International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 10, October- 2014

Analysis of Wire Rope

Er. G. S. Ramteke*
Department of Mechanical Engineering,
M.Tech.(CAD/CAM) Final Year,
Rajiv Gandhi College of Engineering Research Technology
Chandrapur (MS)-442401 (INDIA)

Prof. Y. L. Yenarkar**
Department of Mechanical Engineering
Rajiv Gandhi College of Engineering Research Technology
Chandrapur (MS)-442401 (INDIA)

Abstract **:- Wire ropes are critical mechanical components in mining and other industries where hoisting is common. Most of the industries follow the replenishment criteria based on the conventional practices. Some research has been carried out on analysis of wire ropes and the FE approach is also reported by some researchers in the recent past. This paper presents a study carried out on simple 7 wire single strand rope using the analytical as well as FE approach. The results obtained are compared. It is concluded that the behavior is significantly altered when rotation of the wire rope is allowed and when the rotation is prevented. Each case has been analyzed and presented.**

Key words- Wire rope, strand, helix, FE approach.

I. INTRODUCTION

A number of studies have been carried out to understand and quantify the wear which occurs in wire rope. The criteria for rope replenishment are mostly based on no. of broken wires per unit length. During service a wire rope continuously deteriorates under several influences which include tension, bending, fatigue, corrosion and wear. Because of the multiple deteriorating factors and the complex interactions between them, replacement criteria is difficult to formulate and is subjective.

S.D.S.R. KARAMCHETTY & W.Y. Yuen [2] studied the contact problem in wire rope. The contact stresses induced at contact points resulted due to deformation under loading. G.A. COSTELLO [3] studied the behavior of a multilayered cable under axial, bending and torsional loading conditions and concluded that centre wire suffers a largest axial stress. J.W. PHILLIPS and G.A. COSTELLO [4] studied the analysis of wire ropes with internal wire rope cores and concluded that strands and wires that are partially aligned subjected to maximum axial strain. On the contrary, the wires that are not axially aligned within strands are subjected to bending & shear stresses and axially aligned wires do not experience the bending & shear stress. S.A.VELINSKY [5] has developed a design methodology for multilayered wire strand. Assumption was made that strands retain its helical shape before and after deformation. WEI JIANG [6] studied the general formulation to analyze wire ropes having simple wire strand and different complex cross sections also. K. KUMAR[7] have studied the contact stresses under tension & torsion and found that contact stresses are influenced by helix angle. C. ERDEM ĐMRAK AND CENGIZ ERDÖNMEZ [8] introduced a technique of modeling of wire rope with IWRC. C. ERDEM EMRAK AND CENGIZ ERDONMEZ [9] presented a three-dimensional modeling approach and studied the finite element analysis of wire ropes. SHIBU. G, MOHANKUMAR K.V AND DEVENDIRAN. S [10] developed the finite element model for multilayered wire rope and declared that the helical wires with a fixed end condition carry large axial load as compared to free end conditions for same axial strain.

In the light of above, it is evident that the analysis of wire rope is significant for decision on optimum replenishment criteria and hence the simple strand wire rope was chosen for analysis of wire rope. The objective is to know the exact behavior of individual wires under loading condition The equations derived by Costello [2] are regarded as a baseline, and finite element analysis results are compared with these analytical results in order to confirm generated finite element model.

II. DESCRIPTION & CALCULATION

The problem of determining the stresses in a rope is an extremely complex one. The geometric data for the chosen single strand rope with 7 wires is as shown in Table-1. The calculations are carried out for two approaches i.e. when rotation prevented and when rotation allowed which are based on the analytical approach by G. A. Costello. The results obtained by considering the different permissible elongations such as 0.2%, 0.25%, 0.3%, 0.35%, 0.4%, 0.45% and 0.5% are tabulated as given in Table 2 & Table 3.

