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Modeling and Analysis of Wire Rope for Transmission Line under Various Loading Conditions

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Abstract: Wire ropes are considered and applied to industrial applications that includes mining, off-shore oil production, and towing or mooring ships. Wire ropes are also used extensively in such diverse transportation applications as ski-lifts, cable cars, bridges, cranes and elevators. Premature failure of ropes can be costly in any application. In mining, the human costs due to the premature failure of a rope can be devastating.

The wire rope considered in present research is IS 398, ACSR Conductor, Theoretical calculations are performed to calculate sag and slack for the rope. Distance between poles is taken as considered 30480mm. Thermal elongation with temperature variation is calculated and also simulated and analyzed with ANSYS design software. Aeolian vibration frequency is calculated to obtain frequencies with different wind speed, Software results for frequencies are found similar to theoretically calculated results.

Experimental analysis is performed in IIT Indore to conduct tensile. It is found that breaking load is approximately 28KN and software simulation results for tensile test are approx. 30KN.

Present research ultimately tried to focus on the modeling and analysis of wire rope for transmission lines considering the pole distance and sag of the wire rope, further comparing the simulated results with the theoretical, and trying to make a common set up for the test and validation of results experimentally.

Keywords: Wire rope analysis, ACSR Conductor, Varying Loading, ANSYS, Sag, Stresses, Displacement.

I. INTRODUCTION

WIRE ROPE is a type of rope which consists of several strands of metal wire laid (or 'twisted') into a helix. Initially wrought iron wires were used, but today steel is the main material used for wire ropes.[1] Wilhelm Albert's first ropes consisted of wires twisted about a hemp rope core, six such strands then being twisted around another hemp rope core in alternating directions for extra stability[2]. Earlier forms of wire rope had been made by covering a bundle of wires.

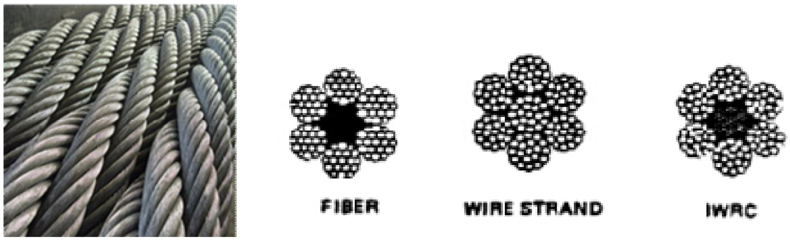

Fig 1: Wire rope and Core Costruction

Manufacturing a wire rope is similar to making one from natural fibers. The individual wires are first twisted into a strand, and then six or so such strands again twisted around a core.[5] This core may consist of steel, but also of natural fibers such as sisal, manila, henequen, or hemp. This is used to cushion off stress forces when bending the rope.

II. LITERATURE REVIEW

Erdem Imrak [2010] has developed geometrical, mathematical and finite element models of strands and ropes to predict their behavior under various loads. Erdem Imrak [2010] introduce a new technique of modeling wire rope with Independent wire rope core (IWRC) and compare results numerically. The proposed numerical model is solved using FEA and the variation of axial force with the axial strain.

Stanova [2011] presented the mathematical geometric models of the single-lay wire strands and double-lay wire ropes with defined initial parameters. The concrete forms of the parametric equations are derived and presented. Stanova [2011] Mathematical geometric model is implemented in a finite element program using ABAQUS/Explicit software is used. The results obtained confirm the correctness of the derived parametric equations and mathematical and physical importance of the finite element model developed.

Jun MA [2007] numerically simulated the stress and deformation of the wire, obtaining the deformation distribution of each wire within the wire rope under different laying directions. Usabiaga [2005] introduce a new theoretical procedure for modelling wire ropes subjected simultaneously to tensile and torsional loads. He proposed kinematics are based on the assumption that wires are un-lubricated and therefore that no relative sliding between adjacent wires happens. Jeong-In Suh [2006] evaluate the axial fatigue behavior of wire ropes being used as hangers in suspension bridges. Three parameters, mean stress, stress range, and specimen length, were adopted for verification.

