FEM ANALYSIS OF THE STEERING KNUCLE IN ELASTIC-PLASTIC FRACTURE MECHANICS

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ABSTRACT

Finite elements used at present lack such properties as those of the special element PENTA 20. The element proposed has wide application in the fracture analysis of structures, where ductile fracture is investigated. It permits a determination of the relationship between crack tip field parameters, loading, and geometry.

INRODUCTION

In motor vehicles, various mechanical parts are subjected to fatigue stresses of variable amplitude during their service lives. The application of sophisticated calculation techniques (finite element methods), which provide a complete spectrum of stresses acting on components, are becoming increasingly common in the desing phase. This enables the material to be rationally 'distributed' in critical areas where the probability of fatigue failure is highest.

In motor-car vehicles for certain parts and units it does not suffice to determine their immediate strength but it is necessary to calculate their dimensions and configurations in relation to resistance. The knuckle is included amongst these elements. The determination of the needed resistance of the knuckle for particular vehicles constitutes a very difficult problem. This is the reason of presenting some aspects of correct configuration and calculation of dimensions of the knuckle using FEM and fracture mechanics.

OUTER LOADINGS

During exploitation of the vehicle the knuckle is loaded by variable forces which derive from weight, wind force, perpendicular and horizontal mass forces, braking force and side forces. Evindently all these forces must be transferred by the knuckle. The general case of knuckle loading has been presented in Fig.1 where the following forces occur:

F_V - running straight ahead, taking a corner, braking
F_H - running straigt ahead, taking acorner
F_B - braking
F_L - running straight ahead, running over irregular surfaces, forces from the steering system

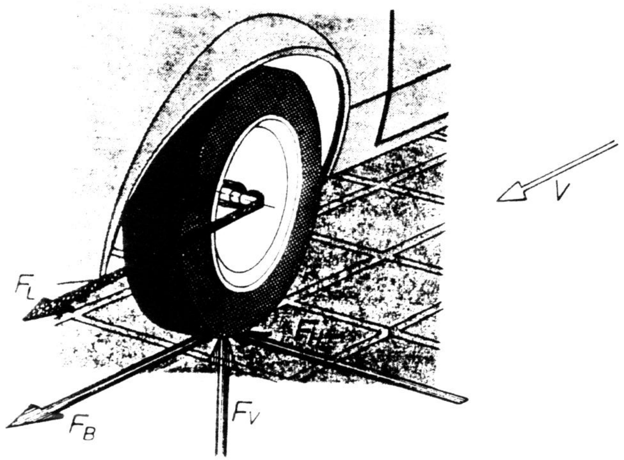

Fig.1. System of forces working on the steering knuckle

In order to determine the knuckle resistance and at the same time to define basic parameters of the mechanics of FEM cracking, a 20-noded isoparametric element has been constructed.

SINGULARITY OF 3-D PRISMATIC QUATER POINT ELEMENT

Following the notation of Reference [1], the geometry of a 20-noded isoparametric element is mapped into the normalized cubic space (ξ,η,ζ):

$$-1 \le \xi,\eta,\zeta \le 1 \qquad (1)$$

through the transformations,

$$x = \sum_{i=1}^{20} N_i(\xi,\eta,\zeta)\, x_i$$

$$y = \sum_{i=1}^{20} N_i(\xi,\eta,\zeta)\, y_i \qquad (2)$$

$$z = \sum_{i=1}^{20} N_i(\xi,\eta,\zeta)\, z_i$$

When referred to the parent element in Fig.1b the shape of the twenty noded, seredipity, isoparametric qurter-point, singular, solid element are given by

$$\begin{aligned} N_i(\xi,\eta,\zeta) = {} & 0.125\,(1+\xi\xi_i)(1+\eta\eta_i)(1+\xi\xi_i)(\xi\xi_i+\eta\eta_i+\zeta\zeta_i-2)\,\xi_i^2\eta_i^2\zeta_i^2 \\ & + 0.25\,(1-\xi^2)(1+\eta\eta_i)(1+\zeta\zeta_i)(1-\xi_i^2) \\ & + 0.25\,(1-\eta^2)(1+\zeta\zeta_i)(1+\xi\xi_i)(1-\eta_i^2) \\ & + 0.25\,(1-\zeta^2)(1+\xi\xi_i)(1+\eta\eta_i)(1-\zeta_i^2)\,. \end{aligned} \qquad (3)$$

For the element shown in Fig.2(a,b) we have , the state of displacement of a point is defined by three displacement components u_x, u_y and u_z, in the directions of the three coordinates x,y and z.