TABLE1. GEOMETRIC DATA FOR SIMPLE STRAIGHT STRAND

Parameter	Unit	Value
Radius of center wire of strand, R_1	Mm	1.97
Radius of outer helical wire of strand,R_2	Mm	1.865
Helix angle of an outside wire, α_2	Degree	78.2^0
Modulus of elasticity, E	N/mm^2	$2x10^5$
Poisson ratio, υ	-	0.3
No. of outer helical wires in a strand,m_2	Nos.	06

TABLE2. ANALYTICAL RESULTS WHEN ROTATION IS PREVENTED

Sr. No	% elongation	Axial load on centre & outer wire		Theoretical calculations					
				Centre wire		Outer helical wire			
		F_1 (N)	F_2 (N)	Axial wire stress N/ mm^2	Max shear stress on c/s (N/ mm^2	Axial stress caused by tension (N/ mm^2	Max. normal stress due to bending (N/ mm^2	Max shear stress due to twisting moment (N/ mm^2	Max normal tensile stress (N/ mm^2
1	0.2	4874	24271	400	0	378	17	13	396
2	0.25	6093	30339	500	0	473	22	16	495
3	0.3	7312	35490	600	0	553	26	19	579
4	0.35	8530	42475	700	0	662	31	23	693
5	0.4	9749	48544	800	0	756	35	26	792
6	0.45	10967	54611	900	0	851	39	30	891
7	0.5	12186	60679	1000	0	946	44	33	990

TABLE 3.ANALYTICAL RESULTS WHEN ROTATION IS ALLOWED

Sr No	% elongation	Axial Load on centre wire & outer wire		Theoretical calculations					
				Centre wire		Outer helical wire			
		F_1 (N)	F_2 (N)	Axial wire stress N/ mm^2	Max shear stress on c/s (N/ mm^2	Axial stress caused by tension (N/ mm^2	Max. normal stress due to bending (N/ mm^2	Max shear stress due to twisting moment (N/ mm^2	Max normal tensile stress (N/ mm^2
1	0.2	0	8548	0	132	133	124	110	257
2	0.25	0	10685	0	165	166	155	137	322
3	0.3	0	12822	0	198	200	186	165	386
4	0.35	0	14959	0	231	233	218	192	451
5	0.4	0	17096	0	264	266	249	220	515
6	0.45	0	19233	0	297	300	280	247	580
7	0.5	0	21370	0	330	333	311	275	644

III. FINITE ELEMENT MODELLING OF WIRE STRAND

A simple straight strand model is constructed with a center wire of radius R_1=1.97mm, surrounded by six helical wires (Radius of outer helical wire of strand, R_2=1.865mm) wound around with the helix angle 78.2^0. The helix angle α_2 is determined by tan $\alpha_2 = p_2 / 2\pi r_2$, where p_2 is the pitch length of strand. The CAD model generated with the geometric data as given in Table-1 is shown in Fig.1.

The CAD model generated has been preprocessed. Surface to surface contact interactions between center and six outer single helical wires and between six helical wires are defined individually. The material properties used for FEA are material- structural steel, Young's Modulus = 2 x 10^{11} Pa, poisons ration=0.3, stiffness behavior – flexible, ultimate tensile strength-4.6 x 10^8 Pa, No. of elements-1360, no. of nodes-7680.

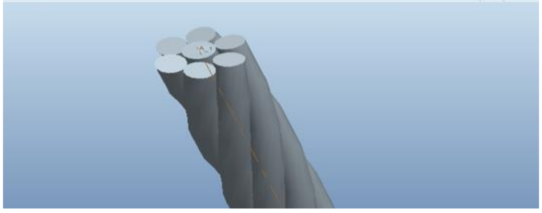

Fig.1 CAD model of wire strand

Selection of appropriate element type is necessary for the analysis. For this analysis, SOLID186 element is used which is a 3D element for centre wire and outer helical wires, TARG170 and CONTA174 element are used for contacts between centre wire and helical wire and among outer helical wires. SURF154 element is used for defining surface contacts. The meshing of element is done as shown in Fig. 2(a). In this quadrilateral meshing is chosen. Load has been calculated based on % elongation applied and the results of analytical approach. Displacement in x, y & z direction at top end is assigned by applying displacement toolbar. Negative pressure has been applied on the bottom end. Using these constraints the finite element analysis was performed to predict the stresses acting on the strand. Analysis result for Von misses stresses in wire strand is shown in Fig.2(b)

