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COMPARATIVE EVALUATION OF DIMENSIONAL VARIATION OF CONNECTOR IN POSTERIOR CANTILEVER FIXED DENTAL PROSTHESIS: A MULTIFACTORIAL FINITE ELEMENT ANALYSIS

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ABSTRACT:

Aim: To evaluate and compare the effect of varying the horizontal dimension, vertical dimension and width of the connector in a posterior cantilever fixed dental prosthesis using finite element analysis. The amount of permanent deformation in the cantilever bridge was also evaluated.

Methods and Material: 2-unit mandibular cantilever bridge in premolar and molar region distal to the retaining abutment was used for the study. Analysis was carried out using Finite Element package ABAQUS 6.12-1. This study was performed by varying the horizontal dimension (H) 1-5 (mm), vertical dimension (V) 1-5 (mm) and width (W) 1-5 (mm). Ni-Cr alloy was used in the study. The connectors were subjected to loads of 45 N, 90 N, 180 N and 600 N. von- Mises stress and principal stress were studied using the analysis.

Results: Stresses were extracted for critical locations e.g. point where connector meets the abutment. Von-mises stress was checked to see if yielding occurred. If yielding was seen, the plastic strain was also extracted. Principal stresses were used to see whether a particular location was in state of tension or compression. Contact status was checked between pontic and gingival.

Conclusion: Geometry of the cross section and horizontal dimension governs the yielding in the bridge. Stress was higher at the location where the connector meets the abutment.

Key-words: Connector, Cantilever bridge, Finite element analysis

INTRODUCTION

A cantilever-fixed partial denture is defined as a fixed partial denture with abutment(s) in only one end in which the other end is unattached.[1] In cases where implants are contraindicated due to limitations in height and width of bone and a conventional fixed partial denture is also contraindicated, the cantilever bridge is the treatment of choice.

Cantilever fixed partial dentures (FPDs) are considered a viable choice in restorative dentistry when treatment is planned carefully and the prosthesis is designed appropriately under favourable intraoral conditions. The stress generated in a cantilever bridge is generally higher as compared to a conventional 3 unit bridge with the connector being the region of high stress concentration. Distal cantilever is chosen here because more stresses are generated on a distal cantilever as compared to a mesial cantilever bridge. If stresses are tolerated for a distal

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cantilever bridge it will be well tolerated by a mesial cantilever bridge. Therefore the study was done on distal cantilever bridge. [2]

A connector is that part of fixed partial denture which connects the pontic with the retainer. Connectors are regions of high stress concentration therefore frequently involve complications,[5] thus proper dimensioning of connectors is required. Dimensioning of the connectors was established by mathematical calculations derived from a formula used by Erhardson. To avoid a fracture of the FPD, a minimum dimension for the cross section of the framework material in the connector area is recommended .Some findings indicate that not only the framework material, but also the composition of the used materials has an influence on the fracture strength of the connector.[3]

Testing the biomechanical performance of the connectors related to their dimensions in clinical studies is difficult because it is difficult to standardize the dimensions of the connectors. Therefore, the analysis of the biomechanics of the connectors has been studied primarily using theoretical analyses. One of them is the finite element analysis. [3]

The finite element method is a numerical method for analysis of stress and deformation in structures of any geometry.[4] It involves three main content : the division of structures into small elements and nodes known as meshing of these structures, assigning material properties, loading and boundry conditions. After the three steps post processing is done to obtain stress and displacement components etc. von-Mises stress is the equivalent stress generated in the material whereas the principal stress is the dominant normal stress and does not include the shear component of stress.

The objective of this research is to analyze the stress distribution in a simplified model of posterior 2 unit cantilever fixed partial denture made of metal and to compare the effects of simulated maximum masticatory loads in order to optimize its design.

MATERIALS AND METHODS

1. Study design

Cantilever bridge subjected to mastication load, was analyzed in detail in the current analysis. Analysis has been carried out using Finite Element Method. Package used for the same is ABAQUS 6.12-1. This study, being a multi-factorial study, was performed by varying horizontal dimension, vertical dimension and width with following combinations (Table 1). An ideal cast was used for the study. Teeth distal to premolar and 1st molar were removed from the model. Now tooth preparation was done on 1st pre-molar and molar teeth. The model was scanned and point cloud data was generated. From this data a simplified CAD model was generated.

