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Computer simulation of the effort states of the teeth's hard tissues

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The study presents a class of effort of brittle media problems. The model of human tooth with non-carious cervical lesion was analysed. Regions of the most disadvantageous loads was determined.

1. Introduction

Analysis of the stress fields at locations where their singularity exists, is a very important problem in research on continuous media. The singularity is a results of defects defined as notches. The experience indicates that the material containing notches undergoes distributive destruction more easily than the one without any defects. And this is caused by stress concentration in the apex of the notch. This phenomenon is observed, among others, in biomechanics of the teeth's hard tissues. As the numerical research in this field was carried on [3, 4, 9], the problem of non-carious angular lesion was examined. Defects of this kind are typically wedge-shaped with sharp edges, hard and smooth surfaces [5, 7].

The etiopathogenesis of angular cervical lesions is complicated and includes (abrasion) and biomechanical (stresses) agents. The non-carious loss of tooth structures is becoming a common problem, especially in the population of young people where the systematic increase of prevalence of these lesions was noted [5, 7]. This study has analysed the influence of angular lesion on effort states in its region.

2. Numerical model

This study was carried out on the model of human lower premolar tooth. Regarding the dynamics of defect growth, two models with different angular lesions in cervical region of the tooth were examined. The alteration of defects geometry was presumed and selected angular defects differed in depth and shape of notches. The finite element mesh was generated by Delaunay triangulation [6]. The density of the mesh in the region of sharp-shaped notch in the bottom of defect inducing stress concentration was increased in the process of discretization. Discrete models with details of division in these regions are shown in Fig. 1.

Model 1 is comprised of 1811 3-node triangular elements and 997 nodes. Model 2 is made up of 1529 elements and 856 nodes. In the process of modelling the surrounding tissues i.e. periodontal tissue, alveolar bone and pulp were considered irrelevant and thus they were omitted [4, 8]. Location

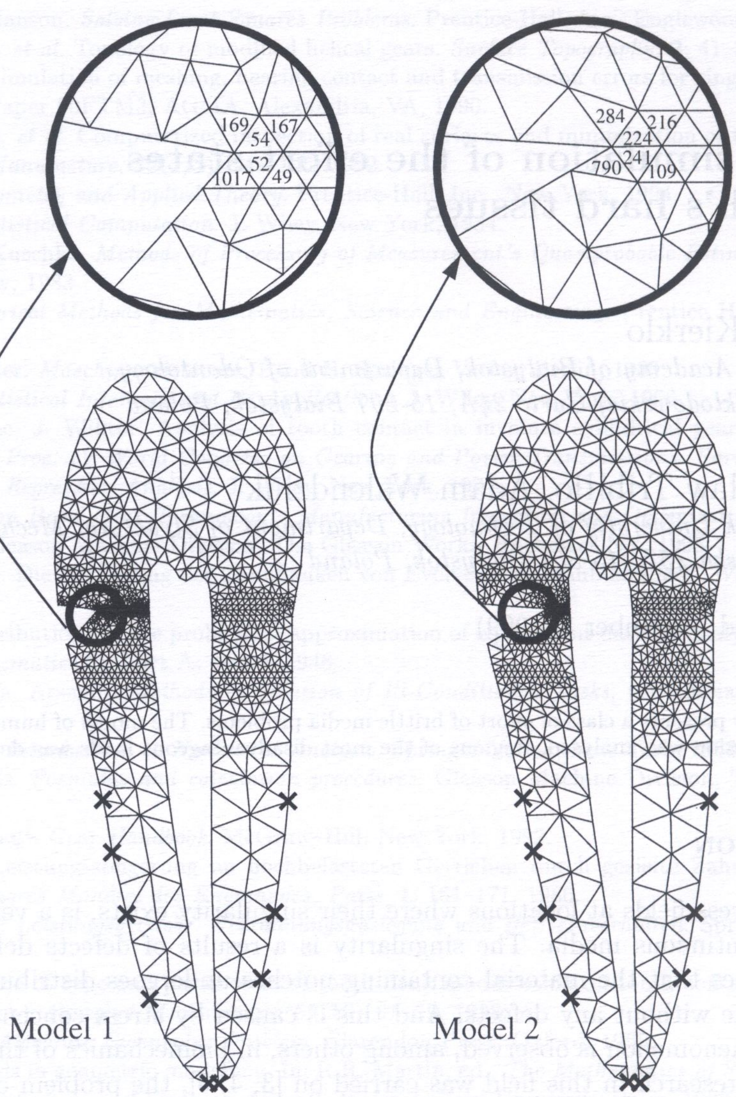

Fig. 1. Discrete models of hard tissues media

of teeth in alveolus was modelled by putting constrains on selected mesh nodes within the area of the root (Fig. 1). Young modulus (E) and Poisson ratio (ν) for the dentin were as follows [2, 8]: $E = 19000$ MPa, $\nu = 0.30$.

