

## On the Physical Analysis of the Fixed-fishing-net Resistance

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### Summary

(1) In order to investigate the under-water resistance of the fixed-net in the running water, the force acting on the sand-bag-ropes of the model-net was measured by two apparatus; one of them was an analytical balance, another was the wire-resistance-strain-meter. That strain meter is water-tight, having high sensitivity, and is newly-devised by the writer for the sake of this experiment. And the model-net was made according to the full-scale one, in which the length of the rope was made to be a fraction of the original one, while the angle to the water-bottom was kept equal to that of the actual case.

(2) It was ascertained that the force acting on the fixed-net was to be adequately expressed in the following equation,

$$R = C \frac{\rho}{2} S_0 (1 - kV) V^2$$

Here,  $k$  is the coefficient of the net-deformation, and  $C$  is the coefficient of the drag influenced by the factors except the deformation. Therefore in any fixed-net, the approximate value of the drag at any current velocity came to be easily computed.

While the current-velocity is lower than 18 cm/sec, the value of  $k$  is 0.025~0.045, and that of  $C$  is approximately  $6.3 \times 10^{-4}$ .

(3) (a) As to the net whose net-foot detaches itself from the water bottom, the hydrodynamic force on the net and its direction were counted. It was ascertained that the vertical component of it is the lift acting on the net, and that the horizontal component of it is the drag on the net, and this is equal to the horizontal component of the force on the rope.

(b) In the one whose net-foot attaches itself to the water-bottom, it was ascertained that besides the force acting on the sand-bag rope, there is another force on the net-foot, and that this works as a kind of downward force. These are the phenomena which have been left unobserved hitherto.

### I. Introduction

(1) In the research on the hydrodynamic force acting on the Fishing-net, the model-net stretched upon the square frame was used by Terada, Sekine, and Nozaki,<sup>1)</sup> the same method has been taken by Tauchi, Miura, and Sugii<sup>2)</sup>; Miyake<sup>3)</sup>; Fujita and Yokota<sup>4)</sup> respectively.

But, according to the results obtained from such experiments, it was difficult to get a reasonable result on the full-scale net. So, to make the model-net, law of comparison derived from the Law of Similarity was presented by Tauchi.<sup>5)</sup> After this the researches on the full-scale-net have been done in accordance with this law. For example, we have the reports on the fixed-net done by Miyamoto<sup>6)</sup> and on hauling-net by Miyazaki<sup>7)</sup> and Sato.<sup>8)9)</sup>

(2) The model experimental researches on the fixed-net have generally been done by the following process, namely, from various directions, the water-current was pushed against the fixed model-net, and then, such items as follows were observed, sketched and photographed; a) The changing shape of the net-deformation and the limiting



current velocity to keep the net effective enough to catch the fish. b) The proper arrangement of the sand-bag, floater, and the sinker firm enough to prevent the net-body being washed away, even under the greatest current velocity. c) The measurement of the force acting on the net by means of measuring the tension, exerted by the net on the sand-bag ropes.

The results of these experiments roughly coincided with the observed results of the full-scale net. When the model-net is made to be of too small scale, the net-rope of the model-net becomes too tough. Although this toughness causes some differences between the model-net and the full scale one, but in the law of comparison, the toughness has been put out of consideration.

And in the experiments done hitherto, the observations of the net-deformation occurring under the various current velocities and directions were carried out, in the actual fishing ground, with almost no experimental analysis done to the net-deformation.

(3) Now, the experiments done hitherto show that the resistance of the net deformed slightly is roughly proportional to the square of the current velocity.<sup>6)8)</sup> And, the resistance of the net  $R$  is generally expressed by the equation,<sup>6)</sup>

$$R = \phi(Re, Fr, D/L) \frac{\rho}{2} S V^2$$

As to  $Re$ , in the fisheries no special experiment has been done; while as to the drag to the square net some experiments have been done.<sup>1)2)3)</sup> In those experiments,  $D$  means the diameter of the net-thread,  $L$ , the length of the one foot of the net-mesh; and here, provided  $D/L$  is 0.01~0.07 and current velocity  $V$  lies within 10~200 cm/sec;  $R = k\rho S V^n$  ( $k = \text{const.}$ ).

In this equation, the relation of  $k$  to  $Re$  was put out of consideration, and  $Fr$  was considered small enough to be neglected, especially in case of the fixed-net. So, putting  $\phi(Re, Fr, D/L) \frac{\rho}{2} S = k$  (const.), many researchers have generally used  $R = kV^n$ .

(4) The equation of  $R = kV^n$  has been used in analyzing the net-resistance in water, but as to  $k$  and  $n$  in various kinds of the fishing net, no unifying result has been obtained.