1.1 Assigning material properties

Material property of the Ni-Cr alloy was assigned to analyze the bridge. The elatic modulus of enamel, dentin and bone were taken as 10 times higher than the elastic modulus of Ni-Cr alloys as these materials are stiffer than the alloy. A bilinear stress-strain curve has been used to run the elasto-plastic simulation (Figure 1). This is known as bilinear hardening. The material properties are mentioned below stress-strain curve has been used (Table 2).

1.2 Meshing

Complete geometry was meshed with higher order tetrahedral elements. Mesh was kept dense near the locations where the probability of high stress was seen (Figure 2). The mesh had 27000 elements and 41982 nodes. Element type was C3D10 i.e. ten noded tetrahedral element.

1.3. Loading and Boundary conditions

Gingiva and alveolar bone were assigned relatively higher youngs's modulus value. A gap between gingiva and pontic was kept, approximately 1mm. For every simulation, it was checked if pontic touches the gingiva. This is an important aspect in cantilever bridge design. The model was provided fixed boundary condition at the teeth bone and gingival.

Masticatory load was applied in –Y direction on abutment and the pontic (Figure 3). Loads applied to the model were 45N, 90 N, 180 N and 600N. Loads were varied from 45N to 600N to check the onset of plasticity and chances of pontic touching gingiva with increase in load. von-Mises stress in the analysis result was studied. Also, the variation of maximum von-Mises stress in the model with variation in load was also plotted. Onset of yielding, if any, was seen by comparing the von-Mises stress with yield stress, per the distortion energy theory. These points have been further explained in the results section. Prinicpal stress was also recorded.

RESULTS:

The stress analysis was performed for both pre-molar and molar cantilever bridge. Similar pattern of stress was found in both the cases. Since the stress pattern and location was same in both the teeth, pre-molar was taken up for detailed study.

Stress was found to be high at the region where connector meets the abutment.

For the case of analysis with 1mm horizontal dimension and (3mm x 5mm) cross-section of bridge, the stress was seen to vary with load. The stress was seen to increase with the load and saturated around 15 MPa. (Figure 4)

The behavior of 2-unit cantilever bridge has been studied in detail, for both elastic and elasto-plastic cases. Yielding, i.e. onset of plastic deformation was seen for the same geometric and loading combination for both the teeth. Two typical stress plots have been shown for pre-molar and molar teeth in support of above findings.(Figure 5a and 5b)

Stress plots of von-Mises stress and principal stress are shown (figure 6) below for 45N load. The von-Mises stress was maximum at the point where connector meets the abutment. Principal stress was high in the region where fibres were in tension. This shows the bending behaviour under the masticatory load. When the load was increased to 250N, yielding was seen at the region where connector meets the abutment in case of 1mm horizontal dimension and 3mm X 5mm vertical dimension.

Bending stress was also monitored for the cantilever bridge. The trend is shown (figure 7) below.

The von-Mises stress was found to vary with load increase as shown (figure 8) below.

A simulation was also run with a very thin cross-section (3 mm vertical dimension, 5mm width and 5mm horizontal dimension. At load of 600N the pontic touched gingiva in this case as shown in displacement plot (figure 9).

DISCUSSION :

Cantilever bridge and fixed partial dentures differ in their load carrying characterstics. This happens due to the load distribution. A fixed partial denture has two supports whereas cantilever bridge has single support. This support is provided by retainers in both the cases. Due to presence of single support load distribution in cantilever is not as good as conventional fixed partial denture. Thus high stresses can be seen under loading.

Study was carried out to see the effect of load on cantilever bridge. The study was based on the concept of multifactorial type of analysis. Three factors horizontal dimension, vertical dimension and width were taken under this study making the study have multiple factors with multiple levels. The following points were observed in the study:

It was seen that the size of abutment (molar or pre-molar) does not play a major role in generating the stress, but the dimension of connector does play a very important role. Therefore the stress location and pattern was same in the premolar and molar for same combination of dimensions.

Manda Marianthi et al. studied the effect of varying the vertical dimension of materials in a cross arch cantilever fixed dental prosthesis in patients with reduced osseous support.

