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Research Article

Finite Element Axisymmetric Models for Conical Wedge Anchorage Used in the Production of Prestressed Steel Reinforced Concretes

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Abstract

The anchor system plays a very important part of the prestressed structure, that contacts and transmits force to the cables when stretching to create residual stress. The operating conditions of the anchor system in general and the anchor core in particular are extremely harsh. In this paper, *ABAQUS* software was applied to model and numerically simulate the axisymmetric loading process of the anchor core in manufacturing prestressed concrete sleepers, to study the effects of tensile forces to the pressure resistance of the cylinder. To verify the analytical results, a Finite Element (*FE*)-model with the same material and geometrical properties was created. The difference is the assumption of plane stress in the analytical solution, can be solved using two - dimensional finite elements, which are most conveniently described in cylindrical (r, θ, z) coordinates. This articles also especially focused on calculating the change of stress on the edges of the anchor core teeth with different tensile forces. We also refered to experimental results to get data on traction force and working conditions to build a calculation model and select input parameters. Comparison of the stress generated on the teeth of the anchor core was performed with three different tensions of *171*, *181* and *191 kN*. The maximum and concentrated stress at the top and root of the anchor core when tensioning the cable has been calculated.

Keywords

Finite Element Axisymmetric Simulation, Finite Element Method, Abaqus, Tensional Forces, Stress Distribution, Effective Stress, Conical Wedge Anchorage

1. Introduction

Prestressed reinforced concrete structures, also known as prestressed reinforced concrete structures, or prestressed concrete, or prestressed concrete [1, 2], were reinforced concrete structures using a very high tensile stress combination of prestressed reinforcement and compressive strength of concrete. The steel reinforcement in concrete, having been stretched by a pre-stressing machine, reached a certain stress value within the elastic limit before these reinforced concrete structures have been loaded. This reinforcement tension caused the concrete structure to deform opposite to the deformation due to load when subjected to load [3, 4]. Thanks to that, these concrete structures were able to withstand larger loads or overcome larger spans than conventional reinforced concrete structures and this also worked for reducing vibra-

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tions in traffic works such as bridge girders, viaducts or railway sleepers.

The anchor system plays a very important part of the prestressed structure, that contacts and transmits force to the cables when stretching to create residual stress. The operating conditions of the anchor system in general and the anchor core in particular are extremely harsh. The anchor core must not only endure great friction when in contact with the cable during the tensioning process, but also must endure pressure from the anchor shell to hold the stretched cable tightly with a pulling force equal to 80% of the cable breaking force when pulling. beam and keep the cable in that condition for the life of the bridge for working anchors (one-time pulling anchors) and a certain period of time for multiple pulling tool anchors. A number of conical anchor cores suitable for use with prestressed concrete have been developed over the past few decades. One of the first designs was by Sayed-Ahmed and Shrive [5, 6], Campbell et al. [7]. Normally, conical (wedge) anchor cores are designed as leaves (including 2, 3 and 4) to create radial pressure from the anchor shell to clamp (hold) the cable when pulling. Many important documents have been written in the field of prestressed concrete such as. [8-14]

Due to the complexity of fatigue damage models for unidirectionally loaded anchor cores [15-18], most current studies on anchor system optimization are conducted based on stress analysis. but it is not possible to evaluate or predict the degree of failure of the anchor core teeth under specific loads. There have been several previous studies by the group on ABAQUS software application to model and a three-dimensional (3D) numerically simulate the load bearing process to calculate pressure as well as shear stress on the anchor shell and anchor core [19, 20]. The studies in this article have been inspired by the results and models used in the above publications. Special focus is on calculating the change of stress on the edges of the anchor core teeth with different tensile forces. Also referred to experimental results to get data on traction force and working conditions to build a calculation model and select input parameters.

2. Finite Element Modeling

2.1. Axisymmetric FEM (Finite Element Method)

To verify the analytical results, a *FE*-model with the same material and geometrical properties was created. The difference is the assumption of plane stress in the analytical solution; in the *FE*-model no such simplification is included. Such problems, known as axisymmetric problems, can be solved using two - dimensional finite elements, which are most conveniently described in cylindrical (r, θ, z) coordinates. When the anchor system operates, the details are compressed under the influence of pressure. Because the material operates within the elastic limit, a force appears in the material to resist deformation in all directions. In the direction of cable tension (z axis) there is axial deformation. However, this deformation is small so it does not significantly affect the stress (residual stress) of the cable.

