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A Basic Study on the Development of Floating Fish Aggregating Devices, Part I

- Laboratory Static Tests on Synthetic Fiber Ropes -

by

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부어초 개발에 관한 기초 연구(I)

- 인조섬유 로우프의 정적시험 -

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Abstract

Fish aggregating devices(FAD) or artificial fish reefs deployed in the ocean space have been developed in various forms. The objective of FAD is to aggregate, cultivate and proliferate aquatic resources by making changes in ocean flows around it, developing spawning grounds, improving feeding areas and protecting larvae and juveniles.

Most floating fish aggregating devices(FFAD) are in the form of surface buoys or sub-surface buoys with a single point mooring system(SPMS). The mooring line of SPMS for the secure positions of FFAD is expected to keep great stresses as a result of the harsh ocean environment.

Laboratory static tests on synthetic fiber ropes used for the SPMS were run. The Nylon wet rope specimen tests under increasing-and-decreasing loads showed about 20% strength drop. Also the logarithmic creep-tie behavior of fiber ropes was observed in the constant load test and compared with Flessner' s formula.

요 약

해양 공간에 설치되어 유체의 흐름과 지형에 변화를 주며, 대상 수산 생물의 유집에 의한 생산 어

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장의 조성과 치어의 보호 육성을 도모하는 중요한 어장 시설인 인공어초의 기술 개발은 점차 다양화되어지고 있다. 부체부와 계류부로 구성되어 있는 부어초의 개발에 있어서는 부어초의 특성 및 안전상 계류시스템의 설계가 극히 중요한 부분이 된다.

이 논문에서는 부어초의 계류시스템에 많이 사용되어지는 나일론, 폴리에스터와 폴리에틸렌으로 이루어진 인조섬유로우프의 정적시험의 과정과 그 결과로서의 Creep거동 및 하중-인장 곡선을 얻었다. 특히 나일론 로우프의 경우 수중에서 20%내외의 강도 하락(Strength drop)이 관찰되며, Creep 시험 곡선은 대수시간 축(longerithmic time axis)상에서 직선을 유지하고, Flessner' s formula와 평행한 결과를 얻었다.

1. Introduction

Synthetic fiber ropes for the secure positions of floating fish aggregating device(FFAD) buoys and ships are expected to keep great stresses as a result of the harsh ocean environment. The rope reacts to stresses and strains as a viscoelastic body. The elongation of the rope under load is largely modified by the arrangement of the fibers in the rope and its construction. At the same time it is very clear that the quality of the material of the rope dominates elongation of the rope.

Static tests for synthetic fiber ropes was conducted in the laboratory. Both plastic and elastic elongations were measured under two testing conditions. The test results under increasing-and -then-decreasing loads are plotted in load-elongation curves. Also the logarithmic creep-time behavior of fiber ropes was observed in the constant load test.

2. Test Procedures

The test procedures consist of five steps as follows :

Step 1. Preparation of rope test speciments
Step 2. Preparation of weights and miscellaneous equipments
Step 3. Calibration of load cell
Step 4. Installation of cathetometers
Step 5. Test under loads

3. Rope Test Specimens

The fiber ropes used in the tests were manufactured by Tokyo Seiko Rope Mfg. Co., Ltd. The synthetic materials of the ropes are nylon, polyethylene and polyester. Sizes, properties and construction of the ropes are shown in Table 1.

Table 1 Four types of synthetic fiber ropes from the tokyo seiko rope company's manual