Ilyin [2008] prepared analytical model for wire ropes which is used to predict the cable stiffness. The young modulus and ultimate tensile strength of the cable specimen are compared with those measured in single strands, extracted from the cable. The cable contraction was monitored during the tensile stress-strain testing. Ridge [8] presents the results of an extensive research program which highlight the practical implications of the torsional fatigue behavior of ropes with especial reference to their use in offshore applications. Considering a finite element model of a simple straight strand, Nawrocki [9] have introduced Cartesian isoparametric formulation. Jiang [10] develop a simple finite element model to analyze that the contacts can occur simultaneously at all possible contact points when the strand is subjected to extension with both ends fixed against rotation. Aeolian vibrations has low amplitude and high frequency vibrations and Wake-induced vibrations are in between the Aeolian and Galloping vibrations[KERMANI M. et al., 2010]. Galloping commonly occurs when there is an asymmetrically ice-coated conductor in the wind flow with a speed above 15 mph (7 m/s). In addition, galloping can also damage the towers with their severe amplitudes. [WANG J. J. 2006] Wake-induced oscillation, which is associated with bundled conductors, is caused by forces that originated by the shielding effect of the wind side conductors in the wind flow of 9 to 40 mph (4 to 18 m/s)[TRANSMISSION REPAIR MANUAL, 2010].

R.B. Kalombo et al., 2015, This paper presents a comparative study for the fatigue behavior between an All Aluminium Alloy Conductor (AAAC) and a Aluminum Conductor Steel Reinforced (ACSR). These cables use Aluminium Alloys (AA) 6201-T81 and 1350-H19, respectively. Nilson Barbieri et al., 2017, The main objective of this work is the analysis of the dynamic behavior of new transmission line cables: Tern (CAA), CA 1120 and CA 6201 (alloy); with mechanical tension variable (7 to 36% of the ultimate tensile strength (UTS)) with and without the inclusion of Stockbridge dampers.

Francesco Foti, 2016, A new formulation for modelling the elastic-plastic behaviour of metallic strands subjected to axial-torsional loads is presented. A full three-dimensional (3D) finite element (FE) model, based on a parametric description of the strand internal geometry, is also developed. R. Baumann and P. Novak, 2017, The paper revisits an important subject in the field of conductor inner mechanics, i.e. the bending behavior of overhead line conductors under tension.

A. Problem Identification

IS 398 wire, ACSR Conductor, were modeled and analyzed under tension loadings, here we have focused on same construction of wire rope. ACSR conductor is made of steel wire core surrounded by seven aluminum conductor wires. Major problem statement covers analysis and comparison of theoretical, software simulation and experimental analysis results with each other to validate analysis techniques.

Considered cable is a single straight strand made of one layer of circular wires helically laid over a central circular straight core wire.

A steel wire as the basic structural member of strands and ropes can be laid in the strand or in the rope as:

1) a core of the strand (the centerline of a core wire forms a straight line),
2) a wire in a layer of the strand (the centerline of a wire in a layer forms a single helical curve),
3) a strand core of the multi-strand rope (the centerline of a core wire forms a single helix), and
4) a wire in a strand layer of the multi-strand rope (the centerline of a wire in a strand layer forms a double helical curve).[2]

B. Methodology

To predict the behavior of the single straight strand under tensile loads, the mathematical geometric model is further implemented in a finite element program. For this purpose ANSYS 14.0 [12] software is used. Generated 3D geometric models of the single straight strand and the results of the finite element elastic behavior analyses of the strand under tension loads are determined.

III. OBJECTIVES OF PRESENT WORK

A. Generation of CAD Model of wire rope of appropriate length and geometry.
B. Analysis of deformation of wire rope using the CAD Model.
C. Theoretical calculations of sag, Aeolian vibration and wind loads etc on the wire rope.
D. Effect of environmental temperature on the wire rope.
E. Validation of tensile load on wire rope with the experimental values in lab.
F. Optimization of length of wire rope for safe condition.

IV. THEORETICAL CALCULATION

Research calculated the wire rope and optimum length for the same the following specification have been taken for the wire rope.

