tire and deformation of the road

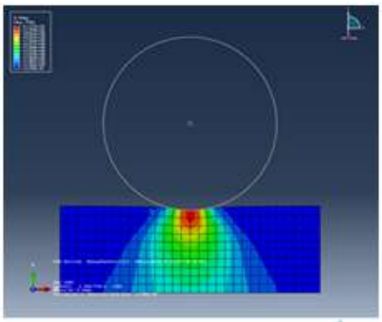

Figure 1: tire sinking 10mm

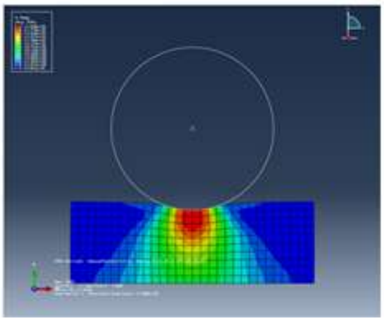

Figure 2: tire sinking 20mm

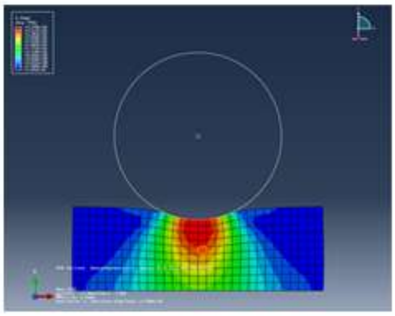

Figure 3: tire sinking 30mm

Figure 1 to figure 3, in turn, is a the stress and deformation of the ground under the sinking 10 mm, 20 mm, 30 mm. The maximum stress and deformation can be seen from the figure in the lower part of the center of the tire, with the increase of sinking, the greater the stress and deformation.

3.2Rigid of the road and deformation of the tire

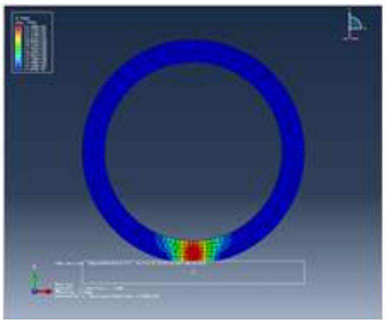

Figure 4:tire sinking 10 mm

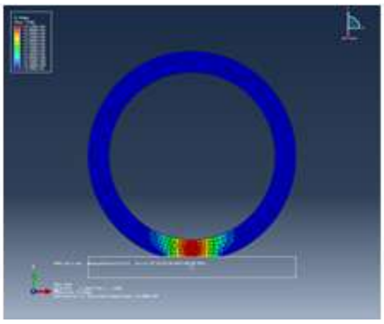

Figure 5: tire sinking 20 mm

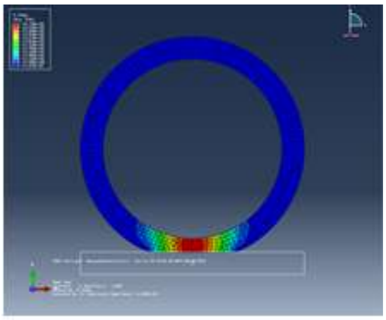

Figure 6: tire sinking 30 mm

Figure 4 to 6, in turn, is the stress and deformation of tire under the sinking 10 mm, 20 mm and 30 mm. The maximum stress and deformation can be seen from the figure in the lower part of the center of the tire,with the increase of sinking,the greater of the stress and deformation.