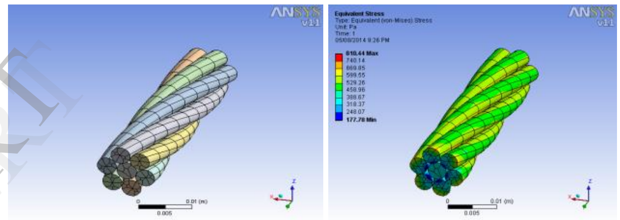

Fig. 2(a) Mesh Fig. 2(b) Analysis result

Prediction of strand response for axial loading has been attempted for the two cases. i.e. rotation of strand under loading is allowed and rotation of strand restricted under loading conditions. The FE analysis results for each of the above mentioned two considerations are given in Table 4 & Table-5.

TABLE 4. FEA RESULTS IS WHEN ROTATION RESTRICTED

% elongation	Load acting on centre wire	Load acting on outer wire	Finite Element Analysis Results						
			Centre wire		Outer helical wire				
	F_1 (N)	F_2 (N)	Shear stress (N/ mm^2)	Von-Misses stress (N/ mm^2)	Von-Misses Stress (N/ mm^2)	Normal stresses (N/ mm^2)	Shear stress (N/ mm^2)	Max. Prin. stress (N/ mm^2)	Min. Principle Stress (N/ mm^2)
0.2	4874	24271	1.0	380	443	38	75	423	39
0.25	6093	30339	1.0	476	554	48	72	532	17
0.3	7312	35490	1.5	544	605	56	63	609	21
0.35	8530	42475	2.0	666	747	67	11	744	34
0.4	9749	48544	2.1	761	851	77	13	846	27
0.45	10967	54611	2.1	857	962	87	13	957	89
0.5	12186	60679	2.2	951	1065	96	15	1064	69

TABLE 5. FEA RESULTS WHEN ROTATION IS ALLOWED

% elongation	Load acting on centre wire	Load acting on outer wire	Finite Element Analysis Results						
			Centre wire		*Outer helical wire*				
	F_1 (N)	*F_2 (N)*	*Shear stress (N/ mm^2)*	*Von-Misse stress (N/ mm^2)*	*Von-Misses Stress (N/ mm^2)*	*Normal stresses (N/ mm^2)*	*Shear stress (N/ mm^2)*	*Max. Prin. stress (N/ mm^2)*	*Min. Principle Stress (N/ mm^2)*
0.2	0	854	0.21	110	140	11	36	135	5
0.25	0	106	0.32	138	176	14	45	169	6
0.3	0	128	0.26	150	190	17	29	203	7
0.35	0	149	0.27	193	246	19	34	237	9
0.4	0	170	0.32	222	282	22	39	272	10
0.45	0	192	0.28	248	316	25	44	305	11
0.5	0	213	0.33	276	352	28	91	339	12

IV. RESULTS OF FEA

For each of these cases, the Finite Element analysis was performed. The stress patterns for various stresses for each of the cases i.e. when rotation is allowed and when rotation is restricted for centre wire and peripheral wire are shown in following figures.

CASE-I (STRAND IS NOT ALLOWED TO ROTATE)