2.2. Modeling

The model is created and analyzed with a nonlinear geometry analysis in Abaqus Standard [21]. Geometry, element distribution, boundary conditions and application of the presetting force are seen in *Figure 1*. All elements are of the three-node axisymmetric element type (*CAX3*): A *3*-node linear axi-symmetric triangle element with reduced integration and hourglass control. *40252* elements have been generated on fiber cables, *42979* elements - on wedge and *3830* elements - on barrel. In the fiber cables-wedge interface and wedge-barrel interface, penalty frictional behavior is applied. Setting the longitudinal motion of the barrels front end to zero throughout the loading provides counteraction. Prescribing a linearly increasing intrusion of the wedge into the anchorage provides the presetting.

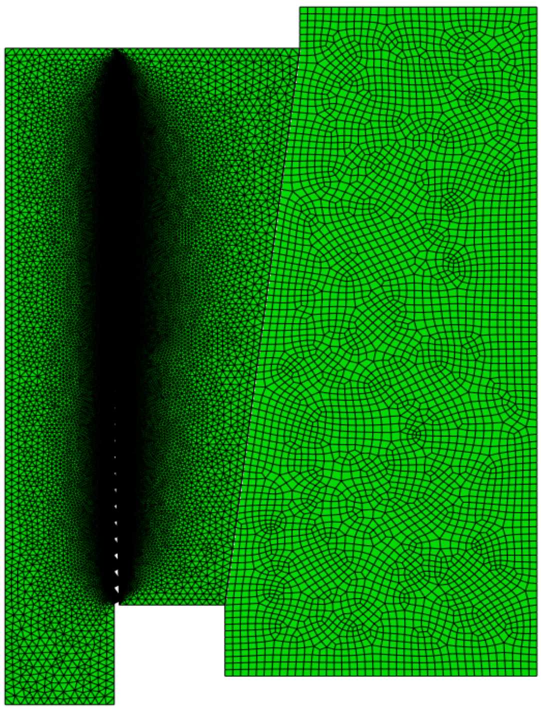

Figure 1. *Geometry, element of the conical wedge anchorage of axial loading.*

The contact output variables in Abaqus can provide the designer a wealth of information about the performance of a connector during all steps of an analysis. When modeling surface - based contact with axisymmetric elements [21] an output quantity of particular use is the maximum torque that can be transmitted about the *z*-axis by a specified contact pair. The maximum torque, *T*, is a scalar value defined as [22]:

$$T = \iint r^2 p d s d\theta \quad (1)$$

where p is the pressure transmitted across the interface, r is the radius to a point on the interface, and s is the current distance along the interface in the r–z plane. This simulation demonstrates the usefulness of the contact interference and pressure penetration options [22] as well as the Abaqus contact output variables in an axisymmetric analysis of a particular threaded connector.

These anchorage consist of an outer barrel in *C45* tool steel and three wedges in *SCM420* steel. As tension is applied to the fiber cables, the wedges are pulled into the barrel and grip around the fiber cables, thus increasing the capacity to transfer the load by friction.

This research helps resetting phase that is further investigated, i.e. when the wedges are pushed slightly into the barrel from behind to ensure that an initial grip exists when the tensile force is applied to the fiber cables. The analytical and finite element models compared in this paper rely on the geometric and material properties listed in *Table 1*. E is the modulus of elasticity for each material and ν is the Poisson ratio.

Table 1*. Material properties [23].*

Material Properties	C45	SCM420
Young's Modulus, E	2e+11	2.09e+11
Poisson ratio, ν	0.3	0.33

3. Results and Discussions

3.1. Distribution Stress

By assuming no such limit exists in an elastic material, i.e. the material will experience a linearly increasing stress with increasing strain, and the parameter that governs this relationship is the elastic modulus, E. This assumption will keep the deformations relatively small without the material having any limitations regarding the stress it can withstand. Because the contact surfaces of the two leaves with the anchor shell are uniform, each half has equal axial displacement, resulting in the cable being compressed concentrically. This compressive force creates normal and shear stress components that cause the two anchor leaves to tighten to hold the cable.

When the pressure increases to a certain limit, the concentrated stress on the anchor core exceeds the allowable limit of the material, which can crack or break (blunt) the anchor core teeth, leading to cable slippage. Therefore, a detailed investigation of each tooth part of the anchor core was studied to make a basis for choosing the appropriate tooth shape and heat treatment regimen.