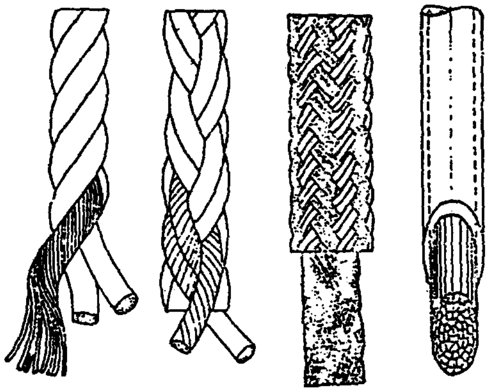
Construction	2×4	2×4	1×8	1×8
material	Nylon	Kyolex (Polyethylene)	Tekmilon (Polyethy--lene)	Vektran (Poly-ester)
diameter (mm)	3	3	3	3
mass (g/m)	6 45	5.85	3.92	4.33
weight in water (g/m)	0.65	-0 4	-0.27	1.18
breaking strength (kgf)	270	180	520	460
elongation percent (%)	35.3	29.7	3.18	4.17
denier (de)	40,320	38,400	36,000	40,000
crosssection area (㎟)	3.93	4.44	4.12	3.15
specific weight	1.14	0.96	0.96	1.41

According to Fig. 1, the type of Nylon and Kyolex ropes in Table 1 is 2×4, 8-strand plaited constructions. Also Tekmilon and Vektran has 1×8, 8-strand plaited construction which is not shown in Fig.1.

The configuration of rope test specimens are shown in Fig.2.

The splicing technique used is eye-splice methods. One of them is for Nylon and Kyolex (polyethylene) test specimens with 2×4,8-strand plaited constructions. (Table 1) The eye-splice method is shown in Fig.3[2].

The other method is for Tekmilon (polyeth ylene) and Vektran (polyester) rope test speci-



(a) (b) (c) (d)

(a) Twisted - three strand rope
(b) Plaited - eight strand rope
(c) Double braided rope (Core-cover braid)
(d) Nolaro or Para rope

Fig. 1 Four basic rope constructions [1]

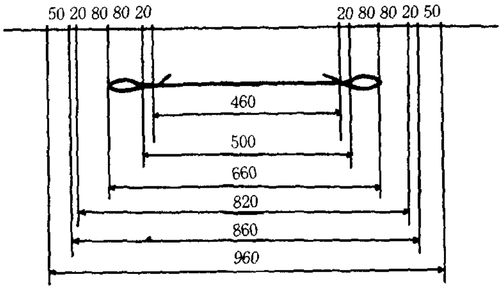


Fig. 2 Configuration of rope test specimens (unit:mm)

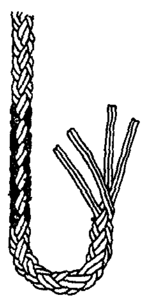


Fig. 3 Eye-splice method for 2 × 4, 8- strand plaited ropes [2]

mens with 1×8, 8-strand plaited constructions. (Table 1) See Fig.4.

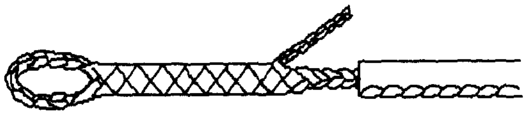


Fig. 4. Eye-splice method for 1 × 8, 8-strand plaited ropes from the Tokyo Seiko Rope Company's manual

4. Preparation of weights and miscellaneous equipments

Five weights, each of them weighs about 100kgf, were prepared for the load cell calibration. See Fig.10, Fig.11.

Also eleven weights, each of them weights about 10kgf, are shown in Fig. 6. They were put on the aluminum channel, one by one, during the tests.

A small bottle with the end of cotton gauze immersed in the water was prepared for wet

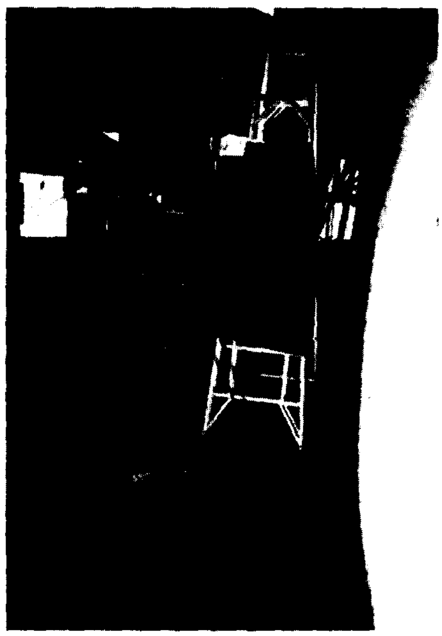


Fig. 5 Assembly of shackles, rope test specimen, an aluminum channel with wire ropes

test condition and tied to the shackle below the load cell(Fig. 6). The other end of gauze was connected to upper part of the rope test specimens, in order for the specimen to be kept in the wet condition during the test.