A. Wire Rope Nomenclature

Steel core wire wire diameter $\mathbf{d_s} = 1.57$ mm, Aluminum Wire diameter $d_{al} = 4.72$ mm, Diameter of cable $\mathbf{D_c} = 14.15$ mm, No. of wire 7 steel and 6 Aluminum, Breaking strength of wire rope 32.41 KN, Unit weight of wire rope $\mathbf{W}$=0.394 kg/m, Considering horizontal tension in wire rope $\mathbf{H}$ = 20% of breaking strength (32.14KN), Environmental temperature $\mathbf{T_{rif}} = 25°C$, Length at environmental temperature $\mathbf{T_{rif} = L_{tar}}$, Length at increased temperature $\mathbf{T = L_T}$, Span length $\mathbf{S} = 304800$mm, Wind speed for Aeolian Vibration$\mathbf{V} = 7$ m/second, Increased temperature $\mathbf{T} = 36°C$, Thermal gradient $\boldsymbol{\alpha} = 19.8 \times 10^{-6}$, Length of wire rope (**L**), Sag (**D**), Frequency (**ω**), Strouhal no. $\mathbf{S_s} = 0.185$.

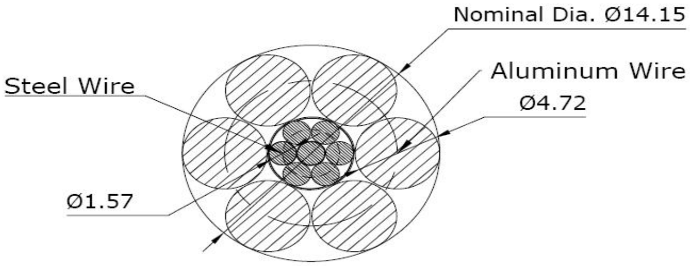

Figure 4 Wire rope Specifications

B. Wire Rope Parameters

Steel core wire wire diameter $\mathbf{d_s} = 1.57$ mm, Aluminum Wire diameter $d_{al} = 4.72$ mm, Diameter of cable $\mathbf{D_c} = 14.15$ mm, Unit weight at 25°C = 0.000394kg/mm, Breaking strength =32140 N, Tension in rope = 6428 N(20% of breaking load) , Wire specification = IS398 ACSR.

Sag Calculation

$$D = W*\text{Span}^2/8*\text{Horizontal Tension}$$

Length of wire rope

$$\mathbf{L = S + (8*D^2/\ 3*S)}$$

Slack = 283.6mm

C. Thermal elongation (Sag change)

As the temperature changes the length and span of the wire rope also changes causing change in the horizontal tension, calculated by the following formula,

$$\mathbf{L_T = L_{Tar}[1+\alpha_{as}\ (T-T_{rif})]}$$

$L_T = 305113.9$mm

V. MODELING AND SIMULATION OF WIRE ROPE

In this work, for conceptual modeling of experimental setup has been modeled in Solid Works 17 software and finite element analysis of the setup has been done in ANSYS 18.0 Workbench. Core wire is created. The helix pitch is 100mm and number of revolution is taken as two. Further double helix with pitch 100mm and two number of revolution generated. Complete wire rope is then modeled with double helix command application that means two layer of wires around core are modelled to create final wire rope model.

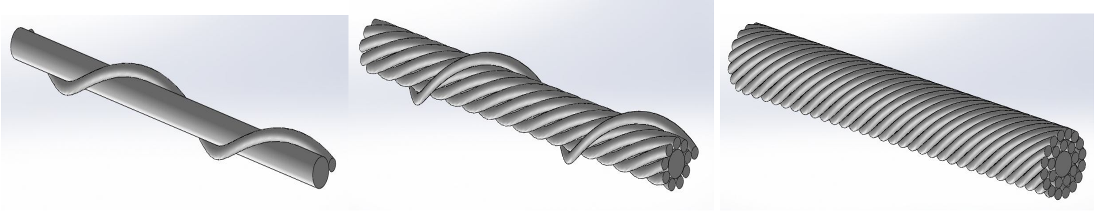

Figure 3: Step of Modeling

ANSYS Workbench, which is used to perform various types of structural and thermal analyses. Selecting structural analysis solver to determine the tensile stress, bending stress and torsion stress of the rope. The stress and deflection are important parameters in the design of a structure for dynamic loading conditions. Meshing is performed and the shape of mesh element is taken as tetrahedral in shape. The number of elements in mesh part is found 18395 and the number of nodes are found as 41476. The rope is fixed from one end and subjected under load of 3000N to 30000 N from second end.