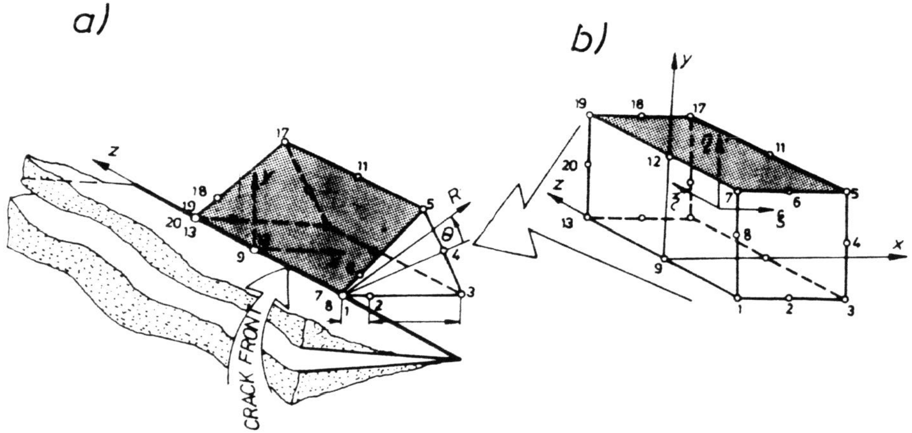

Fig.2. a) 3-D prismatic quarter point element, b) Parent element

Thus

$$\{ u \} = \begin{Bmatrix} u_x \\ u_y \\ u_z \end{Bmatrix} \quad (4)$$

Since the element is isoparametric, both its displacements and coordinates may be written as

$$\{ u \} = \sum_{i=1}^{20} \mathbf{N}_i (\xi, \eta, \zeta)\, \mathbf{u}_i \quad (5)$$

The stiffness matrix of the element can thus be found:

$$[\,K\,] = \int_{1}^{1}\int_{1}^{1}\int_{1}^{1} [B]^T\, [D]\, [B]\, \det|\, J\, |\; d\xi\, d\eta\, d\zeta \quad (6)$$

where [D] is the steffness matrix of the material [1,2], and matrices [B] and |J| have been presented [2].

$$d\{\sigma\} = [D_{e-p}]\; d\{\varepsilon\} \quad (7)$$

with

$$[D_{e-p}] = [D] - [D] \left\{\frac{\partial F}{\partial\{\sigma\}}\right\} \left\{\frac{\partial F}{\partial\{\sigma\}}\right\}^T [D] \left[A + \left\{\frac{\partial F}{\partial\{\sigma\}}\right\}^T, [D]\left\{\frac{\partial F}{\partial\{\sigma\}}\right\}\right]^{-1} \quad (8)$$

The elasto-plastic matrix [D] takes the place of elasticity matrix [D] in incremental analysis. In the element presented in Fig.1 a homogeneous stress and field is assumed in the elasto-plastic range which greatly simplyfies the problem of deriving the matrix $[D_{e-p}]$ and also the isotropic law of material. Using relation (8) and substituting to eq (6) the dependence for elasto-plastic matrix has been obtained.

$$[\,K_{e-p}] = \int_{1}^{1}\int_{1}^{1}\int_{1}^{1} [B]^T\, [D_{e-p}]\, [B]\, \det|\, J\, |\; d\xi\, d\eta\, d\zeta \quad (9)$$

NUMERICAL EXAMPLES

On the grounds of the finite element method and the dependencies derived to describe a three-dimensional PENTA-element, we worked out the RYSA (craze) program. The solution is based on incremental plasticity theory of elastic-perfectly elastic material that satisfies the von Mises yield criterion and its associated flow rule. The finite element solution is obtained by progressing along the loading path.