Also two lamps were prepared for illumination. Two shackles for load cell and a smaller shackle for rope test specimens were assembled(Fig. 5).

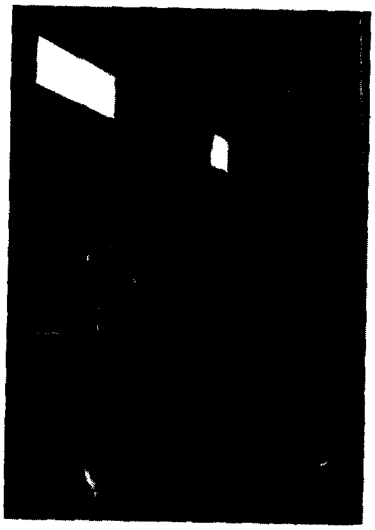


Fig. 6 Test in wet condition

Fig. 7 Rope specimens used in tests

An aluminum channel, 1 meter in length, with several wire ropes was suspended from the end of the rope specimen.A short length of red cotton thread was knotted at two points of the rope test specimens. (Fig. 7) In order to prevent the firm knot from moving along the strained rope test specimens, the author painted white correction fluid on the knots.

5. Installation of Cathetometers

Two cathetometers were used in measuring the distance between the two knots (gauge marks) of the rope specimens(Fig. 8, Fig. 12).

They were placed about 2 meters in front of the assembly of the rope test specimen. The larger cathetometer was installed in a vertical position and the smaller one was put on the box. In order for the larger cathetometer to be set upright (in the gravitational direction), the screws of its legs were adjusted using a spirit level. (B and L in Fig. 9) The adjustment tech-

Fig. 8 Installation of cathetometers

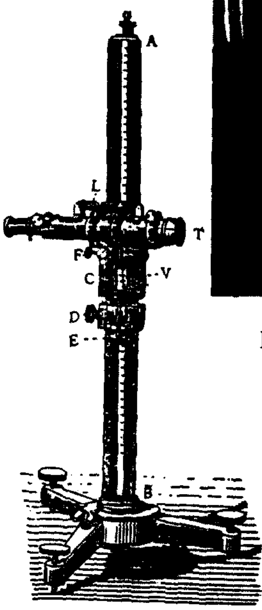


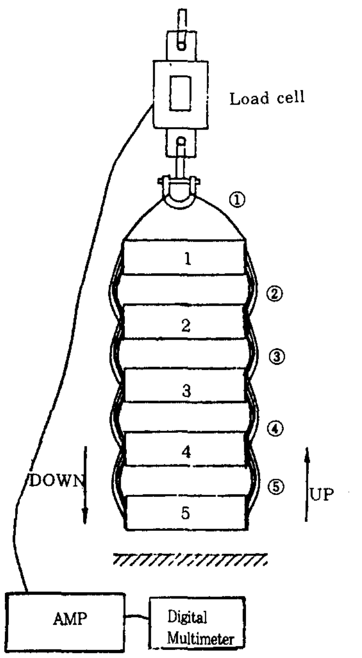
Fig. 9 Cathetometers and its parts

nique can be found at the reference [3]. The smaller one was also adjusted, in the similar way, using its built-in round spirit level.

6. Calibration of Load Cell

The apparatus for the load cell calibration consists of wire ropes, shackles, an amplifier, a digital multimeter and five rectangular weights, each of them weighs about 100kgf. The apparatus arrangement is shown in Fig.10. By lifting weights one by one and then lowering them the calibration was conducted.(Fig.11)Table 2 shows the calibration results.

