624.071.2:539.434

On the Creep and the Relaxation of Spiral Ropes*

By Mikio NAKAI**, Susumu SATO***, Toshio AIDA****,
and Hiroyuki TOMIOKA§

Spiral ropes are widely used as standing ropes in long bridges, suspension bridges or constructions with suspended ceilings. In these constructions, creep strain occurs inevitably. Also a relaxation of stress of PC strands (a kind of spiral rope) used in the prestressed concrete occurs. Therefore, to estimate the creep strain and the relaxation values of spiral ropes is one of the important problems in the design of bridges and prestressed concrete structures.

The authors have carried out creep and relaxation tests of spiral ropes used as standing ropes and have calculated the creep strain and relaxation values by considering the creep strain of a single wire and by applying the analytical method, whose validity has been proven for the purpose of understanding the mechanical properties of ropes. Consequently, it has been made clear that the creep strain and the relaxation are influenced by the clearance between wire layers of the rope, and that they can be estimated by the analytical method presented in this paper.

1. Introduction

Spiral ropes are widely used as standing ropes in long bridges, suspension bridges or constructions with suspended ceilings. In these constructions, the creep strain of spiral ropes occurs inevitably owing to the constant tension acting on them during their years of use. PC strands (spiral rope) as well as PC wire are used in the prestressed concrete. As these strands are set at constant intervals, their relaxation occurs. Therefore, to estimate the creep strain and the relaxation values of spiral rope is one of the important problems in the design of suspension bridges and prestressed concrete structures.

Many studies on the creep and the relaxation of PC wire have been carried out theoretically and experimentally⁽¹⁾⁻⁽⁴⁾. But few studies on strands (spiral rope) have been done, except the following experimental studies^{(5),(6)}. R.Helms⁽⁶⁾ has carried out over long periods of time, a creep test of ACSR (Aluminum Conductor Steel Reinforced), a kind of spiral rope, used as an electric cable. In another study⁽⁷⁾ the creep strain of the electric cable has measured in the field where the cable was laid. But the method to esti-

mate theoretically the creep strain and relaxation values of spiral ropes has not yet been established.

The authors have carried out creep and relaxation tests of spiral ropes and tried to make clear the creep and relaxation properties of spiral ropes under theoretical consideration. Furthermore, an expression which shows the curve of the creep strain of a single wire was proved by a test of a wire. On the basis of the expression, the creep strain and relaxation values of spiral ropes were estimated by applying the analytical method^{(8),(9)}, which had been confirmed to be useful for the analysis of mechanical properties of rope. These results were compared with experimental results. Also the creep testing result of ACSR obtained by R.Helms was compared with the results of the authors' analytical method.

2. Experimental results

2.1 Experimental method and spiral ropes tested

A schematic figure of the experimental equipment is shown in Fig.1⁽⁴⁾. Constant load was applied to specimens by putting dead weights and a traveling weight on the lever of the creep tester which was of the lever type. The extension of the specimen was measured by means of a differential transformer. Relaxation values were measured with the same equipment by moving automatically the traveling weight along the lever in order to keep the detected extension constant. The time from zero load to the load tested (the loading time) was 60 sec, but with varied loading time also the creep and relaxation tests were carried out. Testing tempera-

* Received 3rd April, 1973

** Lecturer, Faculty of Engineering, Kyoto University, Kyoto.

*** Assistant professor, Faculty of Engineering, Kyoto University.

**** Professor, Faculty of Engineering, Kyoto University.

§ Engineer, Shinko Wire Co. Ltd.

ture was held at a constant $20^{\circ} \pm 1^{\circ} \text{C}$.

The constructions of the spiral ropes tested are given in Table 1. The experimental wires contain 0.6% carbon and they are generally used in wire rope.

2.2 Experimental results

(a) Effects of the construction of spiral rope

The creep and relaxation tests on a single wire and spiral ropes with 7, 19 and 37 (A) wires were respectively carried out under a 65% load of aggregate breaking forces (this force is not an actual breaking force, but a breaking force obtained by multiplying the total sectional area of a wire by its tensile strength.) The experimental results are plotted in Figs.2 and 3.

Now we shall calculate theoretically the tensile load acting on each wire of the rope by applying the analytical method⁽⁹⁾ deduced from the assumption that all wires of a rope touch perfectly each other when the tensile load is applied and that a perfect contact pressure develops between the wire layers of the rope. The calculated results are shown in Table 2. From Table 2, we see that the tensile loads acting on the core wires of spiral ropes, which are directly related to the creep strain of the rope, are nearly equal to the tensile load 117 kg acting on a single wire. However, it is evident from Figs.2 and 3, that the creep strain and the relaxation values of all ropes are several times as large as that of a single

wire, and that they become larger in a rope with more layers.

