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CONTACT ANALYSIS OF CRAWLER PADS

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ABSTRACT
In this paper, we present a 2D model of inelastic contact between load carrying rollers and crawler pads, in case of wheel excavators. Plastic deformation of roller path at crawler pads cause malfunctioning, therefore it is necessary to estimate the load level that causes plasticization and to see distribution of the stress and strain. In repairing process, a welded layer of hard material is laid on the contact surface. Through simulation, we investigate the influence of thickness and hardness of that layer on plastic deformations. The code "Cont2D" specially developed for such problems has been used.
Keywords: contact, plasticity, finite element, stress, strain

1. INTRODUCTION

Bucket wheel excavators in opencast mining have a weight of several hundreds of tons. It is spread across two crawler undercarriages consisting of 2x36 crawler pads. The enormous weight, dynamics effects and non-uniformly distributed loads result in a high level of contact stresses at the critical drive components. Two such components are the drive sprocket or tumbler and the so-called crawler pads or shoes from the track assemblies. Factors contributing to high loads also include high track tension and driving on uneven terrain. The contact forces in the contact regions induce plastic deformations. The motivating example for this study is the large mining shovel or crawler Rs402. This vehicle has an approximate operating weight of 450 tons and a max. speed 0.56 m/s. A 3D model and the cross section of roller/crawler pads are illustrated in Figure 1.1 and Figure 1.2.

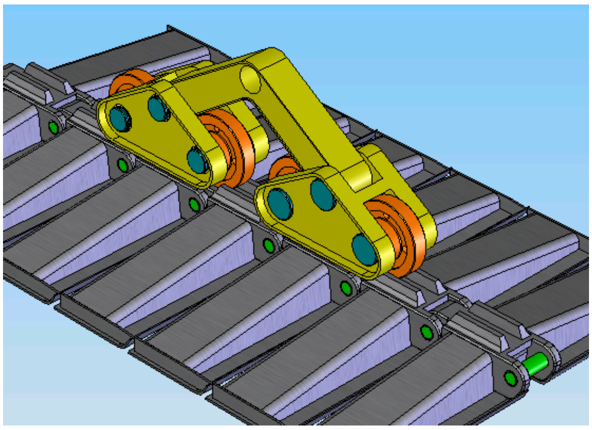

Figure 1.1 3D model of Roller/Crawler pads

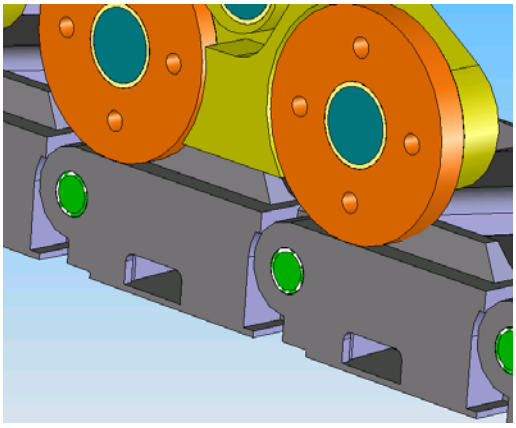

Figure 1.2 Cutaway view of the pads

2. FEM MODELING

A static, small-deformation 2D analysis type was used. In order to overcome locking phenomena in incompressible plasticity we assume plane stress with thickness model. The shoe was modeled by 1250 Q4 elements. The rolling cylinder (roller) was modeled by 650 Q4 elements. In the contact region a coarse to finer mesh transition is performed. A detailed view of the FEM model is given in Fig.2.1 The layer of welded material is modeled with the same type of elements but mesh density is increased, to be able to capture contact stresses distribution. External force is assumed to act on nodes at lower half of inner circle, with distribution given in the Fig.2.1.