Apparatus Arrangement For Load Cell Calibration & Their Weights



Weights	
Number	Weight
1	99.0kgf
2	100.3
3	100.6
4	99.1
5	99.1

Wire Ropes & Schakles	
Number	weight
①	1.62kgf
②	0.40
③	0.40
④	0.38
⑤	0.38

Fig. 10 Apparatus arrangement for load cell calibration

Table 2 Data from load cell calibration

	weight number	UP		DOWN		
		AMP	Digital Multimeter	AMP	Digital Multimeter	
1st trial	1	100.5kgf	2.019kgf	100.4kgf	2.016kgf	
	2	200.8	4.027	201.0	4.030	
	3	301.5	6.042	301.9	6.049	
	4	401.1	8.035	401.2	8.037	hysterisis -0.489 mvolt
	5	500.1	10.016			0.050 mvolt
2nd trial	1	100.4kgf	2.017kgf	100.5kgf	2.020kgf	
	2	200.9	4.029	200.9	4.029	
	3	301.6	6.044	301.6	6.044	
	4	400.9	8.032	401.0	8.034	
	5	500.0	10.014			-0.290 mvolt
3rd trial	1	100.5kgf	2.020kgf	100.3kgf	2.017kgf	
	2	200.9	4.029	200.9	4.031	
	3	301.7	6.047	301.7	6.047	499.8kg/
	4	401.1	8.037	401.0	8.035	6000 strain
	5	500.1	10.019			10.011 volt/ 6000 strain

Fig. 11 Load cell calibration procedures

7. Laboratory Static Tests

Two laboratory static tests for synthetic fiber ropes were run as follows :

1) Load-Strain Test :
   Increasing-and-then-decreasing loads
2) Creep test: Constant load

Initial loading was 2.43 kgf which was the weight of the aluminum channel with wire ropes and a shackle.

Old rope test specimens were defined as ropes which had been already loaded with about 115 kgf (maximum load) in the previous test.

Wet rope test specimens were defined as ropes which had been immersed in the water a day before the test and kept their wet condition during the test.

Fig. 12 shows the reading from cathetometers for measuring the distance between two knots (gauge marks) of the rope test specimen.

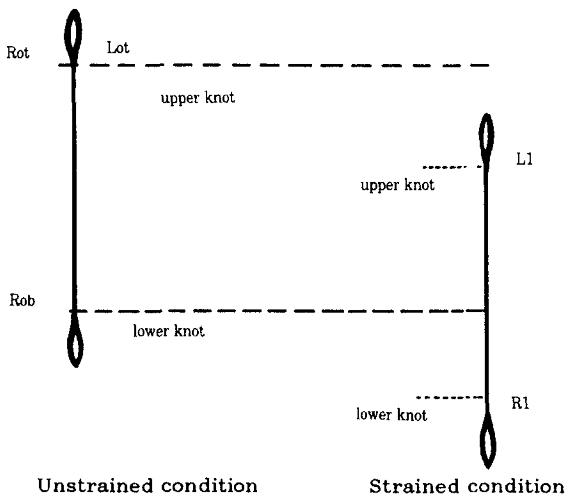


Fig. 12 Reading from cathetometers for measuring the distance between rope specimen knots.

In the unloaded condition three readings, Rot and Rob from the larger cathetometer and Lot from the smaller one, were obtained. After loaded, two new positions of the strained rope test specimen's knots were measured by R1 and L1, respectively from the larger cathetometer and smaller one.

The following relations between these readings give the length of the rope test specimen and its elongation.

Initial unstrained length	Lo=Rot-Rob	(1)
Strained length	L=(Rot-R1)+(L1-Lot)	(2)
Elongation	L=(Rob-R1)+(L1-Lot)	(3)

By relations (1), (2) and (3), the elongation rates of the rope test specimen can be calculated at each prescribed load.