These experimental results show that a clearance exists between wire layers of the rope because all wire layers of the rope do not contact perfectly each other. Especially, the creep strain may become larger, because the total clearance between layers is larger with more layers. From further consideration of Figs.2 and 3, it is seen that the rate of the creep strain of spiral rope (the creep rate) increases initially, but becomes smaller with the lapse of time. This phenomenon seems to be caused from the behavior of

Fig.2 Experimental and theoretical results of creep tests on a single wire and various spiral ropes

Fig.3 Experimental and theoretical results of relaxation tests on a single wire and various spiral ropes

Fig.1 Experimental equipment

Table 2. Tensile loads acting on each wire of ropes

Construction of wire	Tensile loads kg	
	Core wire	Side wire
A wire	117	—
1 X 7 O/S	115	91
1 X 19 O/S	118	93
1 X 37 O/S	119	94

Table 1. Construction of ropes tested

Construction of rope	Diameter of rope (mm)	Diameter of wire (mm)		Breaking force kg	Aggregate breaking force kg	Yielding load kg	Angle of lay
		Core wire	Side wire				
A wire	—	1.09	—	180	180	—	—
1 X 7 O/S	3.09	1.09	1.00	960	1020	—	10° 46'
1 X 19 O/S	5.09	1.09	1.00	2600	2760	—	10° 46'
1 X 37 O/S (A)	7.09	1.09	1.00	5110	5370	4545	10° 46'
1 X 37 O/S (B)	6.94	1.00	0.92	4580	4820	3975	10° 46'

each layer of the rope to contact much more closely after a lapse of time.

The above experimental results can be explained by the following phenomena particular to the rope. The creep strain of the rope consists of two kinds of creep strains. One is caused by the tensile load acting on a wire, when all wire layers adhere perfectly to each other and a contact pressure occurs between two layers. The other is an extension due to the construction of the rope. The extension is caused by a reduction in the diameter of the rope when the contact pressure does not act between the two layers, (the creep strain due to the construction of the rope is equal to the creep strain of a core wire when additional tensile load acts on a core wire owing to a reduction of the diameter of the rope.) Therefore, it is evident that the creep strain of spiral rope is several times as large as that of a single wire, because the creep strain due to the construction of the rope increases with an increase in the number of layers. Also the decrease of the creep rate with time depends on the decrease in the creep strain due to the construction of the rope.

(b) Effects of load

In order to investigate more deeply into the phenomena of creep and relaxation behavior particular to the rope, the creep and relaxation tests on spiral rope (B), with 37 wires, were carried out under various tensile loads with the results as shown in Figs.4 and 5.

Fig.4 Experimental and theoretical results of creep tests on 1 X 37 O/S (B) rope

Fig.5 Experimental and theoretical results of relaxation tests on 1 X 37 O/S (B) rope

In Fig.6, the creep strain and the relaxation values after 10 hours are given in relation to various loads. According to these figures, the creep strain is small under low tensile loads, but it increases remarkably with an increase of the tensile load. When the tensile load increases to a breaking point of the rope, the creep strain tends to decrease.

The relaxation value increases up to 60% of the tensile load that would break the rope, but it begins to decrease under a higher tensile load. These results can be interpreted as follows: The creep strain and the relaxation value increase naturally, because the tensile load acting on a wire becomes higher with an increase of the load acting on the whole rope. But under higher loads both the creep strain and the relaxation value decrease on account of a decrease of the creep strain due to the construction of the rope.

(c) Effects of the loading time

It has been made clear that the clearance between wire layers of the rope has an important effect on creep strain

Fig.6 Relation between initial load and creep strain or relaxation value on 1 X 37 O/S (B) rope

Fig.7 Relation between loading time and relaxation value on 1 X 37 O/S (B) rope

and relaxation. Therefore, the loading time up to initial load in relaxation tests may have an effect on the relaxation value. Figure 7 shows the experimental results obtained under various loading times. From Fig.7, the relaxation values become smaller with the increase of loading time owing to the larger initial strain caused by the reduction of the diameter of the rope. Also the influence of the loading time on the relaxation values decreases under higher initial loads, because the rope is tightened much more than under lower initial loads.