The authors concluded that increasing the vertical dimension is beneficial for the connector distal to the retaining abutment.[4]

Although the connector has thin region midway between pontic and abutment, the stress was higher at the location where the connector meets the abutment. Two factors play major role in this phenomenon:

a. Due to sudden change of geometry a high value of stress concentration occurs at the location where abutment meets bridge.

b. Sudden change in stiffness at the same location as abutment has more support from the root. Root provides good support to the abutment and helps resist deformation. Pontic, however, owing to lesser support and smaller cross section in comparison to abutment sees high stress. Pontic does not offer much resistance to bending and hence the high stress location does not occur at the point where the connector meets pontic.

The saturation in stress value in case of connector with horizontal dimension 1mm, (3mm x 4mm) cross section occurs because after a certain amount of deformation, the pontic touches gingiva and no further increase in stress occurs.

A bilinear stress-strain curve was used to study the response of the bridge beyond the yield strength of material. This is called as elasto-plastic finite element analysis. Yielding can cause permanent deformation and at times rupture of the material. Therefore, the importance of taking into account the elasto-plastic nature of material becomes an important ingredient of study.

The next paragraph discusses the effect of material and dimensions on the response of bridge under the loading. In addition to material properties, contact modeling is also required to see the possibility of pontic touching ginigiva. Contact modeling capability of ABAQUS was used in this.

Geometry of the cross section and horizontal dimension govern the yielding in the bridge. Small cross section and large horizontal dimension lead to higher stresses and yielding also occurs at lower value of loads (~45-90N) in these cases. Initially the bending stress is seen to increase as the load is increased. But once the complete load is reached, the stress is almost constant. This happens because of plastic deformation. Under such cases, the plastic flow initiates. This means that the amount of stress required to strain the material beyond yield point does not increase sharply from the yield stress.

Rezaei Mohammad Mir et al. studied the influence of connector width on the stress distribution of posterior bridges under loading. They concluded that stress concentrations were observed within or near the connectors. The von Mises stress decreased by increasing connector width, regardless of whether the loading was applied vertically or at an angle. [6]

With lesser section modulus the bending of bridge is more. In such cases, the pontic can even touch the gingiva. This can be source of pain in patients. This was assessed from stress analysis by monitoring the contact forces between the pontic and gingiva. Initially the pontic is away from gingiva. As it is loaded, it bends towards gingiva. This keeps on going and the contact force remains zero till the time it touches the gingiva. A sudden increase in contact force is seen (see Figure 9). This marks the initiation of contact between gingiva and pontic.

A general trend was observed in all the connectors which are related to response to applied load. All the cases were bending dominated. The upper fibers underwent tension and lower fibers underwent compression. Thus making the upper region, near the location where connector meets retainer, a critical location. Whenever yielding was seen, it was seen to initiate at these critical locations. To see the chances of pontic touching the gingiva, contact pressure was also studied.

Contact pressure is distribution of load, transferred from one contacting body to another, when two bodies come in contact. When two bodies are separated, i.e. not in contact, the contact pressure is zero. A sudden jump is seen in contact pressure as soon as bodies touch each other. Similar trend in contact pressure was seen in case of connectors that underwent high amount of deformation. When connector deformed excessively the pontic touched ginigiva. The contact force between pontic and gingiva showed sudden peak when pontic touched gingiva. This high deformation due to bending and yielding may result in permanent deformation in the bridge. Thus the intended function will not be served. If the bridge yields and the load is removed from the pontic, it will not regain its original shape. Only a small portion of strain will be recovered. Rest will remain as permanent deformation. Therefore, smaller cross-section pontics with large horizontal dimensions should not be used.

Limitations of the study:

- **Cracking of cantilever bridge**: Cracking can be predicted using element deletion/X-FEM techniques. Therefore, it has not been considered in the analysis. However, current elasto-plastic analysis does point out the potential locations of failure.

- **Fatigue due to masticatory load fluctuation**: Bridges will not be subjected to constant load. The load will be of fluctuating nature in real life. This indicates the need of fatigue study of cantilever bridge. This again would require S-N an E-N curve for the material under study and consideration of residual stress accumulation with cycles in the material.

- **Thermal Cycling**: The cantilever bridge, when in mouth, will see fluctuation in temperatures due to eating habits of the patient. This again would require S-N and E-N curve for the analysis, as this becomes a case of thermal fatigue.

- **Permanent deformation due thermal loading**: Cantilever bridge can get deformed permanently due the sudden increase in temperature.

This again is not possible in current scope of work.