For the sake of good understanding, the following labels are used.

KD-1-0 : The new, dry load-strain test of Kyolex rope test specimen No. 1
KD-1-1 : The first old, dry load-strain test of Kyolex rope test specimen No.1
KD-1-2 : The second old, dry load-strain test of Kyolex rope test specimen No.1
KD-2-0 : The new, dry load-strain test of Kyolex rope test specimen No.2
NW-1-0 : The new, wet load-strain test of Nylon rope test specimen No.1
Etc.

8. Ropes Under the Load-elongation Test

If a new rope is put into used and tested under the increasing-and-then-decreasing loads, it is observed, that the initial load elongation curve is never reached again in subsequent loadings.

The rope test specimens of four types in Table 1 were tested in new rope and old rope conditions, respectively. The time interval between both conditions was at least 3 hours. Therefore the respective load-elongation curves were drawn starting from the same origin, not from the permanent elongation shortly after each test.

The test speed was controlled in about 5.5 minute interval, because of difficulties in reading rapidly scales of cathetometer and creeps behavior of synthetic fiber ropes. About 4 minutes after each loading were included in that interval as an waiting time. So it took about 1.5

minutes to read scales of the cathetometers and add (or release) a weight of about 1 kgf.

The test results show closed curves in the load-elongation plane, which are called hysterisis loops due to a permanent elongation of the specimens(*Fig. 13 to 16*).

Fig. 13 shows the hysterisis loops (1), (2) and (3) of 2×4, 8-strand plaited Nylon. Straight lines can be drawn inside the upper part of each hysterisis loop which shows a linear property and its steepness may represent property Young's modulus of each rope. Then the old rope test, ND-1-1 (loop 2 , shows Young's modulus higher than that of the new rope test, ND-1-0 (loop 1), due to hardening effect. It means a loss in ability to accommodate dynamic loads due to harsh ocean environments.

Also the strength drop of about 20 % is shown, when the results of new wet rope test NW-2-0 (loop 3) are compared with those of the newdry rope test ND-1-0 (loop 1).

Five tests were conducted using two new Kyolex rope test specimens. Loops (1)and (5) were drawn from the new rope condition. Loops (2) and (3) were drawn from the first old rope condition after new rope test of Loops (1) and (5), respectively. Also Loop (4) was plotted from the test results after the first old rope test of loop (2).

It was found that tests, KD-1-0 (Loop 1) and KD-1-1 (Loop 2), had the low reliability in their results because of the loose knots tied on the strained rope specimen No. 1. When Loops (3), (4) and (5) from tests (KD-1-2, KD-2-0 and KD-2-1) are compared with each other, it is

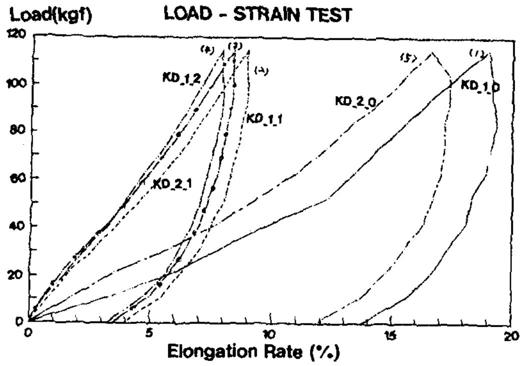


Fig. 14 Load-elongation curve of Kyolex (polyethylene) 2×4, *8-strand plaited rope*