(d) Effects of pre-tension

According to experimental results described in (a), (b) and (c), it is desirable to reduce the clearance between wire layers as much as possible for practical use, thereby decreasing the creep strain and the relaxation values. In general use pre-tension (pre-tension means high loads acting on the rope for a set time before its use.) is performed as one method for reducing the clearance of the rope. The relaxation values in the spiral rope with 37 wires were measured to study how much pre-tension influences the relaxation values, and results are plotted in Fig.8. The relaxation tests were performed under an initial load of 3487 kg using two different ropes. A 3487 kg load acted on one rope and a 3863 kg load did on the other rope for ten minutes before the test.

Under higher pre-tension, the relaxation values decrease on account of the reduction of clearance between the wire layers. Thus, it is clear that pre-tension is very effective for the relaxation of the rope.

3. Method for calculation of creep strain and relaxation values

For the calculation of creep strain and relaxation values of spiral rope, it is necessary to be able to calculate the creep strain of a wire, of which the rope consists. Referring to earlier studies⁽¹⁾,⁽²⁾, we shall calculate the creep strain of a wire.

3.1 Expression for the creep strain of a single wire

Although the creep strain of a wire has been expressed by various equations,

Fig.8 Influence of pre-tension on relaxation value of 1 X 37 O/S (A) rope

the creep strain ϵ_c of PC wire can be expressed as follows⁽²⁾;

$$\epsilon_c = A\sigma^\beta t^\gamma \quad \dots\dots\dots(1)$$

A, β, γ : constant, σ : stress kg/mm²

t : time sec, ϵ_c : %

The creep strain ϵ_c is generally a function of temperature, but A is a constant value because creep tests were done at a constant temperature in this study. Substituting $\beta=6.0$ (according to Ref.(2), $\beta=9.22$, but β -value of the drawn wire used in the spiral rope is about 6.0) and $\gamma=0.184$ into Eq.(1) and determining A -value such that ϵ_c may agree with the experimental result, we obtain $A=1.2 \times 10^{15}$. The curve for the creep strain ϵ_c calculated is indicated in Fig.2. Thus the creep strain of a single wire can be calculated by substituting A, β and γ -values described above into Eq.(1).

On the other hand, through studies of PC wire it was found that the relaxation values could be predicted from Eq.(1) according to the strain hardening theory⁽¹⁰⁾. From Eq.(1), the relaxation values are expressed as Eq.(2).

$$\int_{\alpha}^1 \frac{(1-\alpha)^{1/\gamma-1}}{\alpha^{\beta/\gamma}} d\alpha = (\sigma_0)^{(\beta-1)/\gamma} \gamma (AE)^{1/\gamma} t \quad \dots\dots\dots(2)$$

where $\alpha = \sigma/\sigma_0$, σ_0 : initial stress, E : modulus of elasticity of a wire.

The results calculated from Eq.(2), which are shown in Fig.3, agree very well with the experimental results. Consequently, it is evident that the creep strain of a single wire can be expressed by Eq.(1), and that the relaxation can be predicted by Eq.(2) deduced from Eq.(1), using the strain hardening theory.

3.2 Method for the calculation of creep strain and relaxation values of rope

As creep strain and relaxation values of a single wire can be calculated as described in 3.1, the creep strain of a rope which consists of wires may be calculated by the authors' previous analytical method⁽⁹⁾ on the mechanical properties of rope, if the tensile load acting on each wire of the rope can be known. The mechanical properties of the rope under tension have been already studied and the analytical method has been established⁽⁹⁾.

Now equating $\partial h_1/h_1$ (the strain of side wire in the axial direction of the rope) with $\partial h_0/h_0$ (the strain in the axial direction of core wire), $\partial h_1/h_1$ (the specific angle of side wire) with $\partial \psi_0/h_0$ (the specific angle of core wire), and $\partial r_1/r_1$ (the strain in the radial direction of side wire) with $\partial r_0/r_0$ (the strain in the radial direction of core wire), we obtain Eq.(3) which holds between side and core wire. (Slide between wires is not taken into

account.) Moreover, the specific angle of the rope $\partial\psi_1/h_1 = 0$, because both ends of the rope are fixed in creep and relaxation tests. (the rope used as a standing rope is fixed at both ends.)