- **Growth of flaws in fabrication stage**: During fabrication, certain flaws (microcracks, blow holes) can get generated in the bridge. These can grow in size under loading and cause catastrophic failure. However, such kind of analysis is very advanced and beyond the scope of current work.

Scope for further studies:

- Most of the studies in literature cover basic design principles but not on the geometry of connectors in a cantilever fixed partial denture. The current study can also be used to study different loading conditions in the oral cavity. Also fatigue and thermal changes in the mouth can be accounted for.

- Clinical and laboratory trials similar to this FEA study can also be done to check for the accuracy of this study. This would also help us understand the accuracy of modeling, meshing and loading conditions used. Comparing these results will help us in verification and validation of Finite Element Analysis as a tool for testing dental restorations.

- The various limitations listed earlier can be overcome by using better infrastructure and financial and technical assistance from persons experienced in the field of research.

- Since connectors are the weakest link in a fixed partial denture so study of different materials which are used in fabrication of fixed partial dentures can also be studied with finite element method.

CONCLUSIONS:

The following can be concluded from the study:

1. Varying the dimension of connectors plays a major role in preventing failure of the prosthesis.

2. Size of the abutment does not play major role in the stress generation on connectors.

3. Connectors in the cantilever fixed partial dentures showed maximum stress concentration.

4. Stress is higher at the location where the connector meets the abutment.

5. Geometry of the cross section and horizontal dimension govern the yielding in the cantilever bridge. A connector with smaller cross section but larger horizontal dimension would yield earlier as compared to the connector with large cross section and smaller horizontal dimension. This is attributed to section modulus.

6. Greater the Young's modulus of the material used in the connector, lesser will be the bending.

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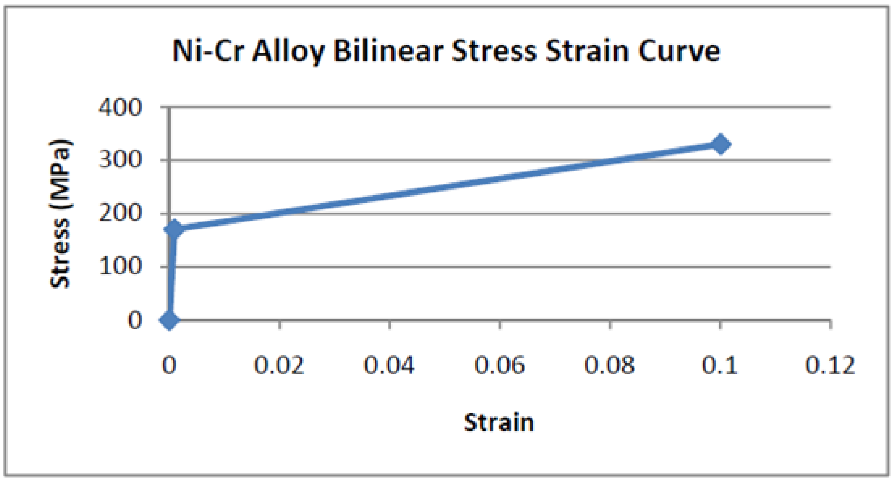
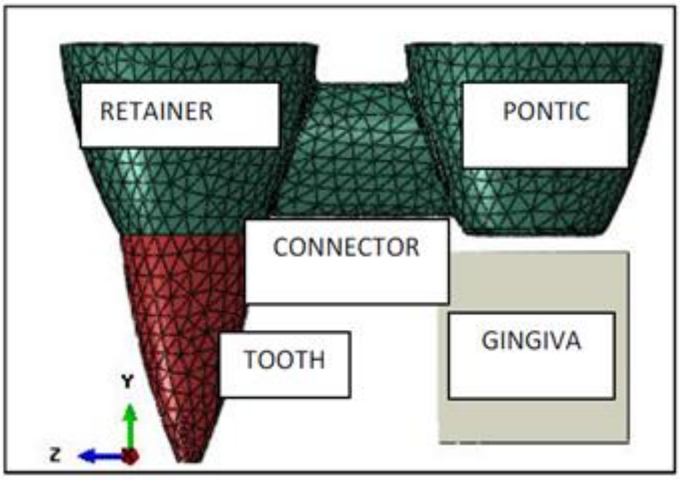
FIGURES,TABLES & GRAPHS:

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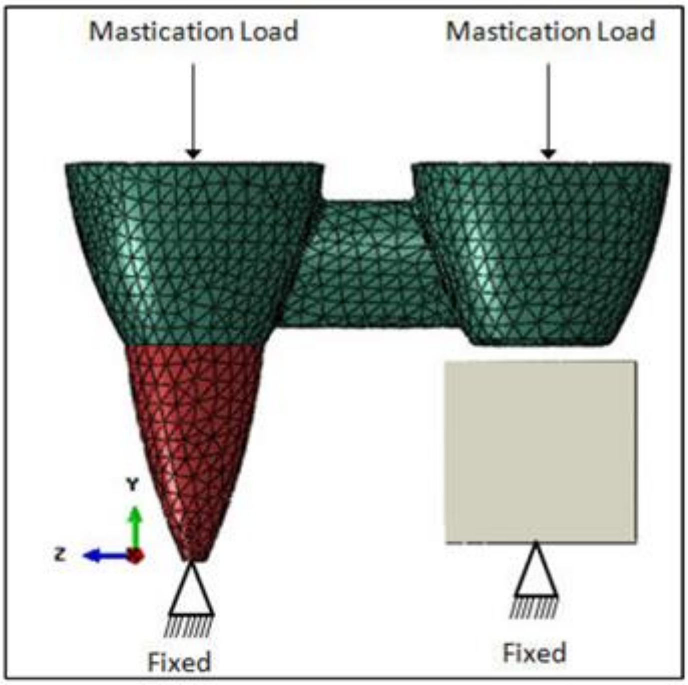
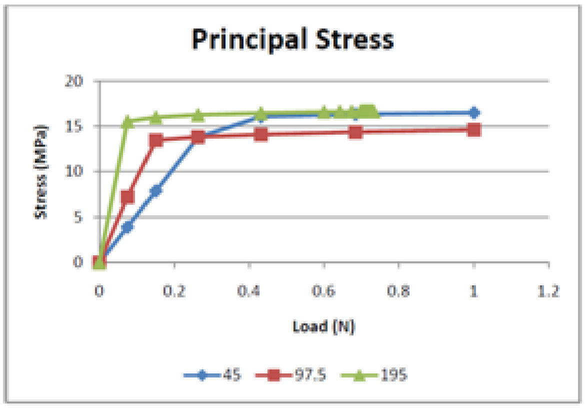
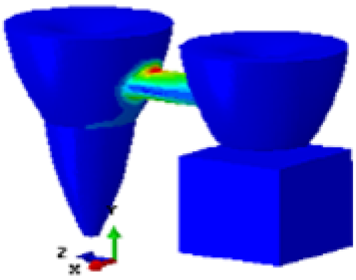
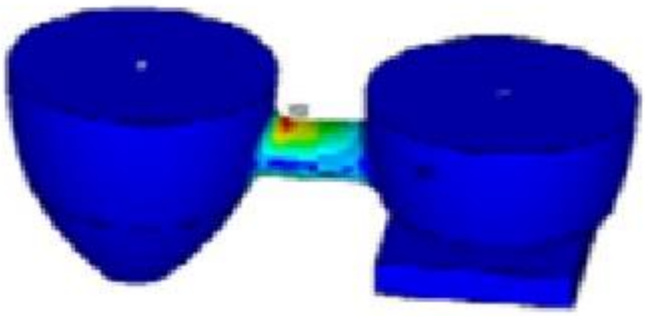
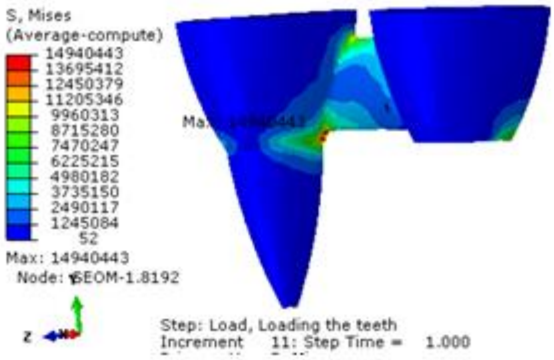
PONTIC
CONNECTOR
GINGIVA
TOOTH
Y
Z