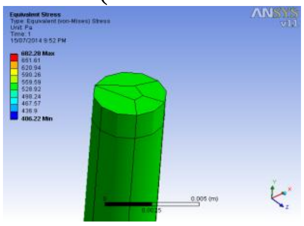

Fig.3 (a) Von Misses Stress In Centre Wire

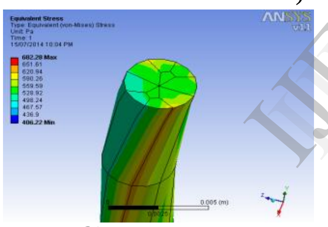

Fig.3(b) Von Misses Stress In Outer Wire

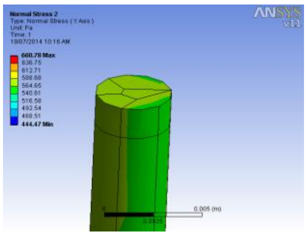

Fig.4(a)Normal Stress(Y-Axis) in centre wire

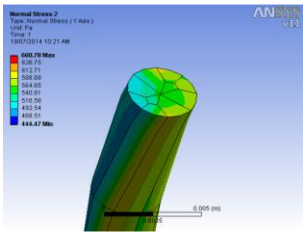

Fig.4(b) Normal Stress (Y-Axis) in outer wire

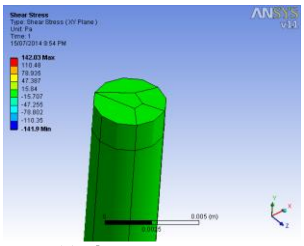

Fig.5(a) Shear Stress in centre Centre wire

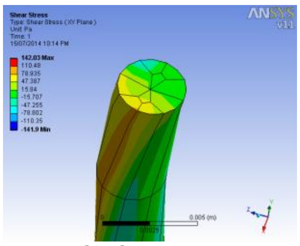

Fig.5(b) Shear Stress in outer wire

As seen in the Fig.3(a)Von Misses stresses in centre wire are constant throughout the entire region when the rotation is not allowed primarily because the stresses include the direct stresses as the major component which is constant throughout whereas the Fig.3(b) shows the localized concentration of stresses at the region of contact between centre & outer wires.

CASE-II (STRAND IS ALLOWED TO ROTATE)

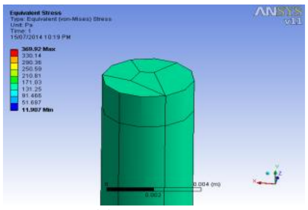

Fig.6(a) Von Misses Stress in centre wire

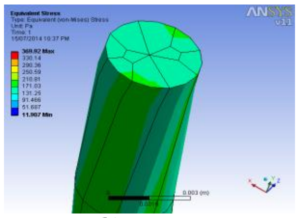

Fig.6(b) Von Misses in outer wire

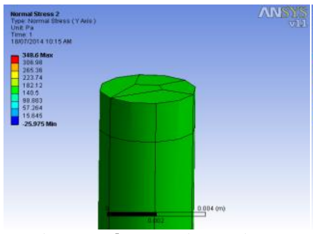

Fig.7a) Normal Stress (Y axis) In centre wire

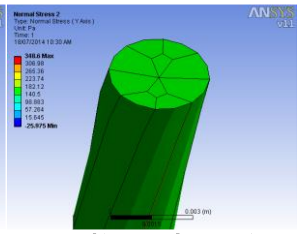

Fig.7b) Normal stress (Y axis) in outer Wire

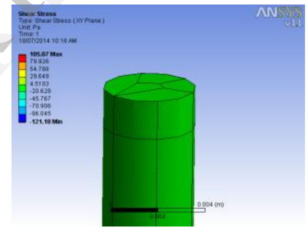

Fig.8 (a) Shear Stress in Centre wire

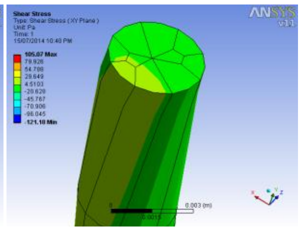

Fig.8(b) Shear stress in outer wire

As shown in Fig. 4 (a) & Fig. 4 (b) normal stresses (Y-Axis) are uniformly distributed in centre wire whereas there appears to be region of concentration in case of outer wire. The similar results are shown in Fig.5(a) & Fig.5(b) displaying the shear stress also follows the same pattern.

As seen in the Fig.6(a) Von Misses stresses in centre wire are constant throughout the entire region when the rotation is allowed primarily because the unwinding of outer wires resulted in some stresses in centre wire which is constant throughout whereas the Fig.6 (b) shows the localized concentration of stresses at the region of contact between centre & outer wires. As shown in Fig.7 (a) & Fig. 7(b) normal stresses (Y-Axis) are uniformly distributed in centre wire as well as in outer wire. Fig.8 (a) & Fig.(b) shows the distribution of shear stress on centre and outer wire.

V. RESULT & DISCUSSION

The wire ropes have varied designs as per applications. To make the study, typical single strand wire rope has been chosen for analysis which includes analytical as well as FE approach. Two results are in agreement in the broader view and consistent for each of the cases.

