On the Flexibility of Wire Ropes

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1. Introduction

The designation, a flexible rope, has been used for a rope such as the 6×37 wire rope, and the stiffness and flexibility of wire ropes also have often come up for discussion. But since there was no adequate method of indicating quantitatively the flexibility of wire ropes, only sensory comparison has been applied to them. By the simple bending test of many sorts of wire ropes, we found that the so-called modulus of elasticity for bending rigidity $-E_r-$ showed a constant value according to their constructions, regardless of their sizes, and we knew that the flexibility of a wire rope could be represented by the "Flexibility Number". So we propose here to use the "Flexibility Number" as a measure of flexibility of wire ropes, presenting the standard values of "Flexibility Number" for the wire ropes of some typical constructions.

2. The Modulus of Elasticity for Bending Rigidity of the Wire Ropes E_r

When we hung the weight P on the middle of a steel bar, supported at two points, the deflection at the middle y is to be expressed by the equation (1):

$$y = -\frac{Pl^3}{48\,EI} \qquad (1)$$

where

l = supporting distance,

E = modulus of elasticity of a steel bar,

I = moment of inertia of a steel bar.

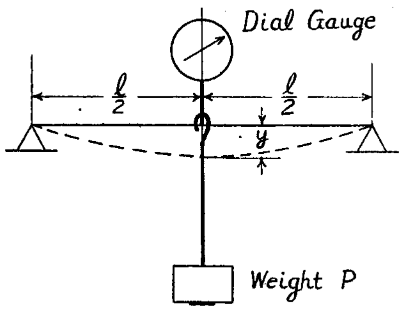


Fig. 1. Test Apparatus.

The deflection of the wire rope Δy, supported at two points as before, after increasing and decreasing the weight at the middle, could also be expressed in a form of equation (2):

$$\Delta y = \frac{\Delta P \cdot l^3}{48\, E_f I_r} \tag{2}$$

where

ΔP and Δy are the increment and decrement of the weight, and the deflection.

I_r is moment of inertia of the wire rope about its axis, regarding which details will be explained in the following chapter. Here we tried to find out, from the experiment, the changes in the value of E_f, calling it the modulus of elasticity for the bending rigidity, and supposing E_f corresponds to the modulus of elasticity E for the steel bar.

E_f, therefore, contains as a matter of fact the influences of the sliding and twisting of each wire.

In the test the distance between supporting points was 50 cm, but for a flexible rope, such as 6×24, 24 cm was taken. In the test it was made clear that when the distance between supporting points is shorter than the pitch of the rope, the value of E_f increases, but that when longer, the distance has no influence upon the measured value of E_f. The deflection was measured by a dial-gauge. Its maximum amount was limited within 9 mm.

3. The Moment of Inertia of the Wire Ropes

The section of a wire in the right angle section of a wire rope is not a circle, but an ellipse. However, since there is no great difference in the usual wire ropes, let us take it as a circle in the calculation of I_r hereafter. The wires are supposed to be fixed, no movement among them considered, or no influence of twisting or of the hemp core heeded. The influences of these neglected factors are also included in E_f.

Table 1. Moment of Inertia of 6×7 Wire Ropes.

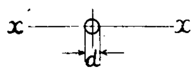
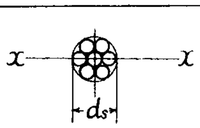
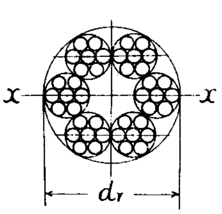
Section	Polar Moment of Inertia	Moment of Inertia
	$\frac{\pi d^4}{32}$	$\frac{\pi d^4}{64}$
	$7\frac{\pi d^4}{32} + 6\frac{\pi d^4}{4} = \frac{55}{32}\pi d^4$	$\frac{55}{64}\pi d^4$
	$6\left\{\frac{55}{32}\pi d^4 + 7\frac{\pi d^2}{4}(3d)^2\right\} = \frac{1677}{16}\pi d^4$	$\frac{1677}{32}\pi d^4$

Table 1 shows how to know the moment of inertia for the typical 7 strand, 6×7.