In this,  $n$  is in any kind of net, smaller than 2 and larger than 1. It has been considered  $n$  is due to the net-deformation brought-forth by the current velocity. In the net which shows greater deformation against the current, for example, in the fixed-net,  $n$  is, generally, far smaller than 2. While, even if the current velocity is constant, the variation in the form and construction of the net itself causes the difference in the deformation, namely, in  $n$ .

The result derived from the fixed-net experiments, however, shows that with the change of  $n$ ,  $k$  changes also. And then there have been no unified considerations covering both  $k$  and  $n$ , though, as to  $n$  some considerations have been paid.

(5) Although the discussions of the buoyancy of the floaters, the weight of the sinkers, the fixing force of the sand-bag and the length of the sand-bag rope have been done according to the results got from the model-net, the clarification of this subject from dynamical view point has been left almost untouched. Therefore, the clarification is considered to be both essential for making the advanced blue-print of the fixed-net and important for the improvement of the fixed-fishing net in general.

## II. Experimental Method and Apparatus

### (1) Kind of Fixed-Net used in the Experiment

The desirable conditions of the fixed-net are as follows: the economy of material and labour; duration of the net body against the damage and forfeit through tide-



current; the high luring capacity for any kind of fish; the firm catching efficiency. The under-water-set fixed-net revised and improved from the sea-bottom fixed-net used in Hokkaido and Tohoku districts was considered to be the very one satisfying those strict conditions. This one, specially devised, is set chiefly along the sea-bottom, and the hem of the net fully or partially is submerged under the sea-surface. And then to improve, in more advanced degree, these special types of fixed-net, some model experiments were carried out on the eleven nets (among which 4 nets are under practical use and 7 nets are newly devised by the author) and as to the other nets of ordinary above-water-setting type, the experiments were done on 18 nets (6 groups, in each group are contained 3 nets) for the purpose of a comparative experiment.

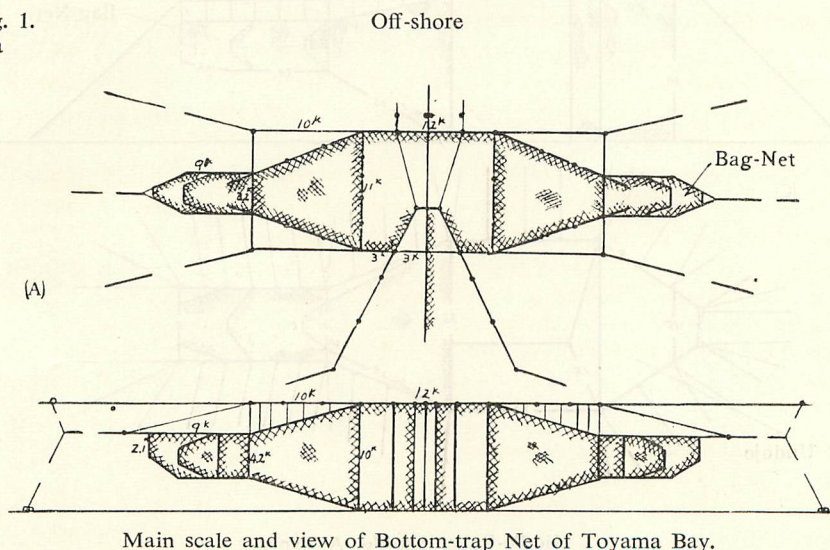
In this research, the fixed-net set under the water was divided into 2 types; the one in which the part of the net-body lies above the water while the rest of it is buried underwater; the second is the one in which the whole of the body is buried underwater.

In other words, in the net of the first type, the buoyancy of which is made to be larger than the total under-water weight of the net, the rope and the sinker; and in the net of the second type the reverse is the case. The first, then, further divided into 2 kinds, (a)<sup>(12)(13)(14)(15)(16)</sup> and (b).<sup>(4)</sup> Likewise, the second one was also divided into 2 kinds, (a) and (b).<sup>(12)(16)(17)</sup> and, in the second type, the experiment on (a) was unnecessary and put out of consideration. Therefore in the case of 1-a, the number of the kind used is 7, in case of 1-b, it is 1, and in case of 2-b, it is 3. Some representative nets among these are shown in Fig. 1 (A), (B), (C), (D), (E), (F).

The model-net used in the experiment was constructed according to the Law of Similarity presented by Tauchi.<sup>(5)</sup> By the way, the model experiment was done under the condition that the range of  $Re$  is  $10^2 \sim 10^4$ , that of  $Fr$  is  $0.03 \sim 0.3$ , and that of  $D/L$   $0.02 \sim 0.05$  ( $D$  means the diameter of the thread used in the experiment, and  $L$  means the length of one leg of the mesh).