On application of axial load, the outer wire of the wire rope shall have tendency to unwind providing some extension. Due to this phenomena, However when the rotation is prevented much of the load is carried by the central wire as it is under the normal load. However the outer wires are subjected to axial, bending and twisting loads. And hence, the normal load on outer wires is significantly lower than load on central wire.

As found in Table 2 & Table 4, it can be seen that the axial stress on the central wire using analytical approach and FE approach has less than 5% deviation and the results are consistent. This can also be verified from Fig.9 & Fig.10 which are graphs showing % elongation verses analytical and FE results.

The Fig. 11, Fig.12 & Fig.13 shows the Von misses stresses, normal stresses and shear stresses obtained by FE analysis in centre and outer helical wires.

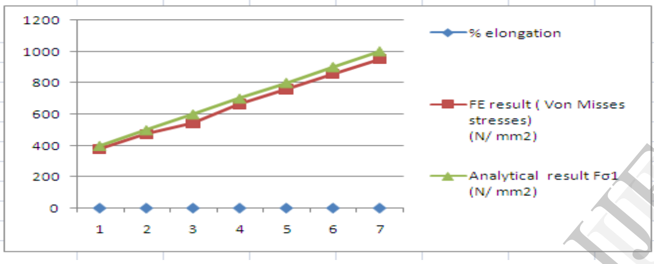

Fig.9. Analytical & FE results for centre wire when rotation is restricted

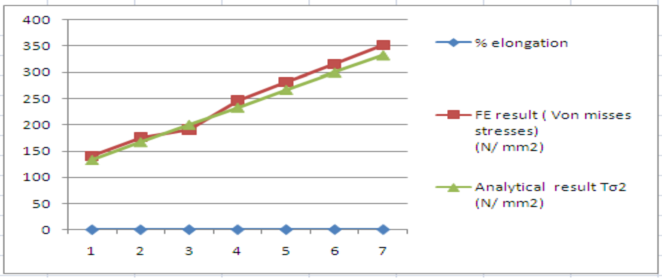

Fig. 10 Analytical & FE results for outer wire when rotation is restricted

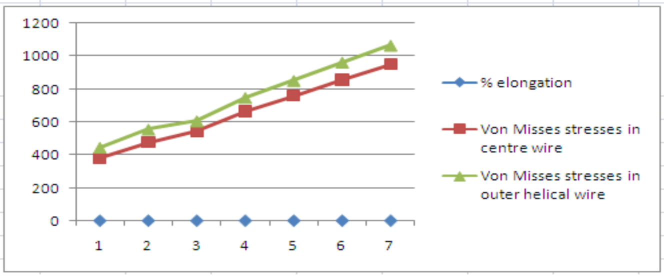

Fig.11 Von misses stresses in centre & outer wires.

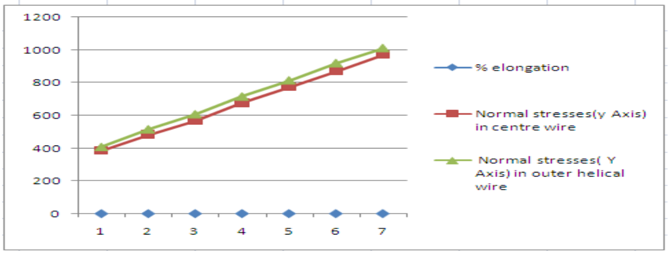

Fig.12 Normal stresses in centre & outer wires.

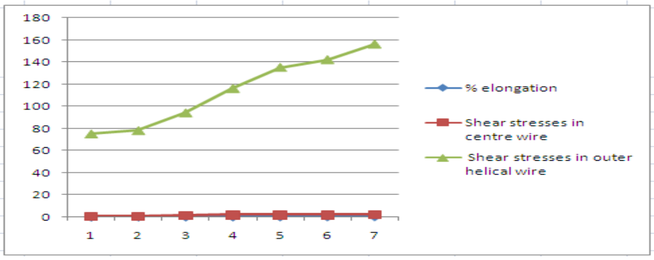

Fig.13 Shear stresses in centre & outer wires.