I_r of 6×19, 6×24, 6×37, or 6×61 wire ropes is also found the same as above. As for $6\times F$ $(\Delta+7)$, $6\times F$ $(\Delta+12+12)$ and other wire ropes the same solution will be derived. But in such a case as constructed with wires having a complicated figure like the locked coil rope, moment of inertia is fixed graphically for these wires. I_r of a locked coil rope, thus obtained, is qualified to be nearly 90% of the I of a round bar with the same diameter. Table 2 shows the result of calculation of I_r for the typical of these various kinds of wire ropes. Thus I_r of a wire rope can be shown mathematically.

Table 2. Moment of Inertia of Some Typical Wire Ropes.

Wire Ropes		Rope Diameter mm	Moment of Inertia cm^4
Locked Coil Rope, 3 Layers	No. 1	36	7.0
	No. 3	29	3.1
	No. 5	25	1.9
Locked Coil Rope, 4 Layers	No. 2	35	6.1
	No. 4	26	2.1
7 Wires Spiral Rope	No. 1	10	0.036
	No. 2	32	3.5
19 Wires Spiral Rope	No. 1	34	4.2
	No. 2	27	1.7
	No. 3	26	1.4
	No. 4	22	0.76
	No. 5	36	5.3
37 Wires Spiral Rope	No. 1	34	4.6
	No. 2	28	2.2
	No. 3	25	1.5
$6\times F$ $(\triangle+7)$	No. 1	32	3.2
6×7	No. 1	32	2.5
	No. 2	30	1.9
	No. 58(1)	34	3.4
6×7 N. I. W. R. C.		32	2.6
6×19		32	2.4
J (6×25)		28	1.7
6×24		32	2.6
6×37		32	2.4

4. The Results of the Bending Test

Fig. 2 shows one example of load-deflection curve. The curve forms a loop according to the increase and decrease of load, but since that loop shows very

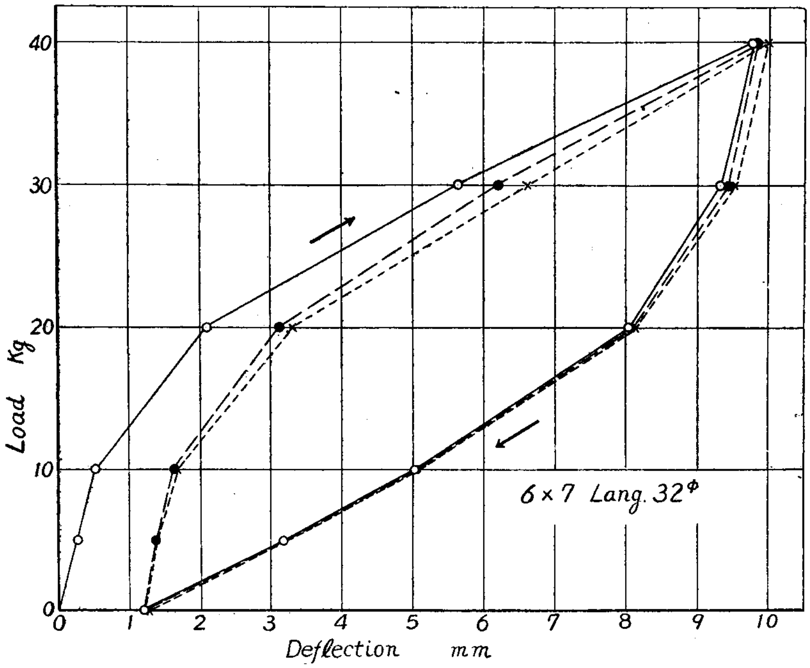


FIG. 2.
Load-Deflection Diagram.

small change after the primary load, the following calculation is done with the average value of the second and third loops. Substituting the increment and decrement of deflection due to the change of load for equation (2), we obtain E_f for the value of each load and it is demonstrated in Fig. 3. The group of curves downward to the right is for the increasing load, and downward to the left is for the decreasing load. From this it becomes clear that the increasing or the decreasing load, after