Especially, the nets used in the comparative experiments consist of the two types, the one is the square-typed simple fixed-net (Fig. 4); the other is the hedge-net (Fig. 5); and in this case the ratio between the buoyancy  $B^*$  and the under-water-weight  $W$  is

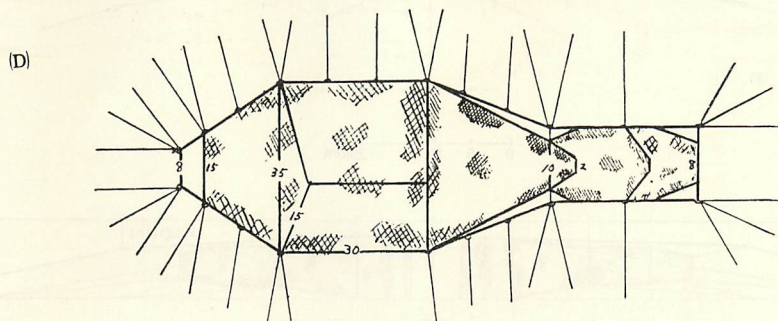
Fig. 1.  
1-a



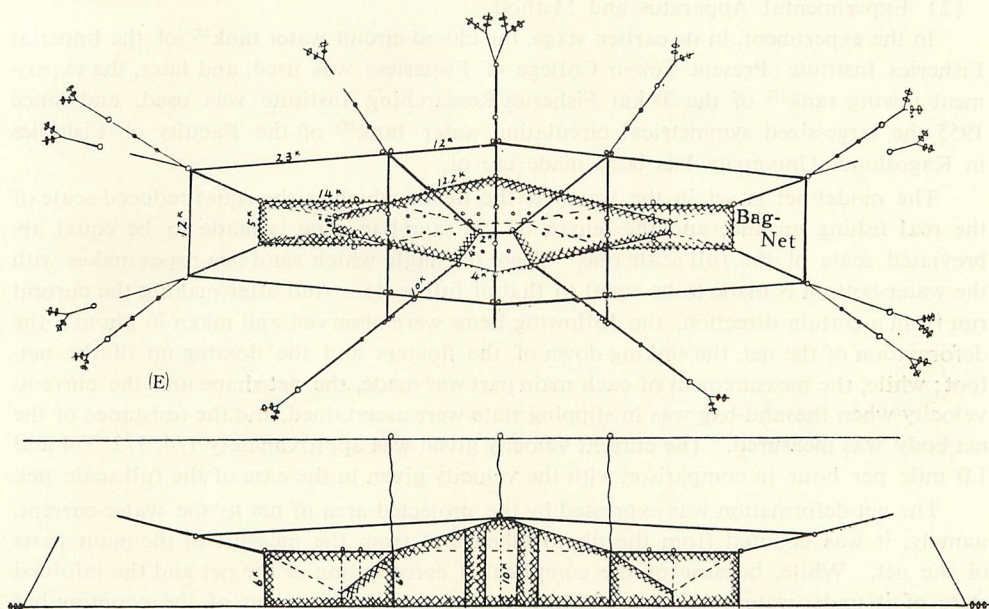
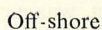








Middle-Rayer Set-Net B-Type.



Main scale and view of improved Bottom Fixed-Net in Hokkaido.



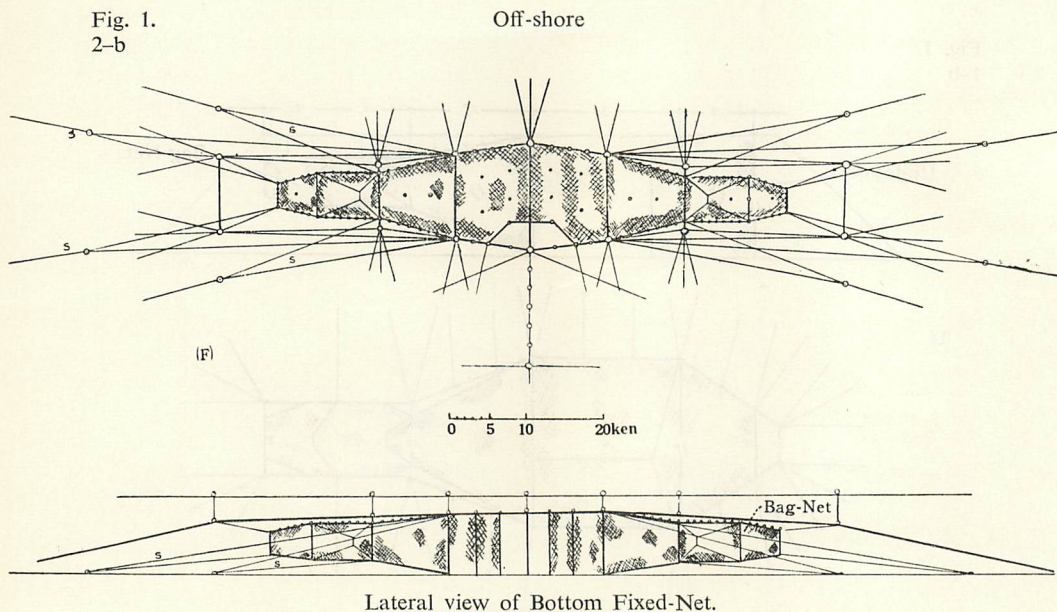


Fig. 1. The kinds of Fixed-Net used in this experiment.