$$\left. \begin{aligned} \partial h_1/h_1 &= j_{11}X_1 + j_{21}P_1 + j_{31}N_1 + (\epsilon_{cs1}) \\ &= j_{10}P_0 + (\epsilon_{c0}) = \partial h_0/h_0 \\ \partial\psi_1/h_1 &= q_{11}X_1 + q_{21}P_1 + q_{31}N_1 + q_{41}(\epsilon_{cs1}) \\ &= 0 = \partial\psi_0/h_0 \\ \partial r_1/r_1 &= k_{11}X_1 + k_{21}P_1 + k_{31}N_1 + k_{41}(\epsilon_{cs1}) \\ &= k'_{10}X_1 + k_{20}P_0 + k_{40}(\epsilon_{c0}) = \partial r_0/r_0 \end{aligned} \right\} \dots\dots\dots(3)$$

Regarding all wire layers untill the (n-1)th layer as a core wire, the same equation as Eq.(3) is obtained for the wire of the n-th layer.

$$\left. \begin{aligned} j_{1n}X_n + j_{2n}P_n + j_{3n}N_n + (\epsilon_{csn}) \\ &= j_{10}P_0 + (\epsilon_{c0}) \\ q_{1n}X_n + q_{2n}P_n + q_{3n}N_n + q_{4n}(\epsilon_{csn}) &= 0 \\ k_{1n}X_n + k_{2n}P_n + k_{3n}N_n + k_{4n}(\epsilon_{csn}) \\ &= \frac{2}{D_{n-1}} \left\{ \left(f_{1n-1} + \frac{d_{n-1}R_{n-1}}{2m_{n-1}a_{n-1}} + K'_n \right) X_{n-1} \right. \\ &\quad \left. + \left(f_{2n-1} - \frac{d_{n-1}\sin\beta_{n-1}}{2m_{n-1}a_{n-1}} \right) P_{n-1} + f_{3n-1}N_{n-1} \right\} \end{aligned} \right\} \dots\dots\dots(4)$$

where suffixes of $X, P, N, D, R, a, K, d, \beta, m$ and the second suffix of $j_{1n}, \dots, q_{1n}, \dots, k_{1n}, \dots, k_{4n}, f_{1n-1}, \dots, f_{3n-1}$ indicate the number of each of the layers ; $j_{11}, j_{21}, j_{31}, j_{1n}, j_{2n}, j_{3n}, q_{11}, q_{21}, q_{31}, q_{1n}, q_{2n}, q_{3n}, k_{11}, k_{21}, k_{31}, k_{1n}, k_{2n}, k_{3n}, j_{10}, k_{20}, f_{1n-1}, f_{2n-1}, f_{3n-1}$: coefficients depending on the geometric and dynamic conditions of a side wire or a core wire. See Ref.(8),(9).

$$q_{4n} = \frac{\cot\beta_n}{R_n}, \quad k_{4n} = \frac{1}{m_n \left(\frac{2R_n}{d_n} - 1 \right)},$$

$$k_{40} = -\frac{1}{m_0}$$

k_{10}, K_n : coefficients which represent how firmly the side wire adheres to the core wire owing to the contact pressure, d_0, d_n : diameters of core and side wire of n-th layer, m_0, m_n : Poisson's number of core and side wire, R_n : pitch radius of side wire of n-th layer, β_n : pitch angle of the side wire of n-th layer, $a_n = Ad_n E_n$, Ad_n : sectional area of side wire of n-th layer, E_n : modulus of elasticity of side wire of n-th layer, D_{n-1} : diameter of the (n-1)th layer, P_0 : tensile load acting on the core wire, X_n : contact pressure per unit length between wire layers, P_n, N_n : tensile load in the axial direction of the rope and torsional moment acting on the side wire of n-th layer, (ϵ_{csn}) : creep strain of a side wire of n-th layer, $(\epsilon_{csn}) = A \sigma_{sn}^{\beta} t^{\gamma}$, σ_{sn} : tensile stress of side wire of n-th layer in its axial direction,

$\sigma_{sn} = p_{zn}/Ad_n$, p_{zn} : tensile load acting on the side wire in its axial direction, $p_{zn} = -R_n X_n + P_n \sin\beta_n^{(1)}$, (ϵ_{c0}) : creep strain of a core wire, $(\epsilon_{c0}) = A \sigma_0^{\beta} t^{\gamma}$, σ_0 : tensile stress of core wire, $\sigma_0 = P_0/(\pi d_0^2/4)$.