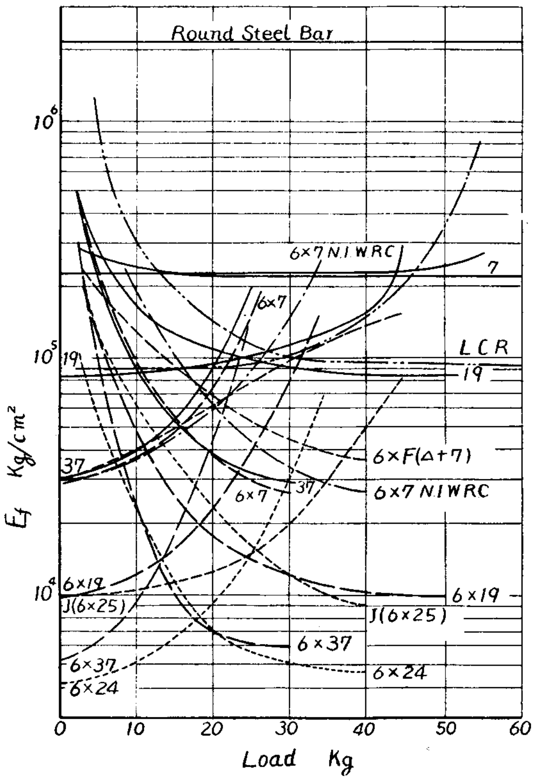


Fig. 3. Measured Values of E_f for Some Typical Wire Ropes.

some extension, shows a certain limit beyond which no more effect is seen upon E_f; moreover, it finally settles to a certain definite value according to the construction of the wire ropes. Therefore we are going to use the last stable value. Table 3 shows this. There is also shown in this table the result of calculation, for the purpose of comparison, obtained by Messrs. S. Ikeda and I. Ueno.[1] From this table we found the theoretical value to be almost equal to the experimental value, the former being less than the latter except in a few cases. It is more interesting to know that this theory is induced without any consideration on the interference of wires to each other.

Table 3. Theoretical and Experimental Values of E_f.

Wire Ropes		Theoretical Values of E_f ($\times 10^5$ kg/cm²)	Experimental Values of E_f ($\times 10^5$ Kg/cm²)	
			Wt. Increasing	Wt. Decreasing
7 Wires Spiral Rope	No. 1	2.602	2.69	2.76
	No. 2	2.600	2.40	2.50
19 Wires Spiral Rope	No. 1	0.851	0.92	0.88
	No. 2	0.810	0.84	0.85
	No. 3	0.851	0.91	0.81
	No. 4	0.848	0.96	1.00
	No. 5	0.858	0.90	0.93
37 Wires Spiral Rope	No. 1	0.421	0.44	0.46
	No. 2	0.426	0.45	0.43
	No. 3	0.422	0.33	0.31
6×7	No. 1	0.247	0.30	0.32
	No. 2	0.227	0.28	0.28
	No. 58(I)	0.243	0.23	0.22
6×7 N. I. W. R. C.		0.246	0.28	0.31
6×19		0.087	0.10	0.10
J (6×25)		0.081	0.10	0.10
6×24		0.054	0.05	0.04
6×37		0.044	0.06	0.05

The more the number of wires increases, generally the smaller E_f becomes. Fig. 4 demonstrates the relation between E_f of the various sorts of wire ropes and the number of wires N in a log-log-chart. From this we found out the fact that plotted points formed quite in a straight line especially in the case of the spiral ropes, and let to the following equation:

$$\log E_f = -1.07 \log N + 6.301 \tag{3}$$

The mutual relation of E_f and the sliding of wires is to be seen in the above equation. Therefore,

$$S = \frac{E}{E_f} \tag{4}$$

S in (4) chiefly expresses the sliding in the wire ropes. Regarding this point discussion will not be given in the present paper.