fixed into the 3 groups of  $1/2$ ,  $1/1$ ,  $2/1$ ,; and in each group the length of the sand-bag rope is made to be 2, 3 and 4 times of the water-depth respectively. And, the net used in order to fix the force to the net-foot, was as shown in Fig. 2-c, namely a piece net of simple construction with the sand-bag ropes 2 times as long as the water depth.

## (2) Experimental Apparatus and Method

In the experiment, in its earlier stage, the closed-circuit water tank<sup>12)</sup> of the Imperial Fisheries Institute (Present Tokyo College of Fisheries) was used, and later, the experiment towing tank<sup>13)</sup> of the Tokai Fisheries Researching Institute was used, and since 1955 the large-sized symmetrical circulating water tank<sup>13)</sup> of the Faculty of Fisheries in Kagoshima University has been made use of.

The model-net is set in the water at the depth which is the equal reduced-scale of the real fishing ground, and the length of the sand-bag rope is made to be equal abbreviated scale of the full scale one. Then, the angle which sand-bag ropes makes with the water-bottom is made to be equal to that of full-scale. And after making the current run from a certain direction, the following items were observed and taken in photo: the deformation of the net, the sinking-down of the floaters and the floating-up of the net-foot; while, the measurement of each main part was made, the net-shape and the current-velocity when the sand-bag was in slipping state were ascertained, and the resistance of the net-body was measured. The current velocity given was approximately  $1/4$ ,  $1/2$ ,  $3/4$  and 1.0 mile per hour in comparison with the velocity given in the case of the full-scale net.

The net-deformation was expressed by the projected-area of net to the water-current, namely, it was counted from the photo taken and from the measure of the main parts of the net. While, because of the complicated construction of the net and the infolded state of it under-water, the vacua of the meshes were not put out of the counting but included in it.



As a trial method, in measuring the resistance exerted by the net on the sand-bag rope, some sets of the frictionless pulley of small type were used, they were set at the places where the sand-bags were fixed, while the ropes of the sand-bag were led to pass through them, and the ropes were gathered into one and then the resistance upon rope was measured with the balance.

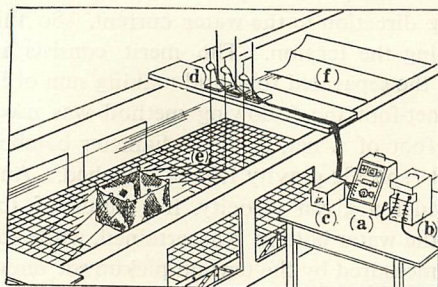


Fig. 2-a. Arrangement of the apparatus.

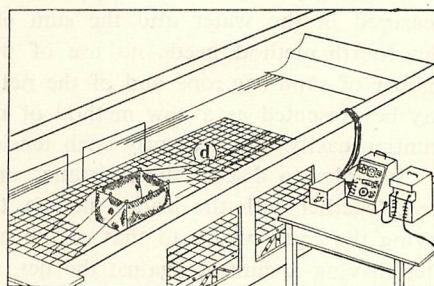


Fig. 2-b. Arrangement of the apparatus.

- (a) Wire resistance strain meter.
- (b) Eliminator. (c) Switch box.
- (d) Tension pickup. (e) Pulley.
- (f) Wave restrain-board.

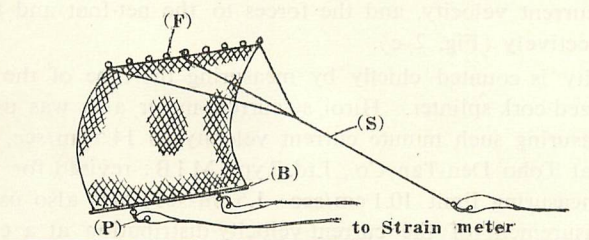


Fig. 2-c. Arrangement of the apparatus.

- (B) Bamboo. (F) Float. (P) Tension pickup. (S) Sand-bag rope.

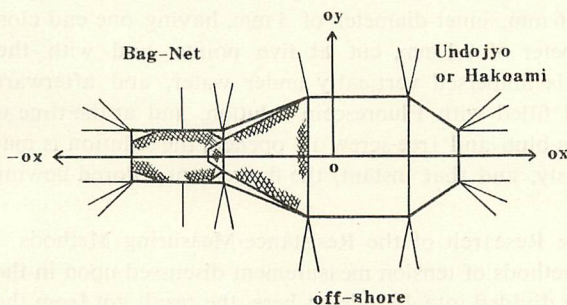


Fig. 2-d. Current direction.