The difference in the values may be attributed to the fact that theoretically the centre wire is considered to be in pure tension which may not be the case as there always be some shear and contact stresses due to outer wires. Also FE approach has used the contact elements describing the contact between the inner & outer wire which is again not considered in analytical approach. Both the graphs are almost parallel, however FE results are diverging for the higher values of % elongation.

When rotation is allowed, the wire rope unwinds and this allows the outer wires to extend more than the centre wire. This result in outer wires taking more load and also reduces the strain in the centre wire. This also makes the reduction in the overall strain in the wire rope increasing the capacity of the wire rope as stresses in the wire appears to be less.

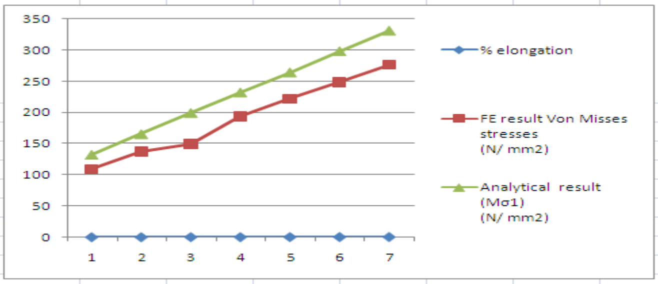

Fig. 14 Analytical & FE results for centre wire when rotation is allowed.

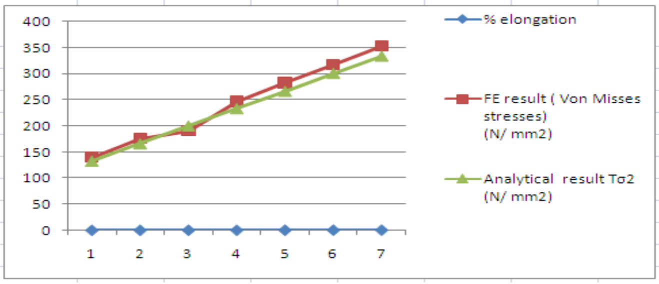

Fig. 15 Analytical & FE results for outer wire when rotation is allowed

Fig. 14 & Fig.15 depicts the behavior of centre wire & outer wires with the increasing elongation, it has been observed that both the stresses are in the agreement and the deviation of FE result from analytical result is about 7%. This attributes to the variation in assumption in FE analysis & analytical calculation and effect of contact element in FE analysis.

Fig.16 & Fig.17 depicts the behavior of von misses stresses in centre wire & peripheral wire when rotation is allowed along with the normal stresses (Y-axis) using FE approach.

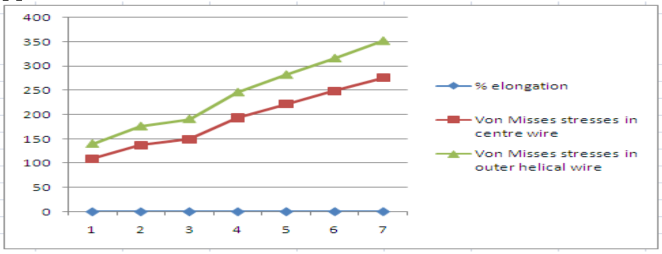

Fig.16 Von Misses stresses in centre & outer wire

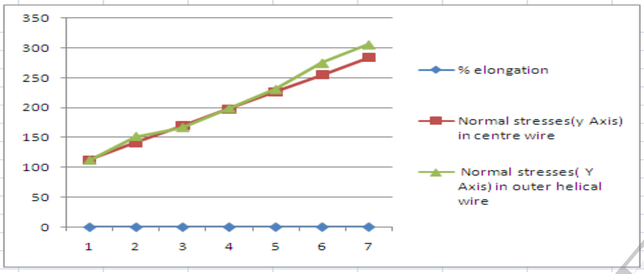

Fig.17 Normal stresses in centre & outer wire

The results obtained using both the approaches indicate that FE analysis could be used to verify with the analytical equations given by G. A. Costello [2].