Mastication Load
Mastication Load
Y
Z
Fixed
Fixed


Principal Stress
Stress (MPa)
Load (N)
45
97.5
195



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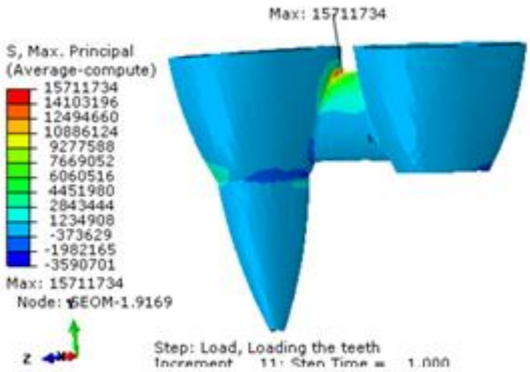
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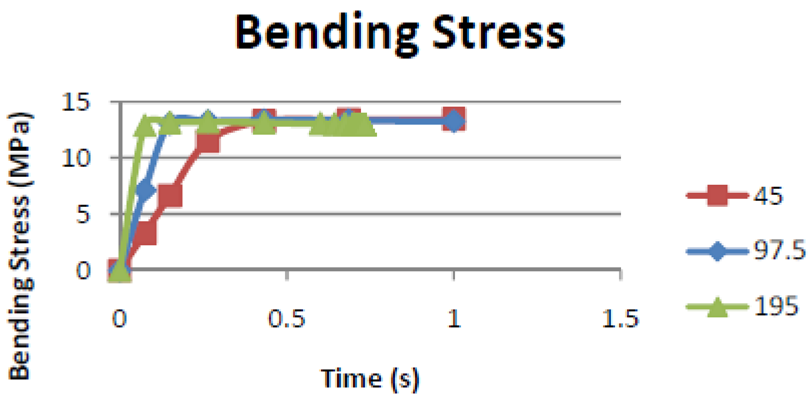
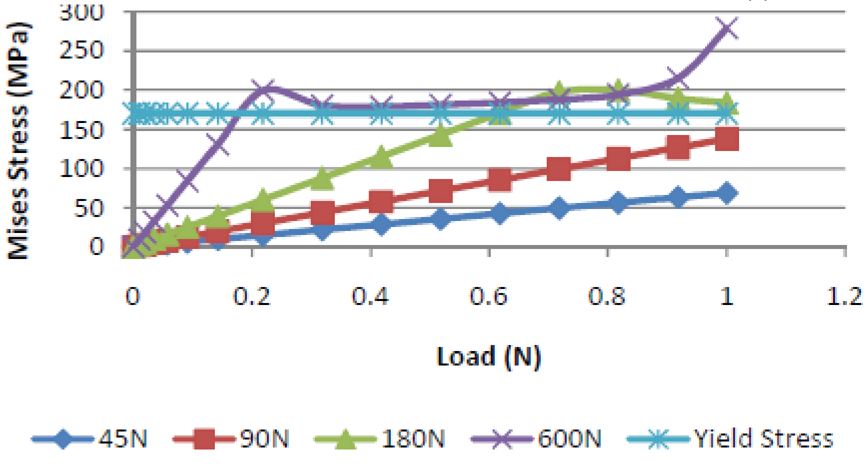
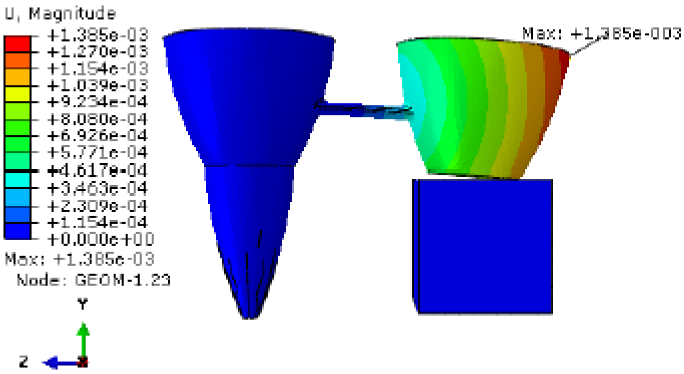
Step: Load, Loading the teeth


Bending Stress
Bending Stress (MPa)
15
10
5
0
0
0.5
1
1.5
Time (s)
45
97.5
195





Dimensions	(mm)
Horizontal	1 -5
Vertical	1-5
Width	1-5

Young's Modulus (MPa)	185000
Poisson's Ratio	0.38
YS (MPa)	170
UTS (MPa)	330
Rupture Strain	0.1