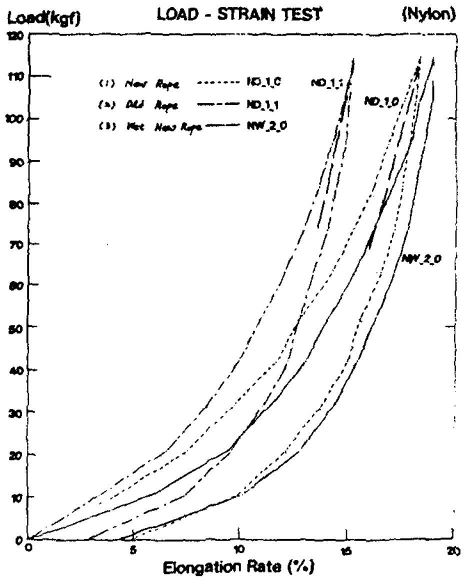


Fig. 13 Load-elongation curve of Nylon 2×4, 8-strand plaited rope

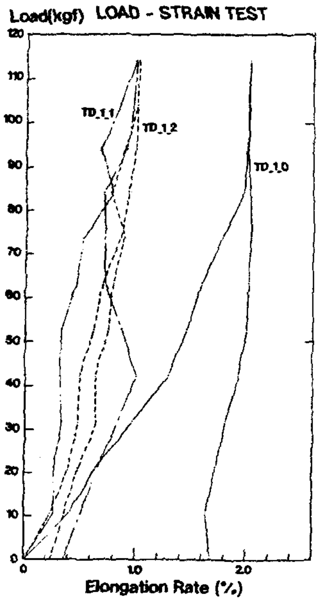


Fig. 15 Load-elongation curve of Tekmilon (polyethylene) 1×8, 8-strand plaited rope

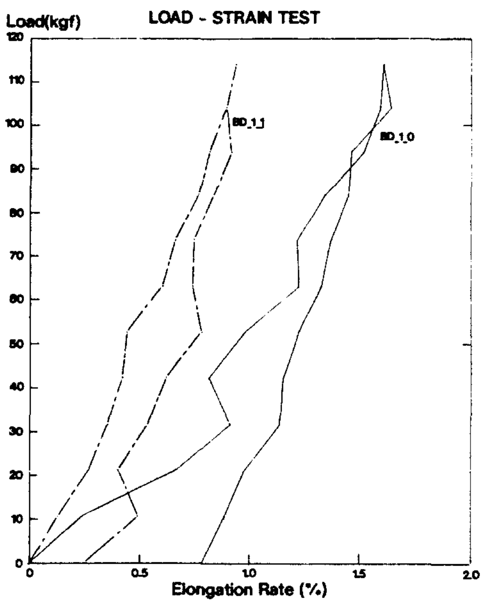


Fig.16 Load-elongation curve of Vektran (polyester)1 × 8, 8-strand plaited rope

concluded that old ropes deteriorate in their ability to accommodate dynamic loads due to severe environments.

The loss in their ability between curves (5) and (3) becomes much smaller than the one between curves (3) and (4) and, therefore, it is inferred that the master hysterisis loop be obtained by only several old rope tests after new rope test.

In case of Vektran and Tekmilon rope specimens, the shape of the hysterisis loops is not smooth, unlike the case of the Nylon and Kyolex specimens. (Fig.15 and 16)

It was considered that the unsmoothness of the load-strain hysterisis loop resulted from the loosening of the cotton thread. After these tests, white correction fluid was used for firm knot of cotton thread.

However, the overall trends are the same as those of Nylon and Kyolex specimens.

9. Ropes Under the Creep Test

The time dependent extension under a constant load is called creep. The test was conducted under 47.319 kgf constant and maintained load.

The creep curves of Nylon 2×4, 8-strand plaited rope test specimen showing extension versus log(time) are plotted in Fig.17. It also shows the creep curve of vektran rope specimen. Curves (2) and (3) has the low reliability because of the loose knots.

All the curves seem to be almost straight lines. It means that the creep-time behavior of Nylon rope test specimen follows a logarithmic law. Flessner [1] derived an empirical formula from his test results for Nylon 2×4, 8-strand plaited rope under 30 % of the rated breaking strength after a time t(hours).

$$TE = 0.22 \log_e(\text{time}) + 24.30 \qquad (4)$$

TE : Total elongation under 30% of RBS

The straight line from Formula (4) was drawn in Fig.17. It seems to be almost parallel to other lines, even though under different loading condition (14.7% of RBS) from Flessner's loading condition (30% of RBS).