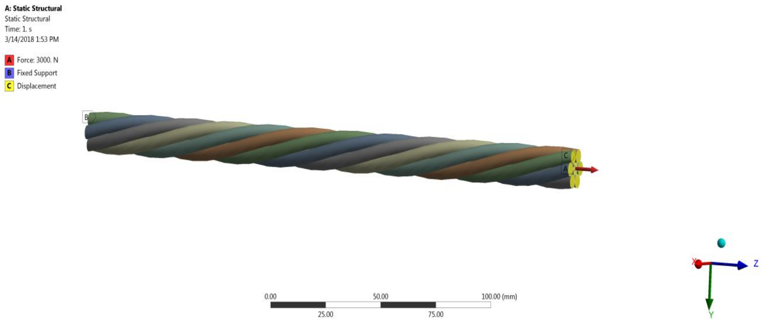

Figure 4: Meshing and Boundary Conditions

Analysis is performed under loading condition of 3000N to 30000N and performing stress analysis it is found that von misses stresses are found max.

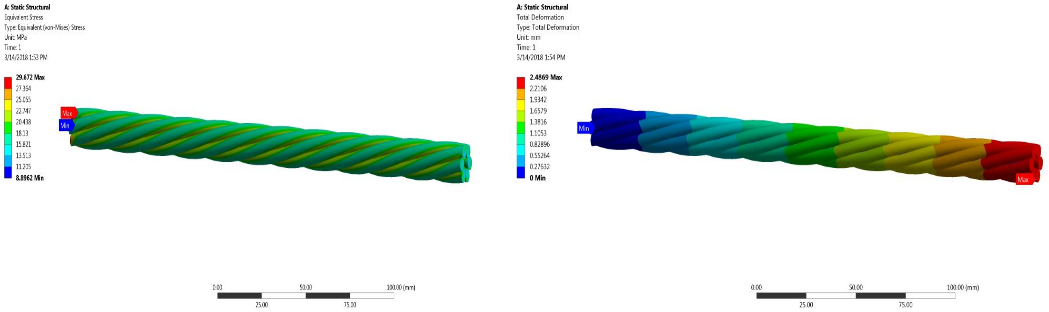

Fig 5: Wire Rope Stress and Displacement Analysis

Iterative analysis is to be performed with different lengths and with different loads and further which will be validated with the experimental result which will be carried by UTM. Thermal Analysis is performed with the temperature range of 5 degree to 25 degree.

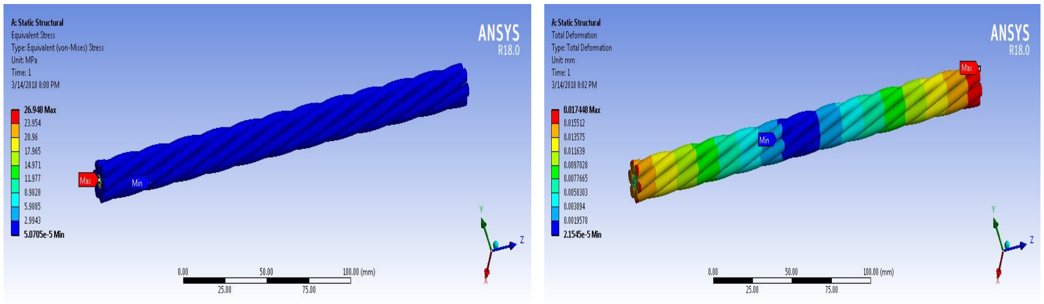

Figure 6: Thermal stresses and expansion analysis

A. Experimental Test Set Up

The major load acting on the wire rope is due to wind load, the elongation of the wire rope was found using ANSYS software in the previous chapters for different specimens of the wire rope, to validate the results and compare the results with theoretical and simulated results I have focused on testing the specimen for tension under different loading conditions and plotted charts for the same. The Test is to be conducted at IIT Indore.

