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STRESSES AROUND A SUBSURFACE CRACK LIKE HOLE UNDER MOVING NORMAL LOAD

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ABSTRACT

Wear is a common phenomenon in the field of mechanical design and surface engineering. One type of wear damage is called as delamination and caused by the subsurface cracking. After formation of microvoids at some distance from surface, cracks are generated by uniting these microvoids.

In the present study, the stress field around a subsurface crack like hole subjected to moving normal loading has been investigated by the finite element method. The variation of stresses and displacements due to location of load and to location of hole were analysed in terms of dimensionless parameters.

Key words: Moving Load, Delamination, Wear, Stress Analysis, Finite Element Method

HAREKETLİ NORMAL KUVVET ETKİSİNDE YÜZEY ALTI ÇATLAK ŞEKİLLİ DELİK CİVARINDAKİ GERİLMELER

ÖZET

Aşınma makine tasarımı ve yüzey mühendisliği açısından sık karşılaşılan bir olgudur. Aşınma hasarlarından birisi de yüzeyaltı çatlaklarının neden olduğu tabakalanma hasarıdır. Yüzeyden herhangi bir mesafede oluşan mikroboşluklar zamanla birleşerek çatlak oluşmasına neden olur.

Bu çalışmada, hareket eden normal yük etkisinde yüzey altında bulunan çatlak şekilli delik civarındaki gerilme alanı sonlu elemanlar metoduyla incelenmiştir. Gerilmelerin ve şekil değiştirmelerin, yükün ve deliğin konumuna göre değişimi boyutsuz parametrelerle belirlenmiştir.

Anahtar Kelimeler: Hareketli Yük, Tabakalanma, Aşınma, Gerilme Analizi, Sonlu Elemanlar Metodu

1. INTRODUCTION

One of the most important design subjects in mechanical engineering is surface and its behavior under several loading and environmental conditions. This behavior is studied in the tribology discipline. Machine components are generally in relative movement according to each other. So, the loads move over one of the component. A most common surface damage is delamination, which begin with formation of microvoids and microcracks under some depth of surface. These cracks propagate and after some times cause damages to the surface.

The original theory of delamination wear is proposed by Suh [1] and expanded by his coworkers [2,3,4]. Since then many studies have been carried out about the moving loads and subsurface cracks. Chen et. al., [5] studied on the initiation and propagation of subsurface cracks under rolling contact. They observed that the depth where the subsurface crack initiates corresponds with the depth of maximum reversed shear stress. Kimura and Okada [6] investigated the sliding damage in plane contact. According to their studies, subsurface defects seem to act as preferential sites of origin of initial crack formation. The cracked material is then removed and causes the damage to propagate in the direction of sliding. Dally et. al. [7] analysed the subsurface crack propagation and implications for wear of elastically deforming materials. They used the photoelastic methods to analyse the stress intensity factors and crack trajectories for subsurface cracks relevant to the process of wear particle generation. A concentrated load is applied to the boundary of the half plane in close proximity to the crack tip. Elsharkawy and Hamrock [8] studied on the determination of maximum shear stress and the von Misses equivalent stress distributions in the solids. Bryant [9] and Olsson [10] studied several phenomenon of moving loading. Bryant investigated the necessary conditions for the minimum volume of beams, consisting of longitudinal segments of different constant cross-sectional areas, subjected to moving loads. Sun and Bell [11] and Alpas et. al. [12] studied delamination of material layers. Alpas et. al. observed that, in ductile materials, the delamination process usually involves large plastic deformation and subsurface damage. They measured the subsurface displacement and microhardness gradients as a function of sliding distance. They concluded that, wear proceeded mainly by a mechanism of delamination via subsurface crack growth. It is proposed that the competition between the plastic strain, which enhances void growth, and the hydrostatic pressure, which suppresses it, is responsible for the generation of a damage gradient so that the delamination takes place at a certain depth where the damage accumulation rate is maximum.