As, the second method, the author used the Amplifier (made at Toyo Measuring Instruments Co., Ltd. Type us-7c). The tension pickup, maximum load 50 gr, length 20 mm, width 8 mm, thickness 3 mm, with somewhat bent and curved form, especially, the one having the water-tight faculty (made at Shinkoh Communication Industry Co., Ltd.) was used in the air in stead of the balance. As the third method, the resistance to every one



rope of the model sand-bag was led one by one from the three pulleys set at the fixing place of the sand-bag to the three tension pickups set in the air, and the sum of the resistance on the three ropes was made (Fig. 2-a).

As the fourth method, the sand-bag ropes were connected to the three pickups set at the fixing place of the sand-bags and the tension upon each one separated rope was measured in the water and the sum of which was brought into account (Fig. 2-b). This fourth method needs no use of pulley, and may be adopted irrespective of the number of sand-bag rope and of the net-setting direction to the water current. So this may be presented as a new method of measuring the tension. The merit consists in counting easily and promptly each tension on the separated rope and making sum of it.

In order to discuss the resistance on the net-foot the following method was used. First, together with the leaden sinkers, to the foot of a net, a small diameter bamboo having the equal width to that of the net foot (specific gravity 1.0) is attached. And after driving a current against the net, and under a given velocity, the status of the slid sinker when the net-foot is lifted from the water-bottom is ascertained, while the force to the sand-bag ropes propping the net is measured by the tension pickup set under the water. Then the sinker is removed and instead of it, at the proper points of the bamboo stick, two tension pickups are attached, and this stick is fixed at the place where the slid sinker was set. The current is sent against the net reproducing the state observed under the given current velocity, and the forces to the net-foot and to sand-bag rope are measured respectively (Fig. 2-c).

Current-velocity is counted chiefly by measuring the time of the flowing distance of the red-bean-sized-cork-splinter. Hiroi's current-meter also was used<sup>10)</sup> by turning reversely. In measuring such minute current velocity as 14.5 cm/sec, the electric currentmeter (made at Toho Den-Tan Co., Ltd. Type M1B: revised for the measurement of low current; measuring limit 10.1 cm/sec~1.5 cm/sec) was also used partially.

And the measurement of the current-velocity-distribution at a certain section of various depths was carried out by the simultaneous discharging, into the water, of the Fluorescein solution (1 mg/ml, 0.1 N. NaOH is used after its being diluted five times) and by photographing the fluorescent colored flowing by 8 mm. camera.

The method of which is as follows; a piece of glass tube with the length of 35 cm, outer-diameter of 6 mm, inner-diameter of 4 mm, having one end closed and with small pores of the diameter of 0.1 mm, cut at five points, and with the interval-distance of 5cm, this tube is immersed vertically under water, and afterwards it is connected with the glass-ball filled with Fluorescein solution, and at the time when pressed air is sent into this glass-blub and free-screw is opened, the solution is made to flow into the water simultaneously, and that instant, the fluorescent colored flowing current is caught by the camera.

### (3) Comparative Research of the Resistance-Measuring Methods

The various methods of tension measurement discussed upon in the above mentioned paragraphs may be divided into 4 kinds, so, here, the result got from the comparative tests of these 4 kinds is described first.

The shape of the net used in this test is as follows; length 28 cm, depth 28 cm, right square shaped net with total buoyancy 6.8 gr, under-water total weight 6.8 gr, with three sand-bag ropes (length 60 cm) attached at the upper current side as shown Fig. 2-a, b.

Three kinds of current-velocity is given, namely, in case of the model-net, 10.25 cm/sec (1/2 mile per hour in the full scale net) 15.35 cm/sec (3/4 mile/h), 20.5 cm/sec (1.0 mile/h). The tension got by 1~4 measuring methods is shown in Table I.