Expressing the number of side wires of n-th layer and tensile load acting on the rope by notations i_n and $\bar{P}$, respectively, we obtain

$$\bar{P} = P_0 + i_1 P_1 + i_2 P_2 + \dots + i_n P_n \dots(5)$$

It is difficult to solve Eqs.(3) and (4), because the stress of the side wire σ_{sn} is a function of P_n, X_n and t , i.e. $\sigma_{sn} = f(X_n, P_n, t)$, and σ_0 is also a function of P_0 and t , i.e. $\sigma_0 = g(P_0, t)$. However, $(P_0)_{t=0}, (X_n)_{t=0}$ and $(P_n)_{t=0}$ at $t=0$ can be analyzed as a function of $\bar{P}$ from Eqs.(3)-(5) by the same analytical method used for tensile properties of the rope. Therefore, assuming that Δt is a very short time and that σ_{sn} and σ_0 after Δt are equal to these at $t=0$, i.e. $\sigma_{sn} = f\{(P_n)_{t=0}, (X_n)_{t=0}\}$, $\sigma_0 = g\{(P_0)_{t=0}\}$, and solving Eqs.(3)-(5), $(P_0)_{t=\Delta t}, (X_n)_{t=\Delta t}, (P_n)_{t=\Delta t}$, and $(N_n)_{t=\Delta t}$ after Δt are obtained as a function of $\bar{P}$. If the same analysis as described above is repeated whenever time t increases by Δt , $(P_0)_T, (X_n)_T, (P_n)_T$ and $(N_n)_T$ an arbitrary time T can be expressed as function of $\bar{P}$.

Thus, the creep strain of the rope becomes as follows;

$$\left(\frac{\partial h_0}{h_0} \right)_{t=T} - \left(\frac{\partial h_0}{h_0} \right)_{t=0} = \left(\frac{\partial h_0}{h_0} \right)_{t=T} - j_{10}(P_0)_{t=0} \dots\dots\dots(6)$$

The creep strain is obtained as a function of $\bar{P}$.

Although σ_{sn} and σ_0 change with time, the creep strain of a wire is calculated by the strain hardening theory. For instance, if σ_1 at time t_1 increases by $\Delta\sigma_1$ after a very short time Δt from t_1 , then the creep strain at $(t_1+\Delta t)$ is approximately given by Eq.(7).

$$(\epsilon_c)_{t_1+\Delta t} = A(\sigma_1+\Delta\sigma_1)^{\beta} \left\{ \left(\frac{\sigma_1}{\sigma_1+\Delta\sigma_1} \right)^{\beta/\gamma} t_1+\Delta t \right\}^{\gamma} \dots\dots\dots(7)$$

Under the condition that the total strain is held constant, namely $\partial h_0/h_0 = j_{10}(P_0)_{t=0} = \text{const}$, the relaxation after a very short time Δt is,

$$\left(\frac{\partial h_0}{h_0} \right)_{t=\Delta t} = j_{10}(P_0)_{t=\Delta t} + (\epsilon_{c0}) = j_{10}(P_0)_{t=0} \dots\dots\dots(8)$$

Substituting $(P_0)_{t=\Delta t}$ obtained from Eq.(8) into Eqs.(3) and (4), $(X_n)_{t=\Delta t}, (P_n)_{t=\Delta t}$ and $(N_n)_{t=\Delta t}$ are obtained after a lapse of time Δt . Furthermore, by substituting these values into Eq.(5), $(\bar{P})_{t=\Delta t}$ can be calculated. If tensile load $(\bar{P})_{t=T}$ acting on the rope can be

obtained by repeating this procedure, the relaxation values of the rope can be calculated by Eq.(9).

$$\frac{(\bar{P})_{t=0} - (\bar{P})_{t=\tau}}{(\bar{P})_{t=0}} \dots\dots\dots(9)$$

In the experiments on the effects of the loading time on relaxation values, when the tensile load begins to act on a rope, we shall express the time t as $t' = 0$. When t' increases up to the loading time t_i , the load increases proportionally to the time owing to the constant loading velocity. By repeating the procedure described above, the total strain of the rope $(\partial h_0/h_0)_{t'=t_i}$ at time $t' = t_i$ is calculated. Creep strain and relaxation values can be calculated under the condition that the total strains in both tests are equal to the initial strain.