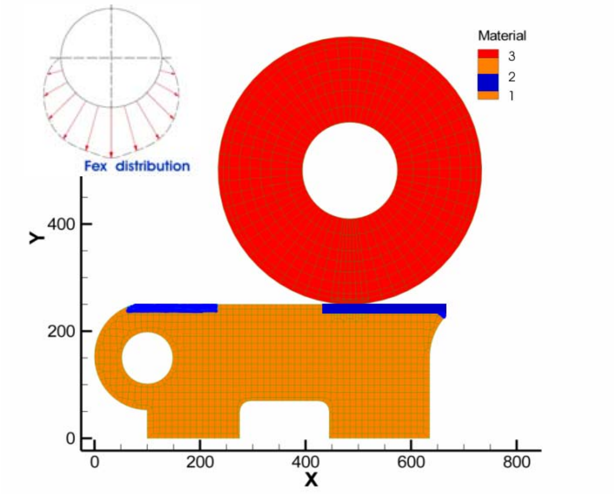

Figure 2.1 FEM model

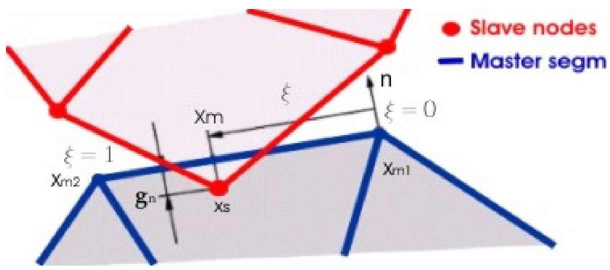

Figure 2.2 N-T-S Contact concept

2.1 Contact modeling

The contact problems correspond to an optimization problem (minimum of deformation energy function) subjected to inequality constraints. Therefore, analytical solutions are obtained for a few relatively simple problems. The contact forces that arise from the inequality constraints over the contact area are unknowns. In addition, the contact area and deformation status of the bodies in contact are also unknowns. These unknowns associated with any contact problem render the resulting problem nonlinear. The numerical algorithm used in this study is based on penalty method for contact constraint regularization. In the above stated problem, the main constraint (in normal direction) is impenetrability condition given by:

$$(u_2 - u_1) \cdot n + g_0 \geq 0 \tag{1}$$

where u_1 and u_2 correspond to displacements of contacting surfaces, n is the normal vector while g_0 is initial gap between two bodies. According to Node-To-Segment approach (Fig. 2.2), the gap function is given by

$$g_n = \left[x - \overline{X}_0(\overline{\xi}) \right] \cdot \overline{n}_0(\overline{\xi}) \tag{2}$$

where n_o is the normal vector, so, contact condition is defined by inequality constraint $\boldsymbol{g_n \geq 0}$.

2.2 Constitutive relation

The basic material of the pads and roller was assumed to be manganese steel with identical behavior in tension and compression. When the contact stresses exceed nominal values, plastic deformation take place. To detect local transition from elastic to plastic state, J2 plasticity model with isotropic, nonlinear hardening is used. Recall that the material will yield if the von Mises equivalent stress reaches the uni-axial yield stress. The yield function for J2 model is given by:

$$F(s, \varepsilon_{ekv}) = \frac{1}{2} \cdot s : s - g(\varepsilon_{ekv}) \tag{3}$$

where s is the deviatoric part of the stress tensor and $g(\varepsilon_{ekv})$ is isotropic hardening function of equivalent plastic strain.

The flow rule is given by

$$\dot{\varepsilon}_{pl} = \dot{\lambda} \cdot \vec{n} = \dot{\lambda} \cdot s \text{ (associative plastic flow rule} \Rightarrow \frac{\partial F}{\partial \sigma} = \frac{\partial F}{\partial s} = s \text{)} \tag{4}$$

The λ is plastic multiplier. Hardening behavior of used materials $g(\varepsilon_{ekv})$ is taken into account by reading externally supplied data file with yield stress - equivalent plastic strain data. Those data are obtained by simple extension tests of each material specimen. Including plastic consistency condition

$$\dot{F} = \frac{\partial F}{\partial s} : \dot{s} = s : \dot{s} = 0 \tag{5}$$

it is possible to solve system of equations by return mapping algorithm. Due to nonlinear hardening law, it is necessary to implement internal Newton-Raphson loop in order to compute correct value of plastic multiplier λ.

2.3 Solution procedure

Substitution of the finite dimensional quantities into the weak form of balance of momentum and implementation of the boundary conditions, gives set of nonlinear equations:

$$F^{\text{int}}(u) + R_C(u) = F^{ext}(t) \tag{6}$$

F^{int} is the internal force vector which depends nonlinearly on nodal displacement vector u and it is given by

$$F^{\text{int}}(u) = \sum_e \int_{\Omega_e} B_I^T \cdot \sigma \cdot d\Omega \tag{7}$$

R_C is the contact force vector which also depends nonlinearly on u. The F^{ext} is external (applied) force vector, which is known function of time. Matrix equation (6) is nonlinear, due to internal and contact force vectors. The residual equation (ignoring the nodal indices), in the matrix form becomes:

$$G(u) = F^{ext} - F_{\text{int}}(u) - Rc(u) = 0 \tag{8}$$

The solution is obtained by linearization of both vectors, in incremental-iterative procedure, using full Newton – Raphson method. In that case, the contact stiffness and element tangential stiffness matrix are defined as:

$$Kc(u) = \frac{\partial}{\partial u} R_C(u) \quad and \quad K^{el}{}_T = \frac{\partial F^{el}{}_{INT}}{\partial u} = \int_{\Omega_{el}} B^T C^T B dV_{el} \tag{9}$$

Tangential stiffness matrix at system level is obtained by assembly of element tangential stiffness matrices. The C^T is tangent material matrix in corresponding integration point.