3. Problem analysis

The influence of localization of tooth's crown loads on the effort of the dentine near the apex of the notch was considered. Problem analysis was performed by the finite element method in displacement approach, with a linear relation σ–ε for the material until its destruction occurred. Stress field in the finite element is given by the equation [1]

$$\sigma_e = E_e \, B_e \, d_e \, , \tag{1}$$

E_e – elasticity matrix,

B_e – strain-displacement matrix,

d_e – nodal points displacements vector for the element.

Displacements of element nodes can be obtained as a result of the linear equations system solution

$$\mathbf{KD} = \mathbf{F}\,. \tag{2}$$

The $\mathbf{K}$ matrix is the global stiffness matrix, $\mathbf{D}$ and $\mathbf{F}$ are nodal displacements and nodal forces vector, respectively,

$$\mathbf{D} = \{d_1, \ldots, d_n\}^T, \qquad \mathbf{F} = \{f_1, \ldots, f_n\}^T, \tag{3}$$

n – number of nodes in the model.

A failure criterion for continuum tissues of dentin was assumed as [3]

$$R_c^2 = \bar{\sigma}_1^2 + \bar{\sigma}_2^2 + \bar{\sigma}_3^2 - 2\nu(\bar{\sigma}_1\bar{\sigma}_2 + \bar{\sigma}_2\bar{\sigma}_3 + \bar{\sigma}_3\bar{\sigma}_1), \tag{4}$$

$$\bar{\sigma}_i = k\sigma_i, \qquad i = 1, 2, 3,$$

$$k = 1 \ \ \text{(compression)}, \qquad k = \frac{R_c}{R_t} \ \ \text{(tension)},$$

σ_i – principal stresses,

R_c, R_t – compressive and tensile strength of tissues.

An equivalent stress obtained from Eq. (4) is defined as follows

$$\sigma_{eq} = \sqrt{\bar{\sigma}_1^2 + \bar{\sigma}_2^2 + \bar{\sigma}_3^2 - 2\nu(\bar{\sigma}_1\bar{\sigma}_2 + \bar{\sigma}_2\bar{\sigma}_3 + \bar{\sigma}_3\bar{\sigma}_1)}\,. \tag{5}$$

In a 2-dimensional space the equation can be written

$$\sigma_{eq} = \sqrt{\bar{\sigma}_1^2 + \bar{\sigma}_2^2 - 2\nu\bar{\sigma}_1\bar{\sigma}_2}\,. \tag{6}$$

Due to relation between stresses in the element and the principal stresses in the form

$$\sigma_i = \sigma_i(\sigma_e) \tag{7}$$

and Eqs. (1), (2), (3), the determination of the most disadvantageous state of effort can be evaluated by just indicating the nodal forces vector

$$\{f_i\}^T, \qquad r_i = 1, \quad i = j; \qquad f_i = 0, \quad i \neq j, \qquad j \in \langle 1, n \rangle \tag{8}$$

which brings on σ_i stresses in selected region, maximizing Eq. (6).