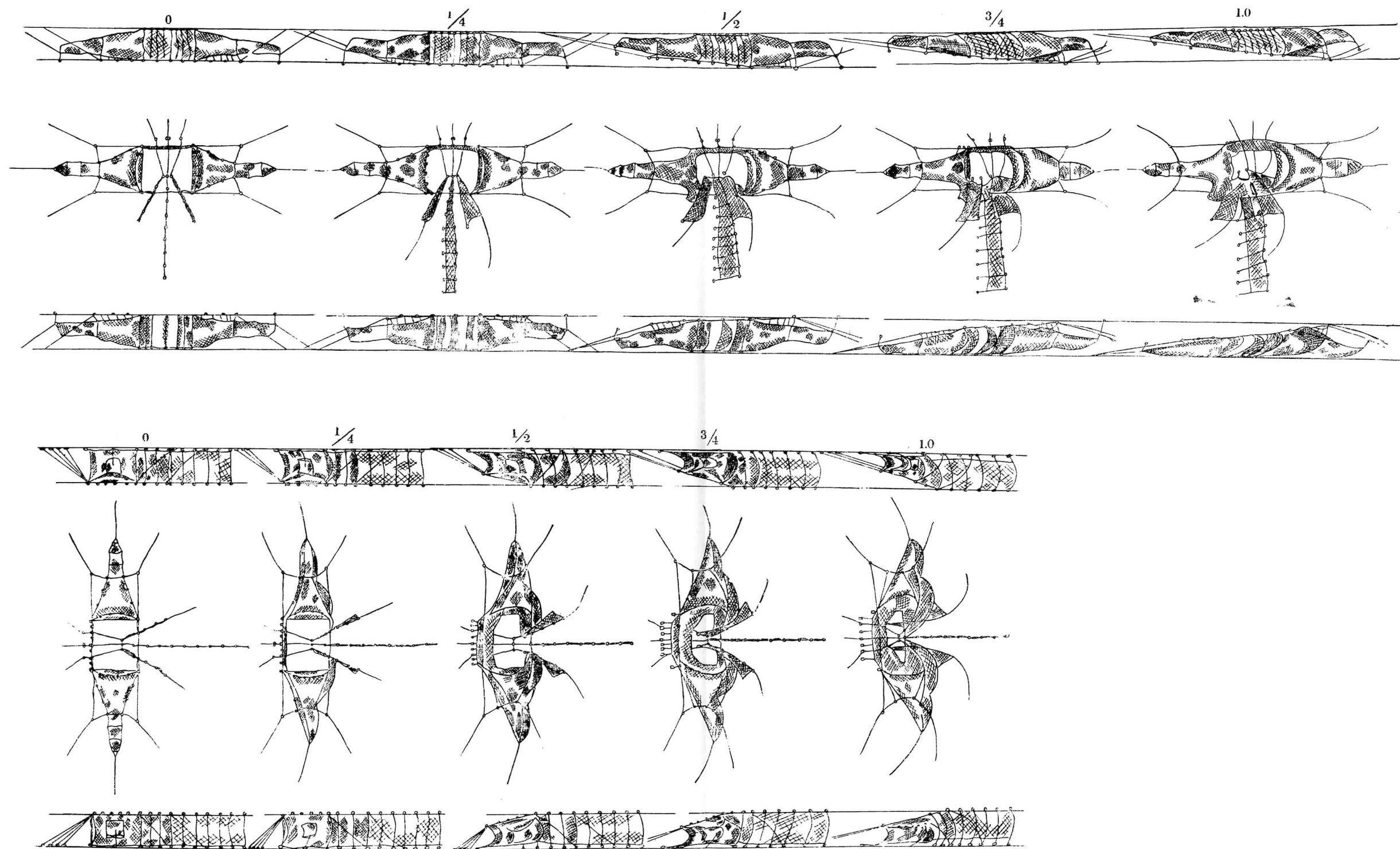


Fig. 3-a. Deformation of net characterized by the current direction and velocity (mile/hour).