Lee et. al. [13] and Lee and Ren [14] used the finite element analysis method for subsurface cracks. Lee at. al., considered a subsurface crack subjected to a moving compressive load, and Lee and Ren studied subsurface stress fýeld created by three dimensionally rough bodies in contact with traction. An analytical study is carried out by Cheng et al [15]. They Used dislocation pile up theory and developed a model for the prediction of crack initiation life under contact fatigue. Near surface crack initiation is investigated by introducing the sliding contact boundary condition.

Ding et. al. [16] focused on the behavior of subsurface cracks beneath gear teeth with a view to developing a fundamental understanding of the mechanisms of pitting/spalling fatigue. They modelled a number of two-dimensional small cracks, parallel to the tangent plane, beneath the pitch line of a gear tooth by using the finite element method. Djabella and Arnell [17,18] analysed the contact stresses in elastic double-layer system under several stationary loading conditions. They also investigated several combinations of elastic layers having different mechanical properties and geometrical conditions.

In this study, a finite rectangular plate having a subsurface crack like elliptical hole have been analysed under moving normal load. First, the location of maximum shearing stresses was investigated for the body having no hole. Then, the analyses were carried out for several location of load. Two positions for the hole were considered. In this respect the problem is a quasi-static stress analysis problem. The finite element method with nine node isoparametric elements have been applied for modelling of the problem.

2. THE FINITE ELEMENT ANALYSIS

The finite element method is now a well-known method having very well defined procedures [19-22]. In this study, a finite element program developed by Topcu and Tasgetiren [23] has been used. The program is a general-purpose program for two-dimensional stress analysis.

The problem, in this study, is a plane stress problem. The schematic representation of the problem and finite element model are given in Figure 1 and 2 respectively. Geometrical configuration have been chosen such that: $H/L=1$, $a/L=0.1$, $b/L=0.2$. Analyses were carried out for two positions of hole ($y/H=0.1$ and 0.2). The load moves in direction shown by the arrow. The problem has been solved for nine position of load as it moves in the direction ($x/L= -0.9, -0.6, -0.3, -0.1, 0, 0.1, 0.3, 0.6, 0.9$). The finite element model contains 420 elements and 1770 nodes. Boundary conditions are given in Figure 2. The material used in the analyses is steel, that is, E=2 x 10^5 Mpa and ν=0.3.

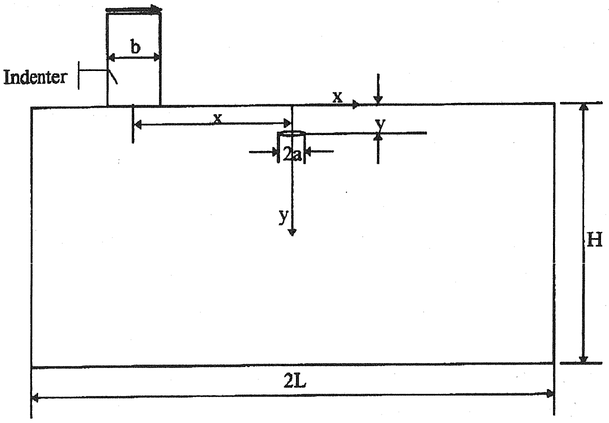

Figure 1. Schematic of the problem.

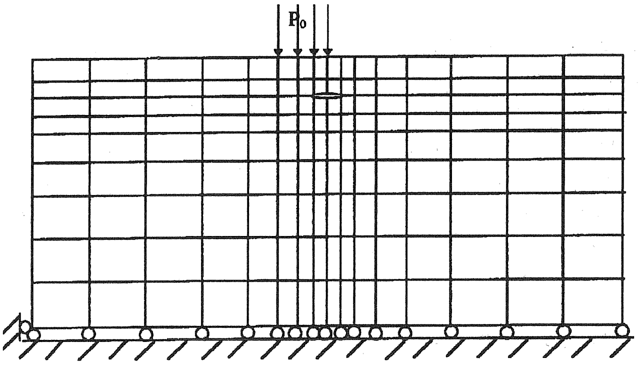

Figure 2. Schematic of the finite element model

3. RESULTS AND DISCUSSION

The deformed geometry of the body with respect to loading position for hole located at y/H=0.2 are given in figure 3 for demonstration purpose. Similar deformed geometry have also been obtained for hole located at y/H=0.1. The deformations for latter case are greater around the hole. For both cases, the deformations are greater for loading at x/L=-0.9 and x/L=0.9 than other loading positions. As can be seen there is symmetry according to loading position.