This software allows us to compute:

- stress intensity factor **K**,
- Rice's integral **J**,
- critical crack extension **COD** , and crack growth Δa,
- obtaining the isolines of respective stresses $\bar{\sigma}_1$,after any load level change.

The program is described in detail in paper [1].

In order to determine the state of effort of the steering knuckle for particular exterior loads which it undergoes during exploitation, calcular of FEM resistance have been made. The knuckle has been modelled with PENTA-type elements which have been described above. Exemplary calculation results have been given in Fig.3.

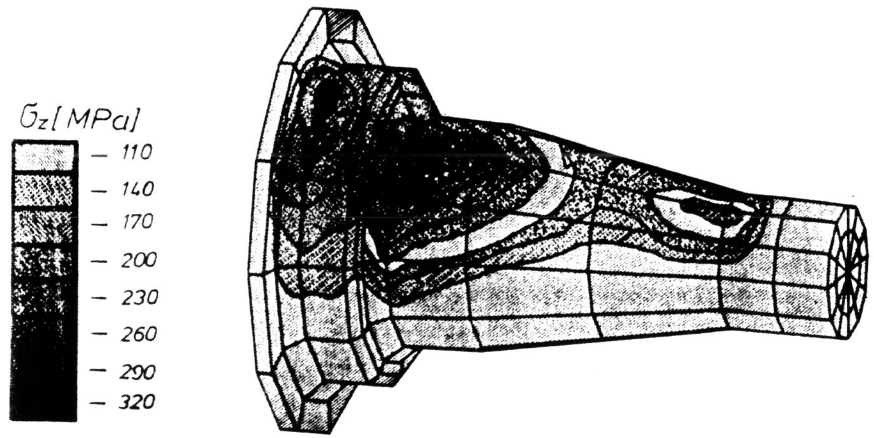

Fig.3. Diagrams of the von Huber-Mises stress in the steering knuckle during initiation of fatigue fructure.

Next, in the place of concentrationof of stress (Fig.3) the initiation of fatigue fracture has been introduced. As result of the change of stress distribution and the increasse of variable number of the change of stress distribution and the increase of variable number of a fructure. Exemplary stages of the development of plastic zones have been presented in Fig.4.

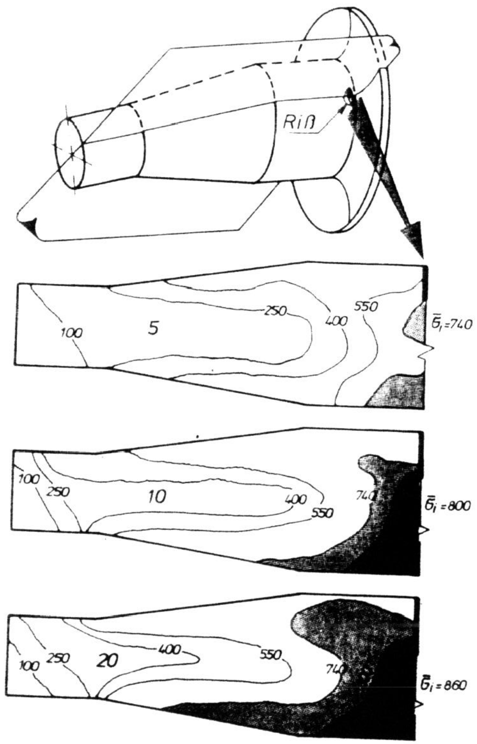

Fig.4. Development of a crack and plastic zones in the knuckle.

After each step of loading the following are obtained from calculations: coefficient of the intensity of stress, growth of the gap, and other parameters of fructure mechanics which are very useful when determining the resistance of such elements.

EXPERIMENTAL INVESTIGATIONS

Investigations knuckle fatigue were carried out on the MTS 80 hydropulse machine. The steering knuckles were constructed of 30H alloy steel for which the limit of resistance to breaking R_m=880 MPa and the creep limit $R_{e0.2}$=740 MPa. In general the real steering knuckles of 15 delivery trucks at 4 levels of maximal Huber-Mises stresses (350,320,280,250 MPa) were examined.