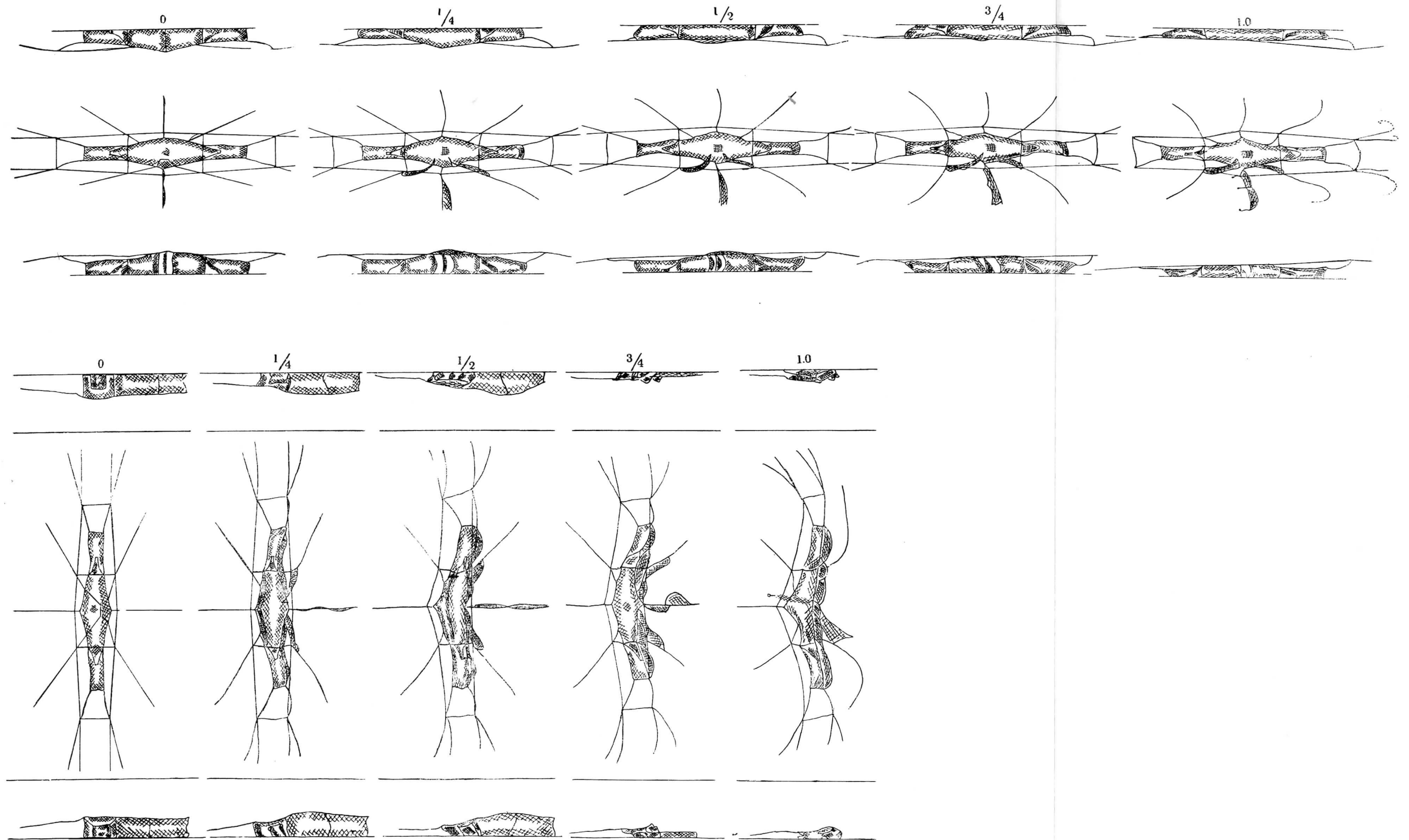


Fig. 3-b. Deformation of net characterized by the current direction and velocity (mile/hour).



Table I. The tension got by four different methods.

Current Velocity cm/sec	Measuring Method	1	2	3	4
10.25		14.2gr( $\times 1.37$ )	14.0gr( $\times 1.39$ )	18.5gr( $\times 1.05$ )	19.5gr( $\times 1.0$ )
15.35		25.7 ( $\times 1.25$ )	25.0 ( $\times 1.28$ )	30.7 ( $\times 1.04$ )	32.0 ( $\times 1.0$ )
20.50		35.7 ( $\times 1.19$ )	36.5 ( $\times 1.16$ )	40.0 ( $\times 1.06$ )	42.5 ( $\times 1.0$ )

In the above Table, between the two methods of the first and the second, there is the difference of 1.4% [ $= (14.2 \sim 14.0) / 14.2 \times 100$ ], 2.8% and 2.2% concerning each current velocity, and this is a quite slight odds, so we might put them out of consideration. In the comparison of the results got through the 3rd and 4th methods, the value got through the 4th shows 5.4%, 4.2% and 5.9% higher values per each current-velocity than the one got through the 3rd method. This might be due to the fact that there was not any friction-resistance as no pully was used in the 4th method. And this, also might be neglected.

There may be noted a considerable difference between the mean value of the first and of the second, and that of the third and the fourth, the measuring methods of which are similar, and there is 25.8% [ $= (14.1 \sim 19.0) / 19.0 \times 100$ ], 19.1% and 12.5% difference with the respective current velocity. And it is ascertained that the smaller is the current velocity the larger becomes the percentage, and it may be considered that the frictions of pully and others give some influence to this percentage, as the resistance was got by measuring the last sand-bag rope uniting all others into one. Among the four methods, then, the fourth may be presented as the most advanced one in measuring the resistance of the sand-bag ropes, as this enables us to get the value most approximate to the exact one.

At the first stage of this research, the first method was chiefly adopted, the third method was used in the comparative experiment shown in Table III and the fourth method was used in making the comparative research of the resistance.

Supposing the value of the fourth might be relied upon, to the measured value got by each method at the each current velocity, the value shown in the brakets in Table I must be multiplied. But in this report no multiplication is made. But this should be taken into consideration in the computation of the resistance.