When applying tensile forces of 171, 181 and 191 *kN* to the conical anchor core and anchor shell system, Abaqus software combines geometric and physical model properties for computational analysis. The residual stress distribution is then evaluated in the wedge. The position of greatest concentration of stress is at the top and root of the anchor core, this is where it comes into contact with the cable and transmits direct friction force to clamp the cable tightly during the tensioning process, creating residual stress for the concrete structure. FEM results show that the equivalent total stress reaches a minimum value from 70 to 813 *MPa* at different load levels, as shown in *Figure 2*.

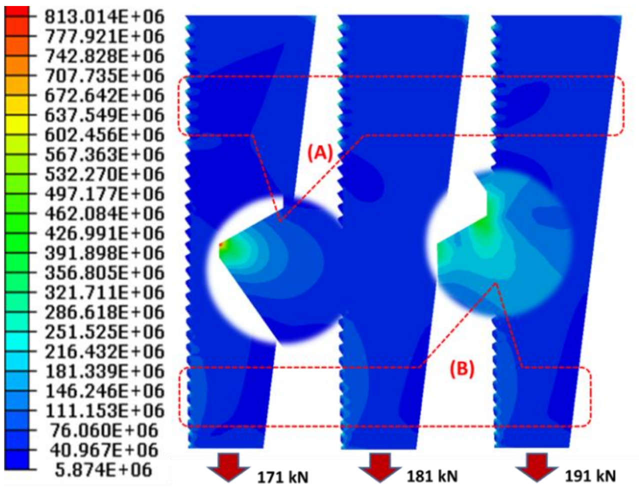

Figure 2*. Stress distribution in the wedge after tensional force loading.*

3.2. Effective Stress on the Threads

All analyses are performed as large-displacement analyses. The results for three cases were identical. *Figure 2* shows the effective stress distributions in the wedge after the tensional force of *171 kN* resolved in the displacement boundary condition. As illustrated in *Figures 2* and *3*, some of the threads on the wedge are beginning to pull out at the end of presetting force. The distributed stress on the wedge is from *450* to *650 MPa*. Specific section on the wedge (thick section *A*) shows a maximum stress of *650* MPa and thin section *B* - the maximum stress on the threads only *420 MPa* - under the damage limit of the wedge.