Forces acting on the steering knuckle were introduced through a specially constructed device. The values of force exerted by the hydraulic pulsator on the steering knuckle were within the range of 5kN to 40kN. Operation of the hydraulic pulsator for individual levels of maximal stress was realized by a single cycle of passage on an irregular surfaced road at a speed of 30 km/h. This was assured by a programme with which the IBM PC controlling the pulsator was equiped. The controlling value in fatigue investigations was maximal force in a single cycle which complied with one of the four maximal levels of stresses. During fatigue investigations only the number of cycles of load changes was recorded. The initiation of a fracture in fatigue failure of the steering knuckle (Fig.5) formed on the surface of the steering knuckle axis in the extreme layers of the greatest stress as obtained from FEM (Fig.3).

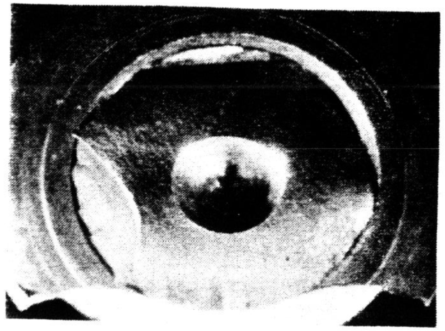

Fig.5. Steering knuckle test .

On the basic of the results obtained from fatigue investigations of the steering knuckle, adiagram was constructed of the Wohler curve in the function of the passage of kilometers, which is presented in Fig.6. Moreover, the curve obtained from numeric simulation using FEM has also been presented in the diagram.

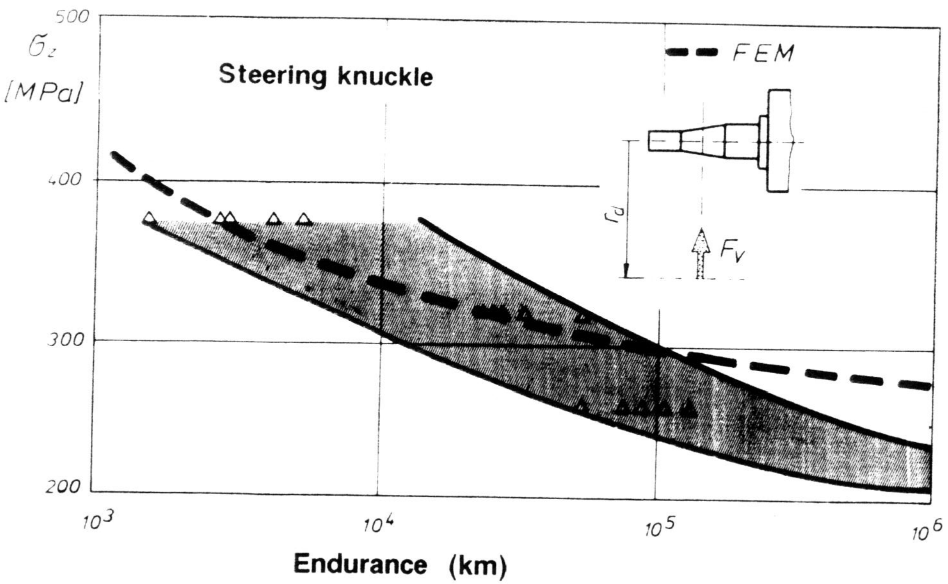

Fig.6. Diagrams of the Wohler curve for steering knuckles obtained experimentally and through FEM.

CONCLUSION

This development deserves wide application to the analysis of most engineering **3-D** structures where fracture is investigated. Finally, through the use of purely elastic and elastic-perfectly plastic results, it is possible to bind all solutions for power hardening materials .Experimental investigations satisfactorily confirrmed the results obtained from numerical simulation of FEM on the basic of fracture mechanics.

REFERENCES

[1]. Atluri S. N., Yagawa G.:Computational Mechanics '88. Theory and applications. *Vol.* 2. Berlin *Springer*, 1988.

[2] El Abdi R. and Valentin G.: Isoparametric elements for a crack normal to the interface between two bonded layers. *Com.* & *Str.*, 1989, Vol.33.