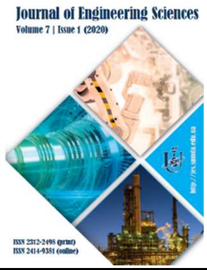
JOURNAL OF ENGINEERING SCIENCES

Volume 7, Issue 1 (2020)

Tombak, A., Onur, Y. A. (2020). Investigation on the mechanical behavior of the prestressing strand by the finite element method. Journal of Engineering Sciences, Vol. 7(1), pp. D1–D4, doi: 10.21272/jes.2020.7(1).d1



Investigation on the Mechanical Behavior of the Prestressing Strand by the Finite Element Method

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Article info:
Paper received: February 1, 2020
The final version of the paper received: June 2, 2020
Paper accepted online: June 16, 2020

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Abstract. Wire ropes that have a wide range of applications endure loads, stresses, strains, and moments while carrying out the duty of carrying loads. Wire ropes and strands are frequently used as load carrying elements due to their flexible structure and being reliable products. A prestressing steel strand is a form of the pattern of 1x6 helical wires which supply extra stiffness. Contact conditions between adjacent wires, helical geometry of wires at outer layers make it difficult to find the mechanic response of wire ropes or strands under axial load. A good way to overcome this difficulty is to perform a computer-aided simulation with finite element method. In this study, a prestressing strand having 11.11 mm diameter is computer-aided modeled by using SolidWorks, and then ANSYS Workbench is used to determine the mechanical response of the investigated rope strand. The findings indicate that results remained in the elastic region in all finite element simulations until the strain value of 0.00728.

Keywords: prestressing strand, finite element method, tensile stress, strain, twisting moment.

1 Introduction

Wire ropes and strands are widely used as load-bearing elements due to their flexible feature and being reliable construction [1]. There are various kinds of rope and strand types in the industry since every rope or strand has a peculiar usage area. The difficulty of the first preparation processes in the experimental studies, especially the impossibility of measuring in the inner parts of ropes, causes increasing the importance of finite element simulations of wire ropes.

Neither rope end casting for test machine connection

having six steel outer wires braided around a steel core wire with a certain lay angle and length. ASTM A416 standard [2] consists of the technical properties of prestressing strands.

In this study, a prestressing strand having 11.11 mm diameter is computer-aided modeled by using SolidWorks and then imported to ANSYS Workbench to conduct finite element simulations. Stress-strain, load-strain, and twisting moment-strain variations have been determined using finite element analysis (FEA) and presented.

2 Literature review

Wokem [3] conducted comprehensive studies on the prestressing strand with different sized. Finite element simulations were performed to determine wire strains and Von-Mises stresses and fatigue lifetime estimations. Wu [4] developed parametric equations to design spiral ropes. Abdullah et al. [5] presented the usage of a parameterized model to investigate strand behavior and evaluated the influences of those parameters on strand response. Wenzheng et al. [6] took the 1x7 rope strand as the research objective and analyzed the influence of wire break on the stress distribution by using Abaqus software

an axial load of 5 kN.

3D modeling of a sling wire rope focusing on different contact types and axial loading types. Kalentev et al. [8] presented the results of a numerical analysis of the stress-strain state of a rope strand with linear contact under tension and torsion loading conditions. Calculations were carried out using ANSYS. Vu et al. [9] were used to finite element method to determine the mechanical behavior of synthetic braided ropes and rope tests were conducted on the hydraulic tensile testing machine. Sasaki et al. [10] tried to estimate the fatigue life of wire ropes for elevators. The authors used contact force between wires determined using finite element analysis.

3 Research Methodology

In the solution of a problem, it is quite a practical method to separate the problem that was initially complicated into sub-problems that are known or can be formulated, and then to solve the real problem using these solutions. Especially in engineering calculations, objects encountered in nature do not fit into any familiar pattern. In this case, the workpiece should be divided into small geometric shapes. Today, various computer programs have been developed to apply this method. ANSYS, which is also used in this study, makes the stress analysis of the given shape using the finite element method [11]. A static structural toolbox was used in ANSYS Workbench so as to perform stress analysis. The interface of ANSYS Workbench is shown in Figure 1.

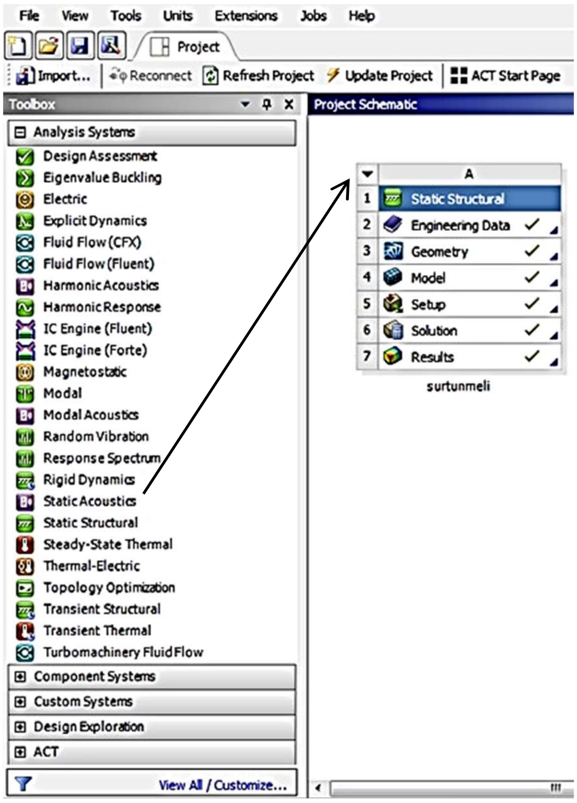

Figure 1 – ANSYS Workbench interface

The finite element model is constructed by using data given in Table 1.