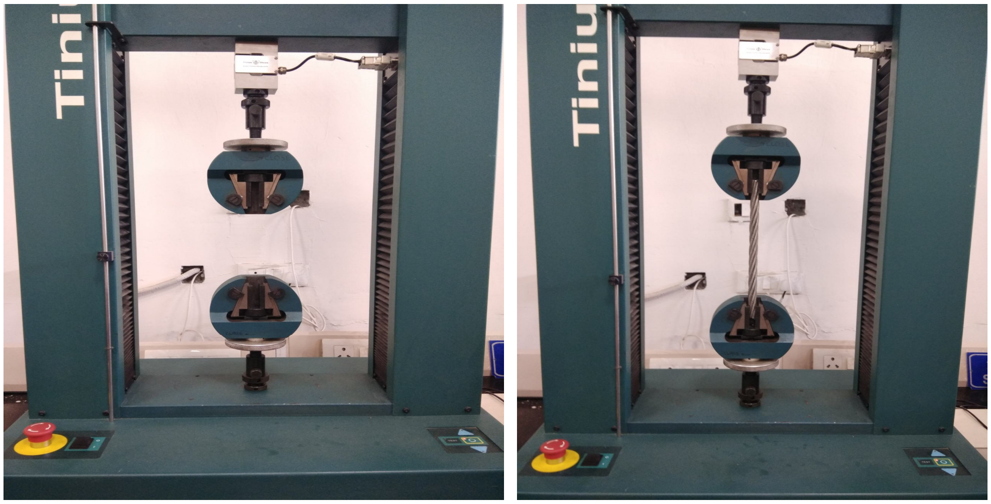

Figure 7: UTM Machine with Both Jaws and Rope Specimen

B. Wire rope specification for experimental validation

Aluminum Conductor Steel Reinforced (ACSR) is concentrically stranded conductor with one or more layers of hard drawn 1350-H19 aluminum wire on galvanized steel wire core. The core can be single wire or stranded depending on the size. Steel core wire is available in Class A, B or Class C galvanization for corrosion protection.

The proportion of steel and aluminum in an ACSR conductor can be selected based on the mechanical strength and current carrying capacity demanded by each application.

ACSR conductors are recognized for their record of economy, dependability and favorable strength / weight ratio. ACSR conductors combine the light weight and good conductivity of aluminum with the high tensile strength and ruggedness of steel. In line design, this can provide higher tensions, less sag, and longer span lengths than obtainable with most other types of overhead conductors.

Variable lengths of the ACSR conductor will be examined By the UTM machine for tension testing and will be validated by theoretical and simulated results.

VI. RESULTS AND CONCLUSION

Results obtained from theoretical, ANSYS and Experimental are tabulated:

Table 1: Structural Analysis Result Table

Theoretical Results			ANSYS Results		Experimental Results	
Load	Stress	Displacement	Stress	Displacement	Stress	Displacement
3000	19.10828025	2.4	27	2.4	20	3.04
6000	38.21656051	4.8	59	4.9	40	5.86
9000	57.32484076	7.2	89	7.4	60	7.84
12000	76.43312102	9.6	118	9.9	80	10.27
15000	95.54140127	12	148	12.4	100	13.47
18000	114.6496815	14.4	170	14.3	120	14.69
21000	133.7579618	16.8	207	17.4	140	17.72
24000	152.866242	19.2	217	19.9	160	20.07
27000	171.9745223	21.6	267	22.3	182	22.21

A. *Thermal Analysis Results*

Table 2: Thermal Analysis Result Table

Theoretical results					ANSYS Results	
Degree	Coefficient of Thermal Expansion	length	Thermal Expansion	Thermal stress	Thermal Expansion	Thermal stress
5	1.98E-05	240	2.38E-02	27.225	0.0174	26.9
10	1.98E-05	240	4.75E-02	54.45	0.0299	46.1
15	1.98E-05	240	7.13E-02	81.675	0.0423	65.4
20	1.98E-05	240	9.50E-02	108.9	0.0548	84.694
25	1.98E-05	240	1.19E-01	136.125	0.0674	103.94