IV. Stress and deformation analysis of three dimensional pneumatic tire

4.1 Stress and deformation analysis of pneumatic tire

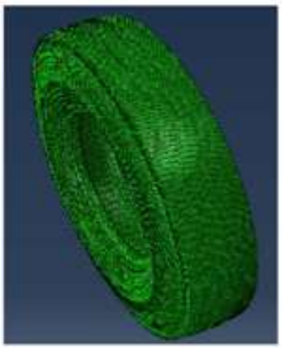

Figure7:the three-dimensional model

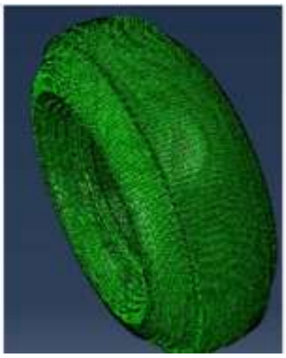

Figure8:the pneumatized three-dimensional model

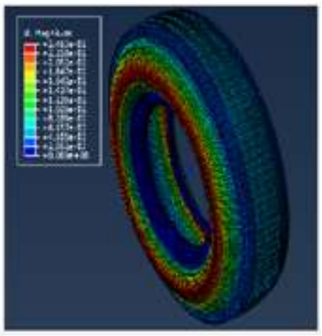

Figure9: the stress distribution of three-dimensional tire model

It can be seen from the graph 7 and graph 8, the shape of the tire taken place great change,tire lateral external expansion, tire crown slightly moving upward,tire crown variations is less than the tire, deformation mainly occurs in the sidewall of the tire place, because the sidewall area is relatively soft, the inflation is most obvious.Tire crown variation is less than the sidewall, tire shoulder on both sides of the same basic, compared with the inflation process in practical life and conform to the situation.

It can be seen from the graph9, after the tire inflate, from the tire bead to trend Mises stress show a trend of decline.The stress of the tire side is bigger, the stress of the tire crown is smaller, so the tire more easily damaged.The Mises stress of beam and cord layer material close to the Mises stress of entire tire,after the inflation of tire, stress of the tire crown part is mainly composed of belt layer and cord fabric layer, so tread stress is small.

4.2 The tire grounding-mark analysis

Under the same tire pressure and the different vertical load,mark of the normal stress distribution and the shape of mark have bigger difference .Figure ten and eleven is two kinds of grounding mark under the charge pressure of 150 mpa and the vertical load in 3000N and 5000N.the graph also shows that under certain pressure, with the increase of vertical load, mark shape from round to oval.At the same time, it can be seen that a maximum normal stress of mark has a tendency to decrease,when the load increase the grounding area increase, lead to the decrease of maximum normal stress and at the same time maximum normal stress more and more deviated from tire crown center, form big middle and small warping phenomenon on both sides.

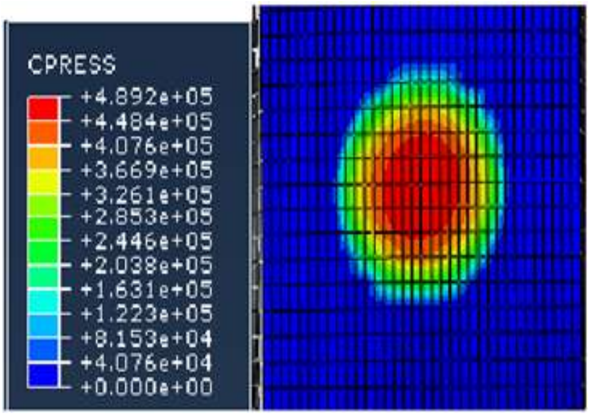

Figure 10: vertical load is 3000N

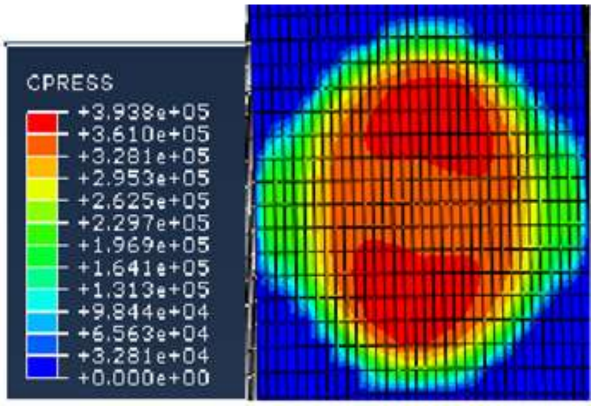

Figure 11: vertical load of 5000 N

V. Summarize

Firstly, this article analyzed the simplified two-dimensional model of the tire and the road surface by finite element method, obtained the stress distribution and deformation condition. Secondly the paper analyzed the deformation and stress of the three-dimensional pneumatic tire and grounding mark, and the same results as the actual stress and deformation of tire and road. Of course, the three dimensional model structure is simplified. Simple model has many shortcomings, the next plan to do some more in-depth study. The tire and the soil are set for the variability body, at the same time to study the steady state of the tire rolling process. The premise to analyze the other performance of tire is to optimize the model，that is to establish the finite element model according the actual structure, at the same time considering the geometric nonlinearity, material nonlinearity, tire nonlinear contact.

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