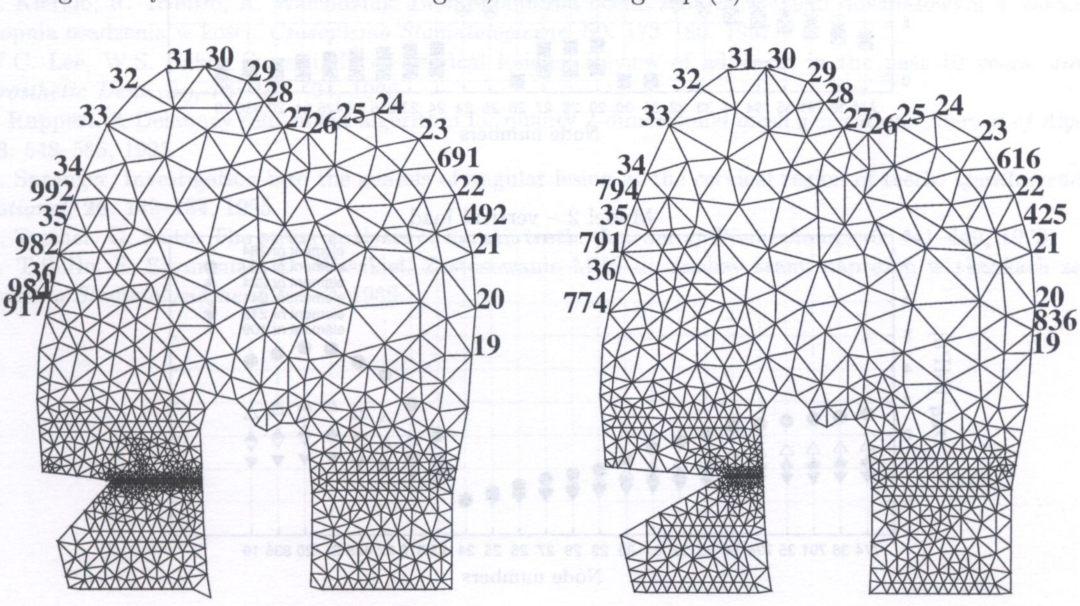

Fig. 2. Number of nodes under the load

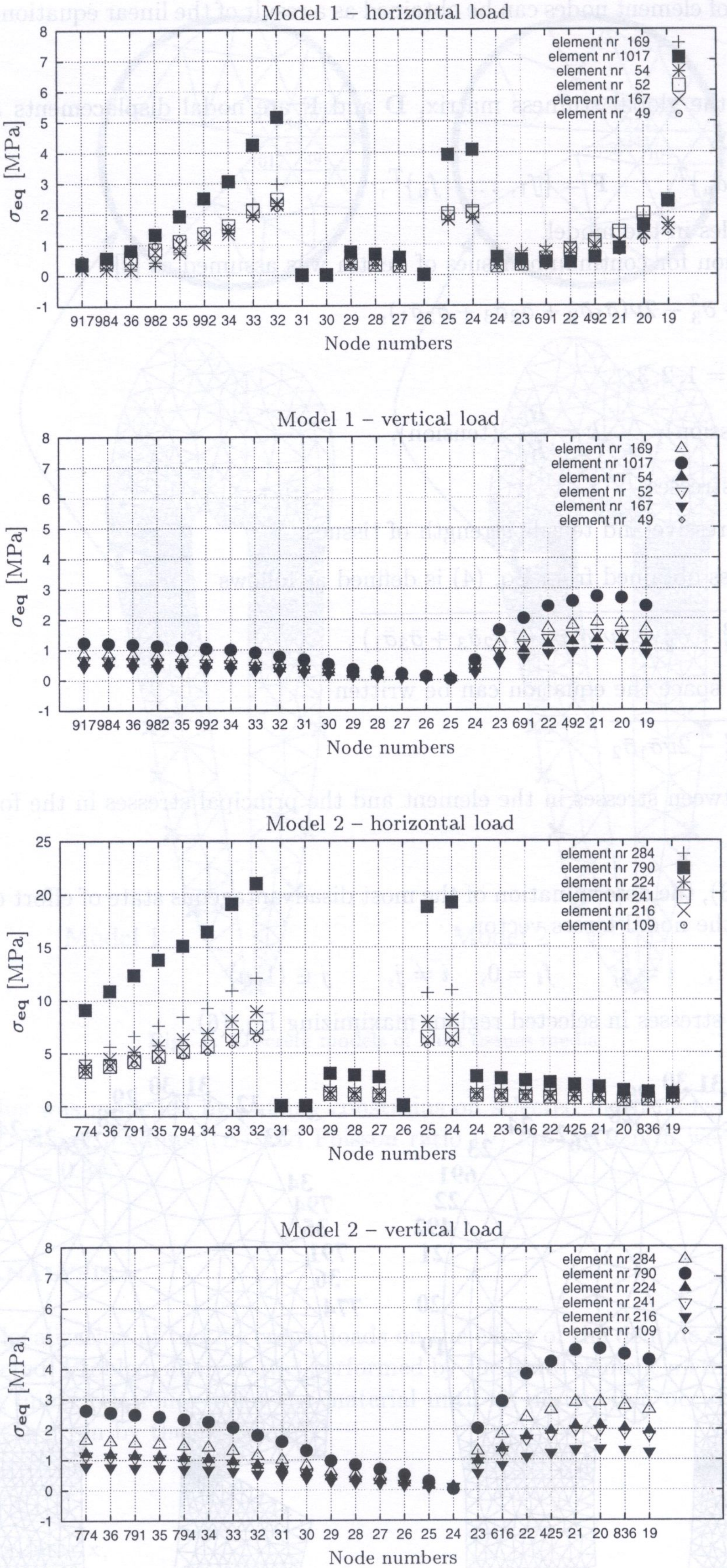

Fig. 3. Values of equivalent stresses in elements for horizontal and vertical components of load

In the regions around notches stress field distribution was marked out in elements numbered as (Fig. 1)

- Model 1 – 169, 1017, 54, 52, 167, 49,
- Model 2 – 284, 790, 224, 241, 216, 109.

The values of stresses were obtained for loads of forces applied in boundary nodes, which are numbered according to Fig. 2. Separation of horizontal and vertical components of loads was performed. It allowed to estimate their influence on stress field distribution, obtained from numerical analysis. Values of σ_{eq} stress in elements are shown in Fig. 3.

4. Results and conclusions

The analysis has shown significant differences between the values of obtained equivalent stresses. It was noted that the horizontal components of loads are principal to effort state and degradation in examined regions of cervical defects. Both for horizontal and vertical components, distribution of application regions of the most disadvantageous loads is similar for both models of angular defects. Equivalent stresses, defining the effort states of the dentin around the bottom of the defect are several times bigger than those in the shallow one.

The results suggest that no angular lesions should be left untreated (regardless of their depth) because it favours their further destruction and intensifies the changes. The functioning of teeth is a complex problem and further refining of research methods is required. The case presented here does not always enable the use of common algorithms of automatic generation in two and three-dimensional space. We have worked out several procedures of generation which are being implemented now.

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