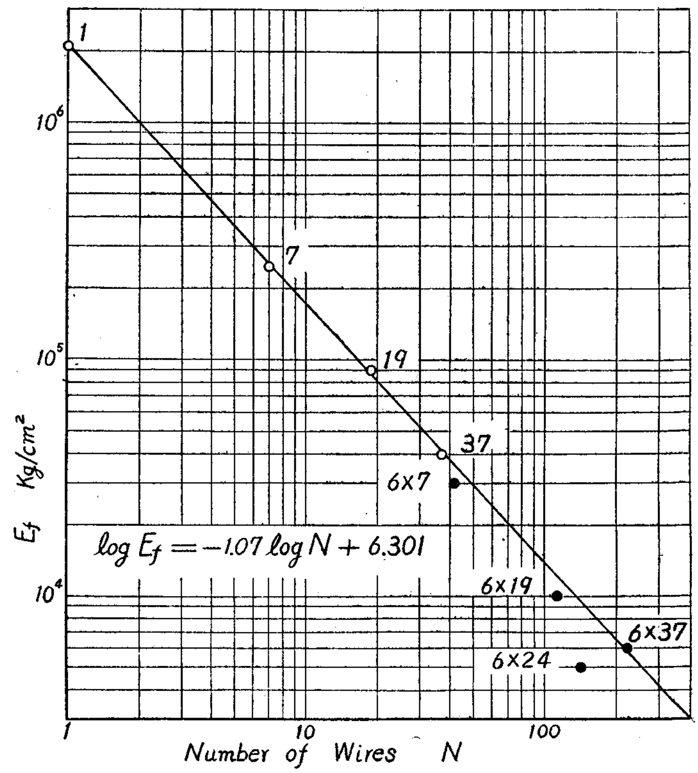


Fig. 4. E_f and Number of Wires.

5. Flexibility Number

We have pointed out that E_f obtained by the simple bending test has a standard value according to the construction of wire ropes and that it will give a suggestion on the flexibility of wire ropes. But since I_r is needed as well as E_f in the comparison of flexibility, we thought out the flexibility number as a measure:

$$F = \frac{EI}{E_f I_r} \tag{5}$$

where

I = moment of inertia of a round steel bar with the same diameter as a wire rope.

That is, the flexibility of a wire rope is nothing but the ratio between the bending rigidity of a round steel bar having the same diameter as a wire rope and the bending rigity of that wire rope.

Thus, it was made clear that the flexibility of a wire rope can definitely be expressed quantitively by this flexibility number, making 1 of a round steel bar a basis; that is, the greater the flexibility number is, the easier is a wire rope to bend.

Table 4 shows the flexibility number of some typical wire ropes. It is worthy of notice that F of a single flattened strand rope is comparatively small compared with 7×6, while F of the N. I. W. R. C. differs little from that of the hemp core.

The values presented here of E_f and F are for the wire ropes of a pitch at present commonly produced and used. Further, it is true that the values of E_f and F change from the average values shown above, according to any conspicuous changes in the pitch of a wire rope.

Table 4. E_f and F.

Wire Ropes	E_f ($\times10^5$ kg/cm^2)	F
Round Steel Bar	21.00	1
7 Wires Spiral Rope	2.40—2.76	11— 13
Locked Coil Rope	0.48—1.35	18— 46
19 Wires Spiral Rope	0.81—1.00	30— 41
37 Wires Sprial Rope	0.31—0.46	63— 89
$6\times$F ($\triangle$+7)	0.30—0.35	99—114
6×7	0.22—0.34	130—180
6×7 N. I. W. R. C.	0.28	154
6×19	0.10	470
6×37	0.06	760
6×24	0.05	920

6. Conclusion

Now we understood that the flexibility of the various sorts of wire ropes can be indicated quantitively by the flexibility number, and would provide a standard for the choosing and using of wire ropes.

We are going to propose here its use, since we think the flexibility number is to be widely used hereafter as a standard to show the mechanical characteristics of a wire rope just as, for example, the tensile strength, strain, or strength reduction ot a wire rope.

The problems of the mutual movements and the friction between the adjacent wires constitute very important elements in deciding the mechanical characteristics of the wire rope. E_f and S treated in this study will give some suggestions regarding these problems. With regard to these problems, however, we will presently discuss in detail.

Reference

1) S. Ikeda & I. Ueno, Trans. of the Soc. of Mech. Engrs., Japan, Vol. 15, No. 51.