The stresses are analysed in terms of principal shearing stresses and von Misses equivalent stresses. In general, these stresses are responsible for failure. The shearing iso-stresses are given in figure 4 and figure 5 for the cases of two hole locations. Because of symmetry, only five loading positions have been given.

The maximum stresses have been obtained below the surface at y/H=0.1 for uncracked geometry. This is in agreement with the literature [24]. Due to this result, one of the hole location is chosen as y/H=0.1. Other hole location is chosen as y/H=0.2 whether a hole located at deeper point than maximum stress location can propagate.

As in the deformation analysis, the stresses are greater for loading at x/L=-0.9 and x/L=0.9. After this loading, stresses reach maximum values for loading at x/L=0. Even for the hole located at deeper point than maximum stresses (y/H=0.2), the stresses reach grater values than uncracked case. The maximum stress field moves to hole front as loading closes the hole location (Figure 5). Maximum shearing stresses caused in the body are given in figure 6. For both cases, stresses are 1.5 times greater than that of uncracked body.

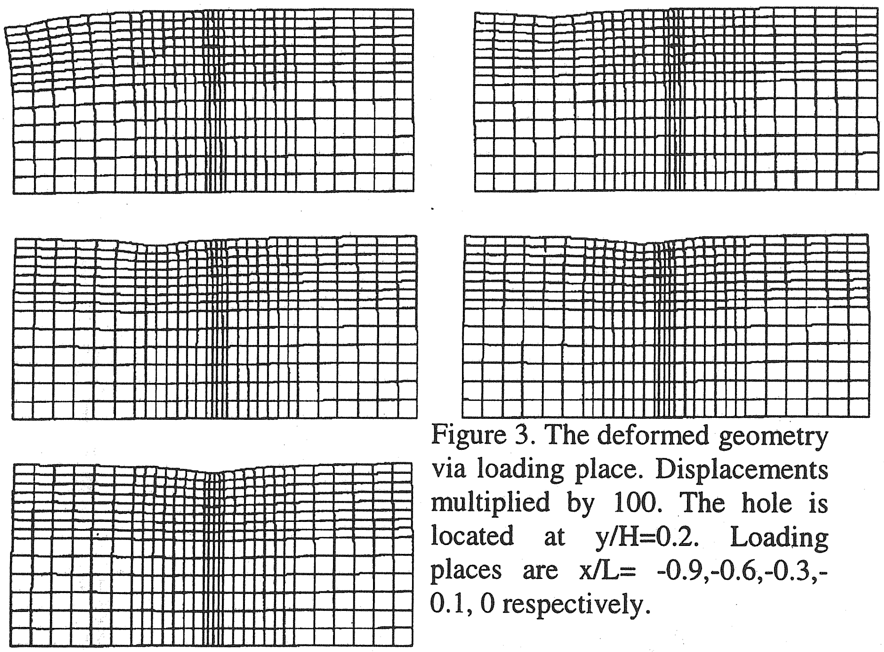

Figure 3. The deformed geometry via loading place. Displacements multiplied by 100. The hole is located at y/H=0.2. Loading places are x/L= -0.9,-0.6,-0.3,-0.1, 0 respectively.