Table 1 – Dimensions of 1x6 prestressing strand

Layer number	Number of wire	Lay angle	Lay length, mm	Wire radius, mm
1	1	0	0	1.875
2	6	81°57′	165	1.840

The prestressing strand investigated has 11.11 mm in diameter. It is frequently used in prestressed concretes, bridge constructions, materials handling industry, or any other heavy constructions. Prestressing strand material is carbon steel and made by the wires drawn, and six wires are braided over a core wire and then thermally treated [2].

Input parameters identified during FEA are as follows: modulus of elasticity is $1.965 \cdot 10^5$ MPa; the Poisson's ratio is 0.3. Ultimate stress is 1.86 GPa. Core or center wire is drawn by means of extrusion. A circle contacting center wire is drawn in the same plane and it is swept along a helix having coil radius (summation of the radius of center and outer wires). A circular pattern is made to complete 1x6 prestressing strand geometry.

The three-dimensional model of the prestressing strand is shown in Figure 2.

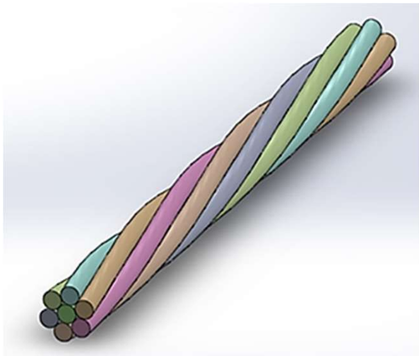

Figure 2 – Solid model of prestressing strand

The prestressing strand is modeled at one pitch length. Solid 186 mesh element containing intermediate nodes is used for meshing. After the finite element model is done, boundary conditions and solution methods are determined by using the "Setup" section of the ANSYS Workbench program's interface. In the "Connections" section, there is the "Contacts" subsection where the contacts of the wires are defined. The contact detection method has been changed to "Nodal – Normal to Target" instead of the standard-setting.

Frictional contact behavior is used between interwire contact. Surface to surface contact type between adjacent wires has been adjusted. The coefficient of friction is selected as 0.115. As boundary conditions, displacements and rotations in the x, y and z axes are constrained at one end of the strand. Only the axial directional movement is allowed at the other end. Finite element analyses were carried out by applying different strain values to the free end of the strand to determine the loads carried by the center wire and the outer wire, the tensile stresses occurred on the center and outer wires and the torsional moment generated in the strand. FEA enables us to reveal variations of those mechanical outputs versus strain values.

4 Results and Discussion

This study presents FEA results of load, stress, and moment value variations of a prestressing strand under external strain. The axial load carried by center wire, outer wires, and whole prestressing strand variations under strain values have been presented in Figure 3. The maximum axial load carried by the prestressing strand is determined as 96.3 kN when strain value becomes $7.28 \cdot 10^{-3}$. It is known that the minimum breaking load is 138.0 kN for the investigated strand.

It can be seen that safe working limits have been approached in accordance with those results. It also shows that material behavior remains in the elastic limits. The maximum axial load carried by center wire is determined as 14.6 kN, and the maximum axial load carried by six outer wires is determined as 81.7 kN when strain value becomes $7.28 \cdot 10^{-3}$ again.

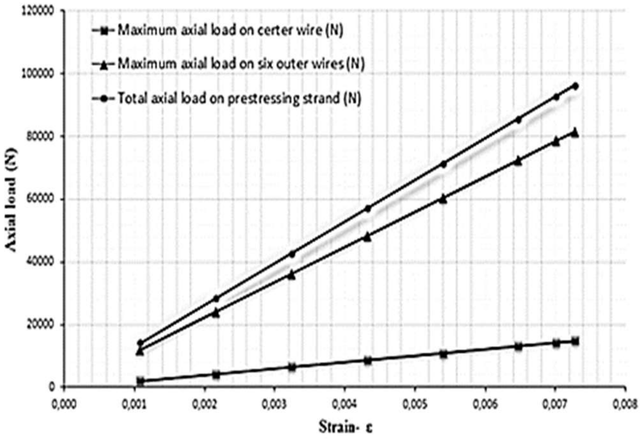

Figure 3 – Axial load-strain results for prestressing strand

Force reaction probe property is used to measure axial load produced upon an outer wire and prestressing strand, as shown in Figures 4 and 5, respectively.