VI. CONCLUSION

The results obtained suggest the allowing rotation decrease the direct stresses. However, these needs to be further investigated as the direct stresses are significant cases in comparison with the operational conditions in which the rotation is not allowed. Normally short distance hauling application and hoisting with guide ways do not allow the rotation. Hence this detailed study for the variation in the rotational elongation is justified. In the real application which involves hauling through a long distance rotation and local unwinding of the wire rope is not uncommon and often is a chief cause of reduction in life of the wire rope. Therefore it is just to conclude that though the analytical results & FE results are in agreement a detailed investigation involving variation in helix angle, coefficient of friction, % elongation, rotational elongation allowed, etc needs to be done.

Further the behavior of wire rope while it is bending over a sheave is also of interest and some study on this could also be done as the centre as well as outer wire in this case shall be subjected to bending and the loading will be significantly complex.

REFERENCE

[1] G.A. COSTELLO, Professor, Dept. of Theoretical & Applied Mechanics, University of Illions, Urbana, " THEORY OF WIRE ROPE", 2nd Edition, SPRINGER Mechanical Engg Series.

[2] S.D.S.R. KARAMCHETTY, Sr. Engineer, Mathtech Inc, Washington DC and W.Y.YUEN The University of Newcastle, N.S.W, Australia "CONTACT PROBLEM IN WIRE ROPES", Journal of mechanical design Vol-01/October 1979,pg:702-710

[3] G.A. COSTELLO, Professor, Dept. of Theoretical & Applied Mechanics, University of Illions, Urbana, " STRESSES IN MULTILAYERED CABLES", Journal of Energy Resources Technology, ASME, Sept-1983, Vol-105, pg:337-340.

[4] J.W. PHILLIPS and G.A. COSTELLO, Professor, Dept. Of Theoretical & Applied Mechanics, University of Illinois at Urbana, "ANALYSIS OF WIRE ROPE WITH INTERNAL WIRE ROPE CORES", Journal of Applied Mechanics, Vol-52, Sept-1985, pg:510-516.

[5] S.A. VELINSKY, Associate Professor, Dept. Of Mechanical Engg, University of Wisconsin-Madison, 1513 University Avenue, Madison, WI-53706," ON THE DESIGN OF WIRE ROPE", Journal of Mechanism, transmission & Automation in design, Sept-1989, Vol-111, pg:382-388

[6] WEI JIANG, Mechanical Engg. Department, Florida International University, Miami, FL-33199," A GENERAL FORMULATION OF THE THEORY OF WIRE ROPES", Journal of Applied Mechanics, Sept-1995, Vol-62, pg:747-755

[7] K.KUMAR, Professor, Department of Aerospace Engineering, Indian Institute of Technology, Kanpur; J.E.COCHRAN, Professor & J.A.CUTCHINS, Professor, Department of Aerospace Engineering, Auburn University, Auburn, AL ," CONTACT STRESSES IN CABLES DUE TO TENSION AND TORSION", Journal of Applied Mechanics, Vol-64, Dec-1997, pg:935-939

[8] C. ERDEM ĐMRAK AND CENGIZ ERDÖNMEZ, Department of Mechanical Engineering, Istanbul Technical University, 34394 Gumussuyu, Istanbul, Turkey "ON THE PROBLEM OF WIRE ROPE MODEL GENERATION WITH AXIAL LOADING" Association for Scientific Research, Mathematical and Computational Applications, Vol. 15, No. 2, pp. 259-268, 2010.

[9] C. ERDEM ĐMRAK AND CENGIZ ERDÖNMEZ, Department of Mechanical Engineering, Istanbul Technical University, 34394 Gumussuyu, Istanbul, Turkey "FINITE ELEMENT MODEL FOR INDEPENDENT WIRE ROPE CORE WITH DOUBLE HELICAL GEOMETRY SUBJECTED TO AXIAL LOADS", Indian Academy of Science, Sadhana Vol. 36, Part 6, Dec 2011, pp. 955-1008.

[10] SHIBU. G, MOHANKUMAR K.V AND DEVENDIRAN. S, "ANALYSIS OF A THREE LAYERED STRAIGHT WIRE ROPE STRAND USING FINITE ELEMENT METHOD." Proceedings of the World Congress on Engineering 2011 VOL III WCE 2011, JULY 6 - 8, 2011, LONDON, U.K.