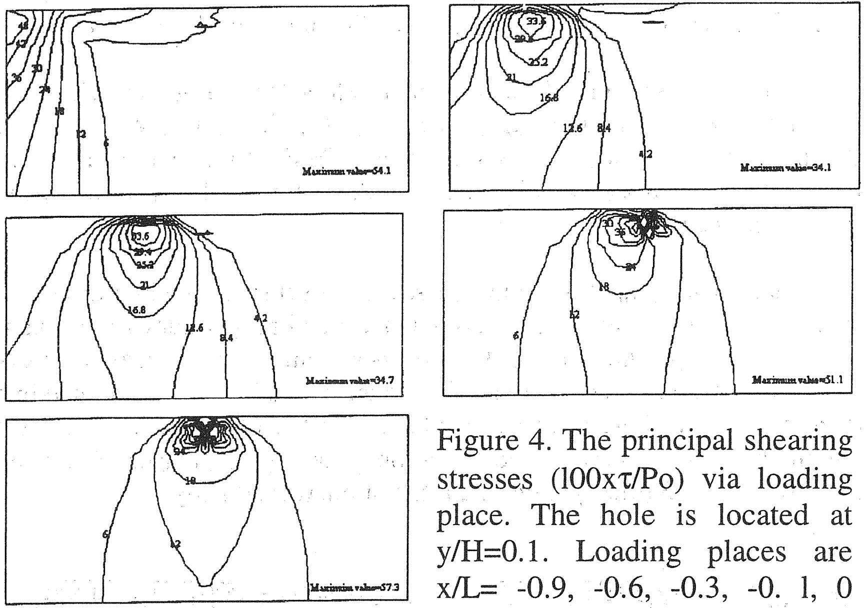

Figure 4. The principal shearing stresses (l00xτ/Po) via loading place. The hole is located at y/H=0.1. Loading places are x/L= -0.9, -0.6, -0.3, -0. 1, 0 respectively.

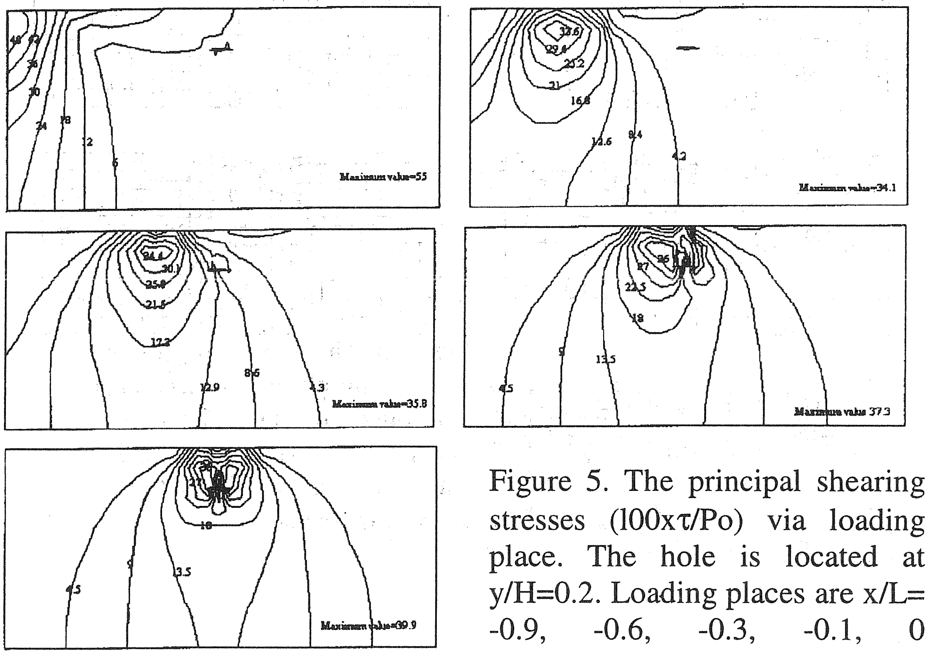

Figure 5. The principal shearing stresses (l00xτ/Po) via loading place. The hole is located at y/H=0.2. Loading places are x/L= -0.9, -0.6, -0.3, -0.1, 0 respectively.