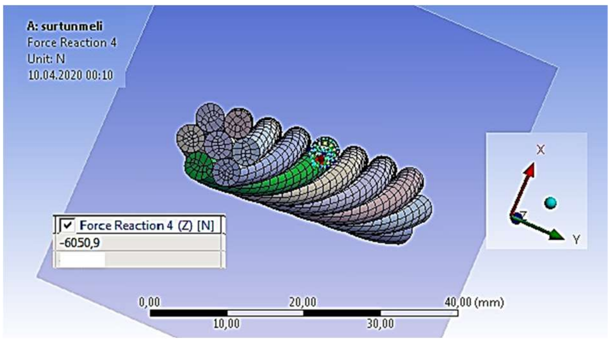

Figure 4 – Force reaction probe used for reading axial load on an outer wire

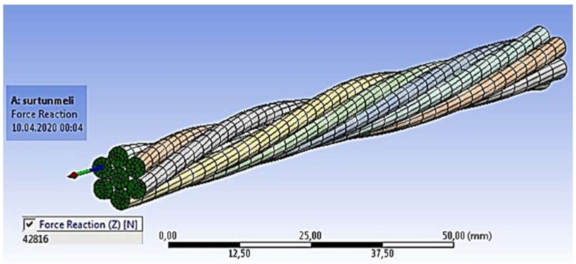

Figure 5 – Force reaction probe used for reading total axial load carried by prestressing strand

The total axial load carried by outer wires is six times greater than the measured axial load since the prestressing strand consists of six outer wires. The total axial load carried by six outer wires is determined as 36.3 kN when strain value becomes $3.24 \cdot 10^{-3}$.

It is seen from Figure 5 that the total axial load carried by the prestressing strand is 42.8 kN when the strain value becomes $3.24 \cdot 10^{-3}$. Tensile stress on the center wire and outer wire variations under strain values have been presented in Figure 6.

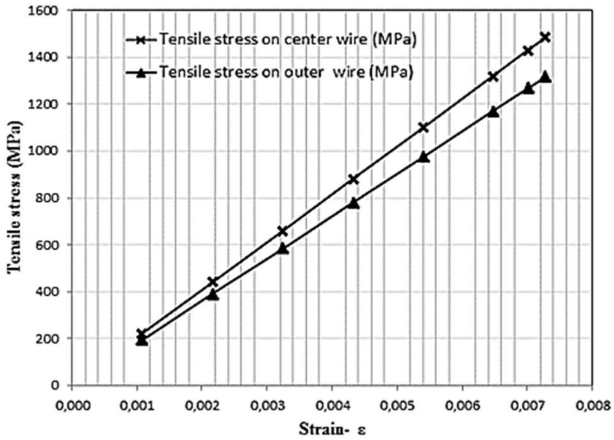

Figure 6 – Tensile stress-strain results for prestressing strand

Tensile stress on the center wire is determined as 1.48 Ga when strain value becomes $7.28 \cdot 10^{-3}$. It is known that the ultimate strength is 1.86 GPa for the investigated strand. It is seen that safe working limits have been approached in accordance with those results. Tensile stress on the outer wire is determined as 1.32 GPa when strain value becomes $7.28 \cdot 10^{-3}$ again.

The torsional moment generated on the prestressing strand variations in accordance with strain values has been presented in Figure 7. The twisting moment on the prestressing strand is determined as 41.3 N·m when strain value becomes $7.28 \cdot 10^{-3}$.

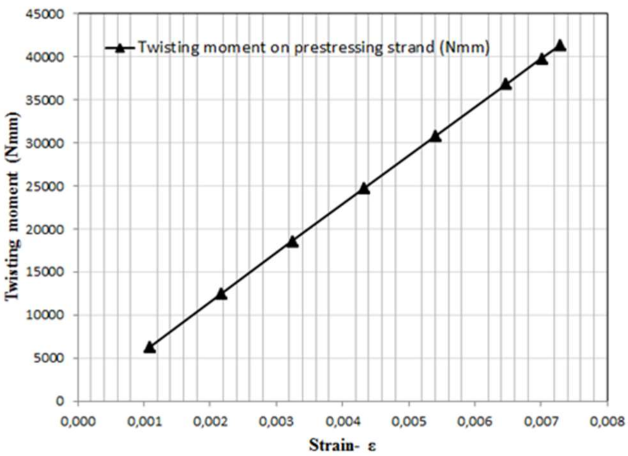

Figure 7 – Twisting moment-strain results for prestressing strand

5 Conclusions

In this study, the mechanical response of the prestressing strand that has 11.11 mm diameter has been determined by means of the finite element method. It can be seen from the results that essential findings have been reached for the rope strand through finite element analysis. The maximum axial load carried by prestressing strand is determined as 96.3 kN, maximum axial load carried by center wire is determined as 14.6 kN, the maximum axial load carried by six outer wires is determined as 81.7 kN; tensile stress on the center wire is determined as 1.48 GPa; tensile stress on the outer wire is determined as 1.32 GPa and twisting moment on prestressing strand is determined as 41.3 N·m when strain value becomes $7.28 \cdot 10^{-3}$. It can be concluded that results remained in the elastic region in all finite element simulations until the strain value of $7.28 \cdot 10^{-3}$.

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