B. *Structural Analysis Graphical Results Comparison*

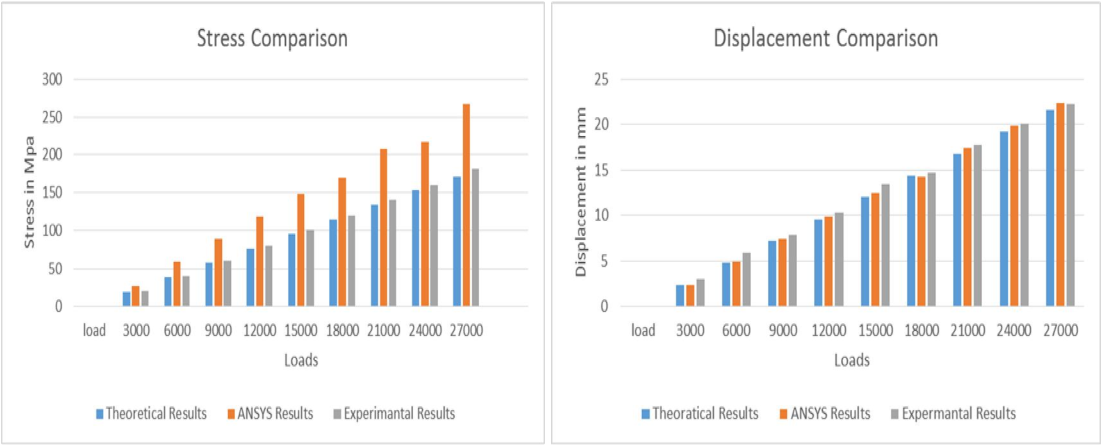

Figure 8: Stresses and Displacement Comparison

C. *Thermal Analysis Graphical Results Comparison*

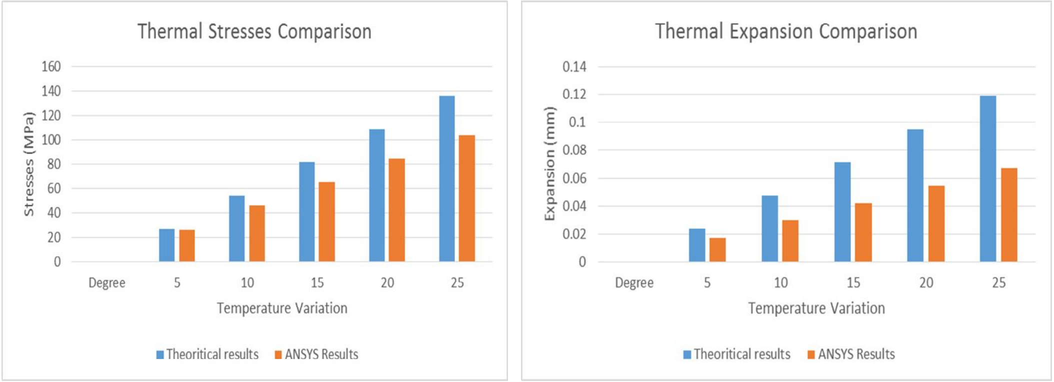

Figure 9: Thermal Stresses and Expansion Comparison

VII. CONCLUSION

Structural analysis is performed to test wire rope, theoretical calculations were performed to calculate sag, stresses and displacement for selected specimen of wire rope. Theoretical calculations are followed by ANSYS software simulation and experimental analysis at IIT Indore. It is concluded that stresses recorded with ANSYS are higher than theoretical and experimental analysis, this is because ANSYS provides results at elements. Displacement recorded for all three testing cases are almost near to each other.

Thermal analysis is performed to observe and study thermal stresses and expansion at normal room temperature. It is concluded that theoretically calculated result values are found similar and very close to each other and hence ANSYS results are validated with theoretical calculations.

A. Future Scope

1) Wire rope special purpose tenting machine can be developed to test ropes for thermal elongation, Aeolian vibrations and tensile strength at common station.
2) The poles level due to land geographical variation may be considered and wire rope may be tested for these situation.
3) Dampers test can be considered and performed with wire rope analysis for different diameters of rope.

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