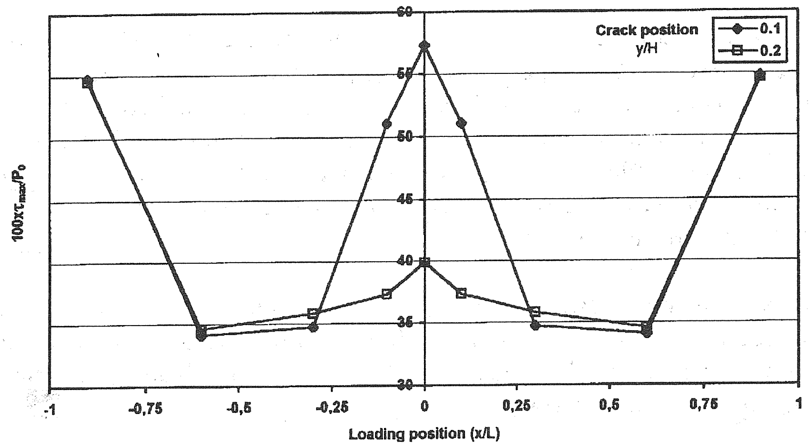

Figure 6. Variation of maximum principal shearing stresses in the solution domain via loading position.

For every loading position, maximum equivalent stresses occur at center of indenter. This stress increases to a maximum value just below the surface and than decreases. The maximum value is greater than applied stress at sides and around the hole. Stresses near the supported edge have greater values than surface for distant location from loading position. The stress distributions are nearly equal for both hole location for x/L=-0.9, -0.6 and -0.3 loading positions. As the load approaches to hole, the distribution varies importantly. The stress at the hole tip reaches its maximum value for loading at x/L=0 and hole location y/H=0.1. This value is 1.2 times greater than applied stress. For both cases of hole location, the stresses are 1. 5 times greater than that of uncracked geometry as in shearing stresses For the hole center, stresses decrease very rapidly on upper surface and than increases from lower surface.

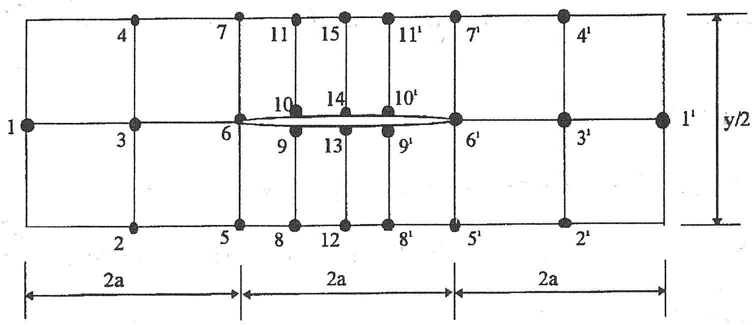

Figure 7. Hole shape and locations of the nodes used to plot von Misses equivalent stresses around the hole.

The von Misses equivalent stress variations around the holes (Fig. 7) are given in figures 8 and 9 with respect to loading position. The symmetry is seen for each point under consideration. Maximum values are reached at hole tip and upper regions of hole for both holes location cases (at point 6, 7 and 6', 7'). For the hole location y/H=0.1, the stresses becomes 1.2 times greater than applied stress. This is, however, lower for other hole location case, but also greater than expected values for uncracked body.

Von Misses equivalent stress values decreases at inner points and lower regions of hole (point 9,13,14 and 9'). At points 13 and 14, the stresses have the minimum values for loading position x/L=0. For other loading positions, the stress variations are also given in these figures.

4. CONCLUSION

A finite element analysis has been applied for the analysis of stresses around a subsurface hole under moving normal load. Analysis has been carried out in terms of principal shear stresses and von Misses equivalent stresses, as these stresses are responsible for cracking. The stresses have been investigated according to the geometrical positions of load and hole.

It is found that both the principal shearing stresses and von misses equivalent stresses take a maximum value (1.2 times greater than applied stress) for uncracked geometry at some depth from the surface (y/H=0.1 for this analysis). The stress values at and near the hole tip is about 1.5 times greater than the values expected for uncracked geometry. This shows that once a subsurface hole is formed, it will grow very rapidly.