3. NUMERICAL SIMULATION

The algorithm for solution of contact problem presented in this paper has been implemented into Cont2D code. The code is intended for numerical simulation of quasi static, 2D, inelastic contact problems. The program is written in FORTRAN-90 and it has a modular structure. Through simulation it is of interest to determine:

- The contact zone dimensions and stresses as a function of external load
- The critical load that is required to initiate plastic flow in the pad
- The influence of the thickness and hardness of welded layer at plastic deformation

The roller was divided into two different mesh density zones. Zone I, close to contact zone had extremely fine mesh to better handle the high stress gradients and to achieve good discretization for accurate detection of the contact area dimensions. Zone II, outside the contact zone, had gradual coarser mesh. The upper surface of the pad is discretized with more then 100 contact segments. The boundary conditions are presented in Fig. 2.1. The bottom nodes at crawler pad are fixed in vertical direction. The load is gradually increased in 25 equally distributed load steps.

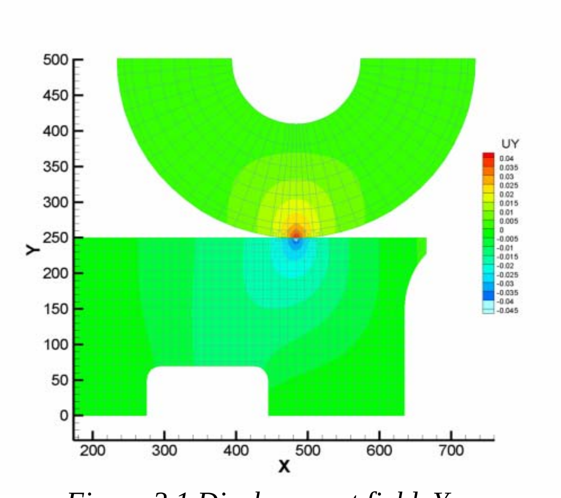

Figure 3.1 Displacement field Y

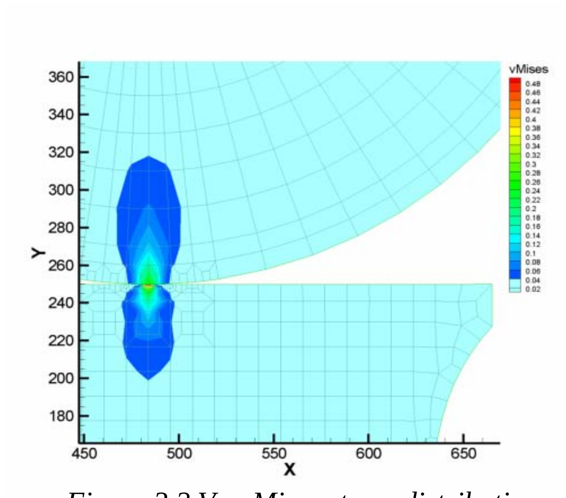

Figure 3.2 Von Mises stress distribution

4. CONCLUSIONS

Although Hertz theory is appropriate to calculate deformations and pressure distributions in the elastic range for homogenous materials, it was not suitable to compute the stress fields beneath the contact in case of plastic deformations of layered materials. The presented FE-simulation is able to compute stress fields distributions in contact of non-homogeneous material (welded layer + basic material). The solution method is applicable to wide range of static and quasi static contact problems with material nonlinearities. If necessary, the contact forces could be evaluated from the current nodal point stresses, in stress recovery procedure. These results meet the expectations and justify the modeling concepts outlined in the preceding section. The main conclusions from the numerical simulations are:

- The stresses caused by nominal load are far away from elastic limit. It could be said that roller path is properly dimensioned with respect to contact stresses. Plastic deformations will occur at much higher load level. Such loads are consequences of non-uniform total load distribution.
- The boundary surface of the plastically deformed material is determined by all the nodes with equivalent (von Mises) stress larger than the initial yield stress. When a welded layer is plastically deformed its ability to sustain further load is reduced. Consequently, a further load increase will mainly affect surrounding zones in the basic material, beneath the surface.
- The algorithm proposed formulations prove to be very robust and efficient for 2D problems. It simplifies the procedure of obtaining the solution of contact problem, and being an effective alternative to other algorithms.
- The final conclusion is that the developed model can be used to gain more insight in the problem and can serve as a basis for development of repairing technology.

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