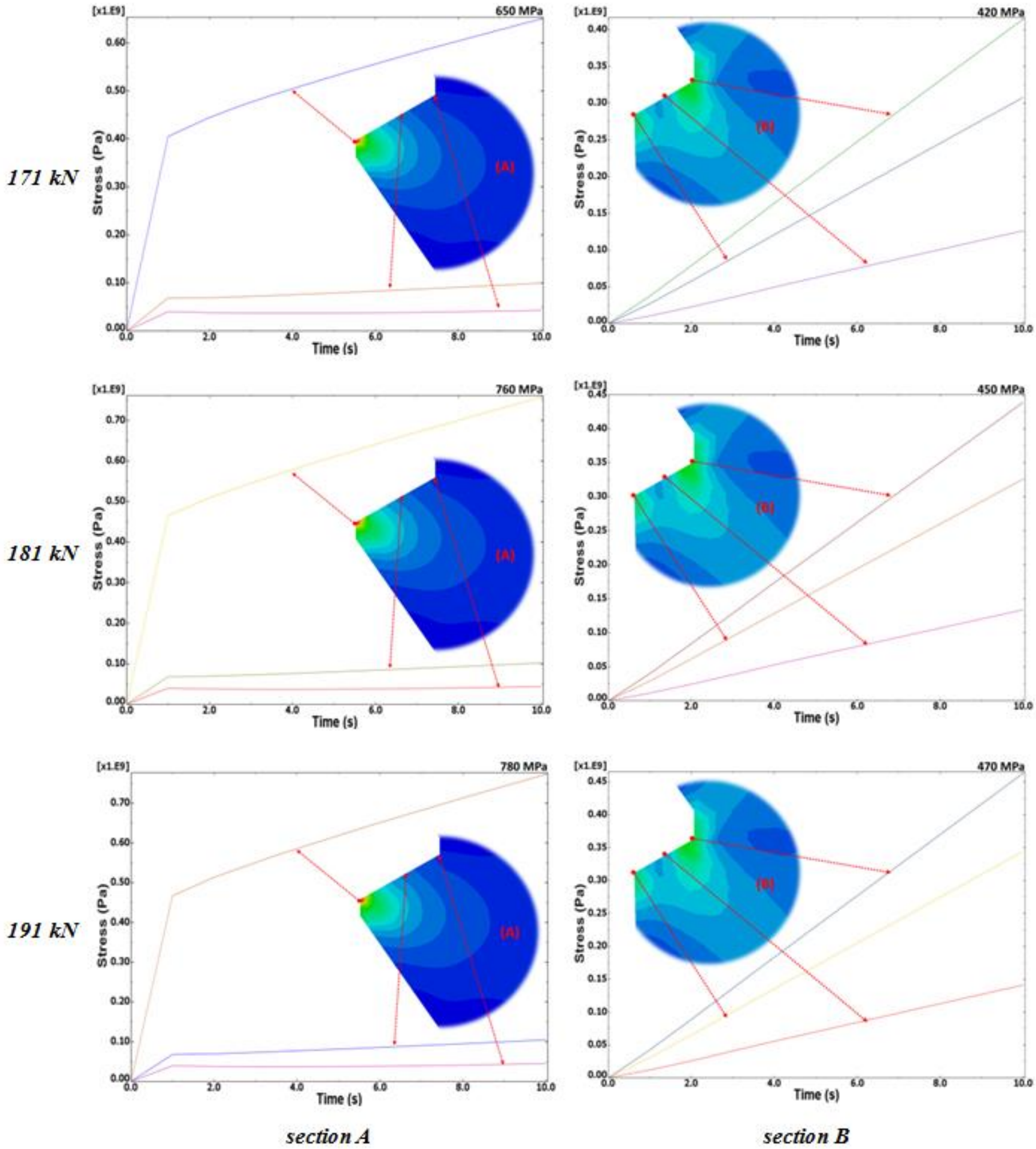

Figure 3. *Plot of stress on the threads after tensional force loading.*

Through results analysis of stress variation it's recognized that the section *A* of the wedge has the highest stress at the top of threads (*650* MPa) and decreasing stress in the thread middle and bottom.

For the section *B*, the highest stress is effective at the bottom (*420 MPa*) and the top (*320 MPa*) of threads, the stress value of thread middle is very low, about *100 MPa*.

With tensional force of *181* and *191 kN* respectively, we see the stress distribution and variation on the wedge similar to the case of *171 kN* load. The difference is that the largest stress value on the wedge is up to *760 MPa* with load *181* kN and *780 MPa* with load *191 kN*.

4. Conclusions

Having used axisymmetric numerical simulation method, the influence of different tension forces on the stress distribution on the anchor core tip and tooth has been successfully studied. From the the results of this study, there have been some conclusions as follows.

The total equivalent stress values increase with the tensional forces of *171*, *181* and *191* kN.

For the wedge section *A*, the highest stress is *650 MPa* in the top of the threads and decreasing stresses – in the threads middle and bottom.

For the wedge section *B*, the highest stress are *420 MPa* effective at the bottom and *320 MPa* at the top of threads, the stress value of the threads middle is very low (about *100 MPa*).

The above results are the basis for choosing design, manufacturing as well as having appropriate heat treatment regime for the anchor core.

Abbreviations

FEM	Finite Element Method
FE	Finite Element
3D	A Three-Dimensional
CAX3	The Three-Node Axisymmetric Element Type

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Author Contributions

Pham Quang is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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Biography

Pham Quang is a Associate Professor at Hanoi University of Science and Technology, Faculty of Materials Engineering. He completed his PhD in Applied Materials Engineering from Chungnam National University (Korea) in 2008, and Postdoctoral research at the Technical University Dresden (Germany) in 2015-2016. Recognized for his exceptional contributions, Dr. Pham has been appointed to the title of Associate Professor, Senior Lecturer in December 2022 at Hanoi University of Science and Technology. He has participated in multiple international research collaboration projects in recent years. He currently serves on the Editorial Boards of numerous publications and has been invited as a Keynote Speaker, Technical Committee Member, Session Chair, and Judge at international conferences.

Research Field

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To study the metal forming deformation of solid, Semi-solid.

To study the FVM, FEM for modeling and computational materials science: including ABAQUS, ANSYS-FLUENT, COMSOL MULTIPHISICS, ANSYS, DEFORM 2D & 3D, MSC.MARC and MSC.SUPERFORGE.