The effect of friction and so, the tractional forces are the subjects of another study.

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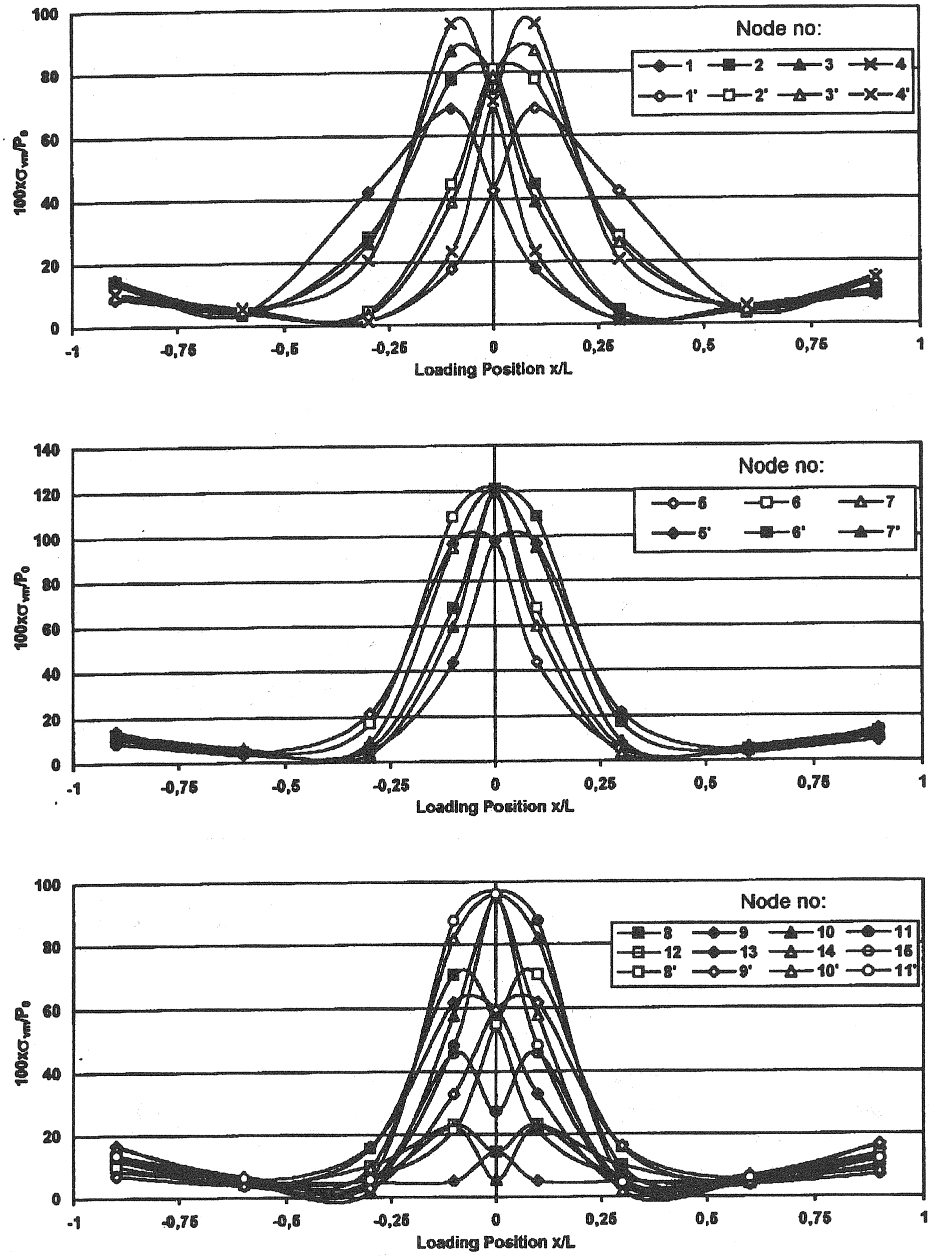

Figure 8. The von Misses equivalent stress variation via loading position around the hole. Location (y/H)=0.1 (The numbers in the legends are given in Figure 7).