In case of the Vektran test rope specimen the creep-time curve appears to be the horizontal straight line. Therefore the polyester rope seems to have a very small creep elongation.

10. Discussions

The permanent and elastic elongations were measured in the load-elongation tests for the synthetic fiber ropes. Also the old rope specimen tests showed Young's modulus higher than the new rope tests due to hardening effect. In the Nylon wet rope specimen tests, about 20 % strength drop was observed as noted in the references [1], [4] and [5].

It was so difficult to increase or decrease loads by counter weights during a very short time interval in the increasing-and-then-decreasing load condition. There is a need of ma-

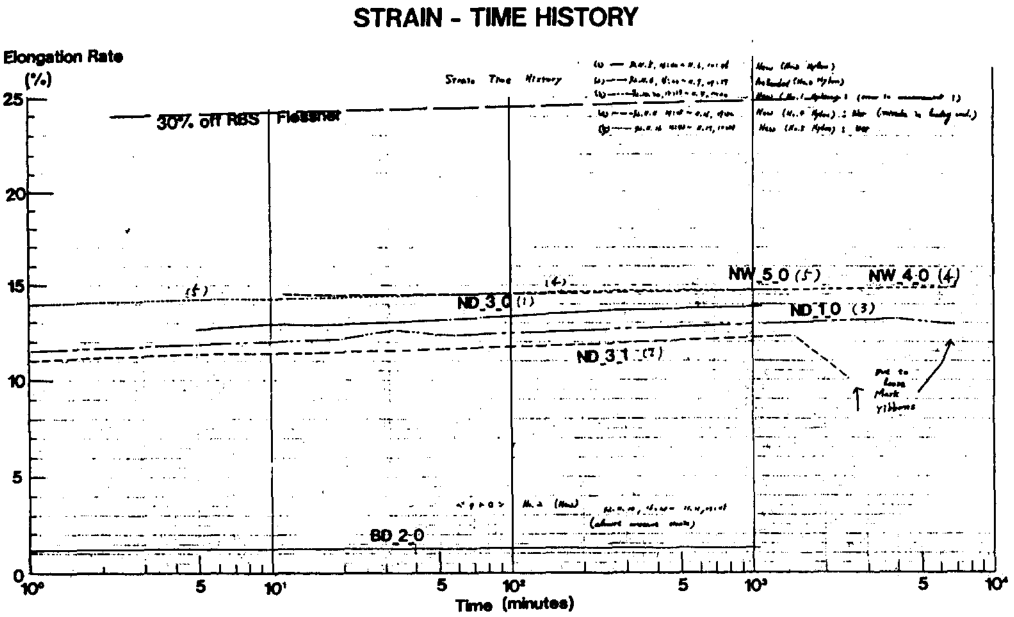


Fig. 17 Creep-time behavior curves of Nylon 2×4, 8-strand plaited rope and Vektran (polyester) 1×8, 8-strand plaited rope

which can make a continuous load change and account for large elongations of the synthetic fiber ropes.

Most of the load-elongation tests conducted in the laboratory took about 2.5 hours on an average. So it was too long to make tests without time delay between new and old or between old rope tests. It is so desirable to make the consecutive hysterisis loops from results in the subsequent tests without intermediate rest time. The final master hysterisis loop and Young's modulus with high reliability may be plotted from the group of hysterisis loops.

The logarithmic-behavior of creep of Nylon 2×4, 8-strand plaited rope specimens was observed as mentioned in the reference[1].

In the creep tests, test results were obtained only from the maintained load.Also results from the recovery state without the load may be needed.

It was so difficult to hold about 80 kgf(30% of the Nylon rated breaking strength) for a long time and to measure very fast elongation within the first few minutes in the current test Apparatus using counter weights. It is desirable to make creep test under 30% of its RBS and to compare them with Flessner's formula, though the current results show the trends similar to the latter.

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