As mentioned above, it is possible to calculate creep strain and relaxation values. However, in the calculation, k_{10} and K_n in Eqs.(3) and (4), which strongly influence the extension due to the construction of the rope, should be determined. Then we shall express k_{10} and K_n as $k_{10} = k_{10} - \eta k_{11}$, $K_n = K_n - \eta k_{1n}$. (k_{10} , K_n : coefficients which express the radial reduction of the rope caused by contact pressure, when all layers adhere to each other firmly^{(8),(9)},

$$k_{10} = \frac{m_0 - 1}{m_0 E_0 \left(1 - \frac{d_1}{2R_1}\right) d_1}$$

$$K_n = \frac{m_n - 1}{m_n E_n \left(1 - \frac{d_n}{2R_n}\right) d_n}$$

η : coefficient which shows the rate of the clearance between layers. $\eta = 0$ means that all layers adhere to each other perfectly.)

η is a function of time t and tensile load $\bar{P}$ and according to experimental results in Figs.2 - 6, η decreases with the increase of time and load. According to various experimental results, η can be expressed by the following

Fig.9 $\bar{P}$ - Strain curves on 1 X 37 O/S (A) rope

equation

$$\eta = 0.04(1 - \xi/0.9) - 1.1 \times 10^{-4} t^{0.3} \dots\dots(10)$$

(ξ : testing tensile load / breaking point of the rope)

The relationship between $\bar{P}$ and $(\partial h_0/h_0)$ can be calculated from Eq. (3) - (5) by using η -value given in Eq.(10), assuming that $t = 0$, when the tensile load does not act on the rope. Figure 9 shows the calculated and experimental results on a 1 X 37 O/S (A) rope under constant loading conditions. From the coincidence of both results, it is found that creep strain and relaxation values of the rope can be calculated by using η in Eq.(10). The $\bar{P} - (\partial h_0/h_0)$ curve obtained through calculations when $\eta = 0$ is shown in Fig.9. Since it is considerably different from the experimental results, it is obvious that a clearance exists between the wire layers. See Figs.2 and 3.

The results obtained by this analytical method are shown in Figs.2 - 5 and 7, and they agree almost completely with experimental results. The fact that both results do not agree entirely is due to the slight difference in the lay of the ropes. Also Fig.8 shows the calculated results of the relaxation values obtained by giving η the values shown in the figure and by using the same coefficients as Eq.(1), though the coefficients in Eq.(1) change in the calculations of the creep strain of wire on account of pre-

Table 3. Construction of ACSR rope 28 ϕ

Material	Steel			Aluminum		
Layer	Core wire	1	2	3	4	5
Number of wires	1	6	12	20	26	32
Diameter of wires (mm)	3.08	2.64-2.71			2.34-2.35

Fig.10 Comparison between experimental and theoretical result on creep strain of ACSR

tension performance. The larger the pre-tension, the smaller η becomes. Thus it is theoretically evident that pre-tension is very useful for the reduction of relaxation values.

The creep strain of ACSR, which had five layers and was used as an electric cable, was calculated by the authors' analytical method. Its construction is shown in Table 3. Figure 10 shows the values calculated by the author and the experimental results given by R. Helms⁽⁶⁾. In our calculation, we assumed that Eq.(1), which was used for the calculation of the creep strain of a steel wire, is applicable to calculating the creep strain of an aluminum wire and that coefficients A , β and γ are respectively, 1.05×10^{-6} , 3.0 and 0.26. From Fig.(10), it is obvious that the calculated result agrees with the experimental result.

As mentioned above, it is clear that we can estimate, prior to use, the creep strain and relaxation values of spiral ropes by using the authors' analytical method.

4. Conclusions

The results of experimental and theoretical studies are summarized as follows.

- (1) The creep strain of spiral ropes is caused by the creep strain of a wire on account of the tensile load acting on it when all layers adhere perfectly to each other, and by the extension due to the construction of the rope when the rope is tightened. Therefore the creep strain of a spiral rope is several times as large as that of a wire. Also the relaxation values of the rope become larger for the same reason.
- (2) The greater the number of layers a rope has, the greater the creep strain and the relaxation values become, because total clearances between wire layers grow larger.
- (3) The creep strain and relaxation values increase gradually with increased tensile loads. But if too high a tensile load acts on the rope, they decrease because the rope is tightened.
- (4) The relaxation values decrease under

longer loading (an increased time from zero load to initial load) because the layers of the rope fit perfectly together.

- (5) The clearance between wire layers has an important effect on the creep strain and relaxation values of the rope. By the use of pre-tension the creep strain and relaxation values can be reduced owing to a reduction of clearance.

- (6) From the coincidence of experimental and theoretical results, it has been made clear that creep strain and relaxation values can be estimated by using an analytical method. This analytical method involves the creep strain of a single wire in calculating the mechanical properties of spiral ropes.

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