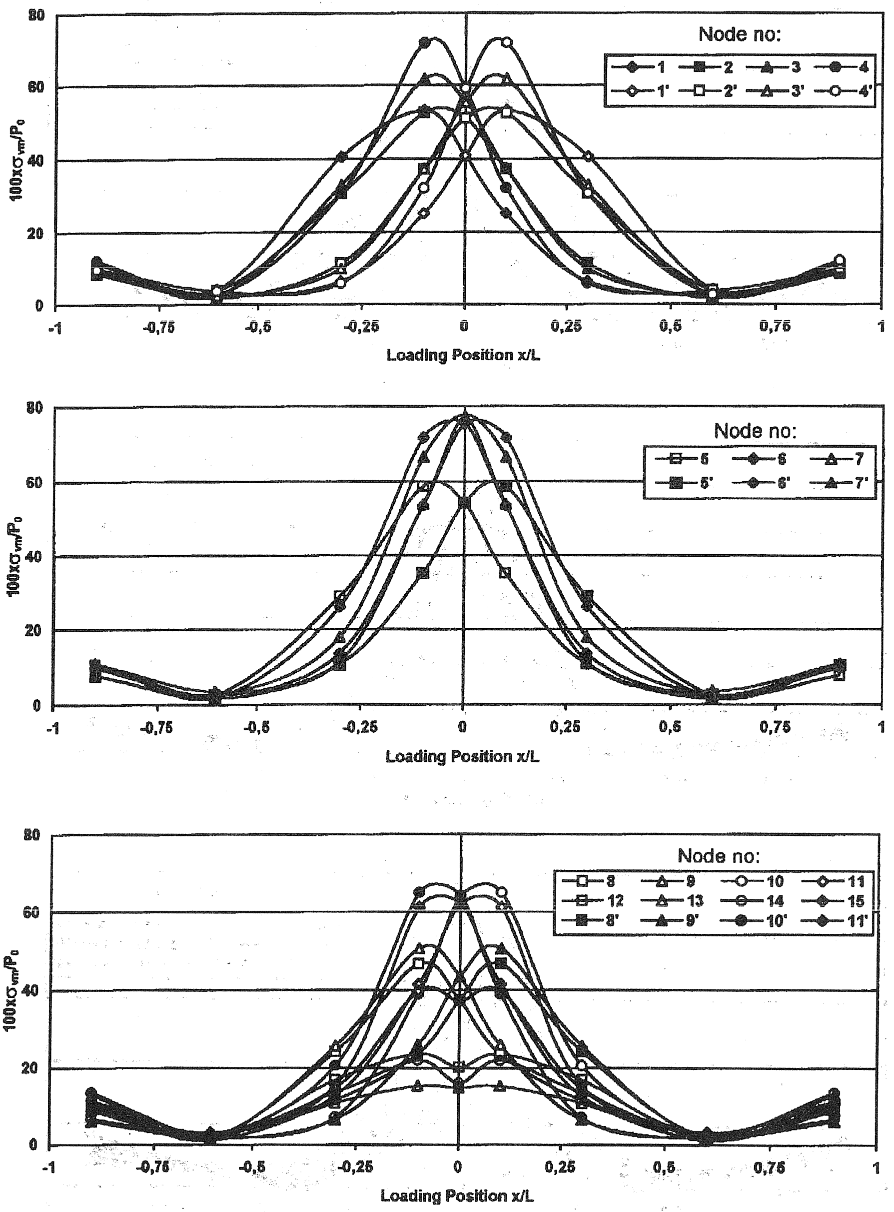

Figure 9. The von Misses equivalent stress variation via loading position around the hole. Location (y/H) =0.2 (The numbers in the legends are given in Figure 7)

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