### III. The Results of the Experiment

On the kind and number of the fixed-net tested by the author, the data was recorded in the paragraph (1) of Section II, in which the variations in the net deformation, the conditinos of the sand-bag slipping were observed, together with the measurement of the resistance acting on the net. In this paper, the resistance of the fixed-net and the net-deformation under water were chiefly discussed, and the effects of them to the fish were left to another paper.

As shown in the former paragraph, in each fixed-net, net-deformation changes, as shown in Fig. 3, according to the current velocity, though here are presented only some representative deformations. The projected-area of the net got from these figures shall be found in the 2nd line of Table II, and the resistance of the net got in the above mentioned first method shall be found in the 9th line, horizontal and vertical component of the resistance in 10th and 11th line respectively. Besides, in this table, the conditions showing the net-state shall be found too. Especially,  $\theta$  denotes the rake-angle of



Table II. Various conditions showing the specific

Name and characteristics of Net	Current direction	1. Velocity cm/sec	2. Projected area $\text{cm}^2$ $S_0(1-kV)$	3. Coefficient of deformation $k$	4. Depth $D$ cm	5. Distance of sinker-site from bottom $H_0$ cm
(1)		0.0	457.5		16.0	0.0
(1-a)		4.7	431.0		"	1.1
Soko-Hisago-Ami	<i>ox</i>	9.4	405.0	0.012	"	0.9
Sum Total of Buoyancy		14.0	379.0		"	0.6
$B=7.5$ gr		18.7	352.0		"	0.5
Sum Total of Under-water-weight		0.0	2022		16.0	0.0
$W=1.8$ gr	<i>oy</i>	4.7	1735	0.03	"	"
$B/W=4.2$		9.4	1450		"	"
		14.0	1165		"	"
		18.7	877		"	"
(2)		0.0	718.0		20.0	0.0
(1-a)	<i>ox</i>	10.3	684.2	0.005	"	3.5
Trap-Net with Bottom Bag-Net		15.4	667.5		"	5.2
$B=97.2$ gr		20.5	651.0		"	6.0
$W=27.0$ gr	<i>-ox</i>	0.0	758.5	0.023	20.0	0.0
$B/W=3.6$		10.3	579.3		"	5.1
		15.4	490.5		"	8.3
		20.5	401.8		"	10.3
(3)		0.0	171.2		12.0	0.0
(1-a)	<i>ox</i>	4.6	154.6	0.021	"	"
Improved Salmon Set-Net B-Type		9.2	138.0		"	"
$B=6.3$ gr		13.8	121.4		"	"
$W=4.7$ gr		18.4	104.8		"	"
$B/W=1.34$	<i>oy</i>	0.0	1054.3	0.046	12.0	0.0
		4.6	831.9		"	1.4
		9.2	609.4		"	2.5
		13.8	386.9		"	3.0
(4)		0.0	568.1		22.6	0.0
(1-a)	<i>ox</i>	8.3	476.8	0.02	"	3.6
Middle-Rayer Yellow-tail Set-Net A-Type		18.2	367.9		"	3.0
$B=94.0$ gr $W=16.7$ gr	<i>-ox</i>	0.0	648.8	0.031	22.6	0.0
$B/W=5.6$		9.5	456.2		"	"
		18.2	279.9		"	7.0
(5)		0.0	253.4		13.6	0.0
(1-a)	<i>ox</i>	6.2	180.2	0.046	"	2.5
Middle-Rayer Yellow-tail Set-Net I-Type		7.7	162.5		"	0.9
$B=34.0$ gr		9.1	146.1		"	0.8
$W=5.2$ gr	<i>-ox</i>	0.0	233.0	0.06	13.6	0.0
$B/W=6.5$		3.7	181.0		"	1.1
		7.7	125.0		"	3.5
		9.1	105.0		"	2.5
(6)		0.0	237.9		13.6	0.0
(1-a)	<i>ox</i>	2.7	210.6	0.052	"	"
Middle-Rayer Yellow-tail Set-Net II-Type		3.7	196.9		"	2.7
$B=33.0$ gr		5.5	169.6		"	1.5
$W=5.9$ gr	<i>-ox</i>	0.0	235.8	0.07	13.6	0.0
$B/W=5.6$		2.2	199.5		"	"
		3.7	174.7		"	1.8
		5.5	145.0		"	2.5



characters of the Net.

6. Distance of bouy-site from bottom $H$ cm	7. Length of Sand-Bag rope $l$ cm	8. $\sin^{-1}(\frac{H}{l})$ $\theta$	9. Force acting on the rope $R$ gr	10. Horizontal force $R\cos\theta$ $P$ gr	11. Vertical force $R\sin\theta$ $Q$ gr	12. Horizontal coefficient of $R$ $C_P$	13. Vertical coefficient of $R$ $C_Q$
15.3	32.0	28°35'	0	0	0	0	0
14.5	"	26°56'	2.0	1.8	0.9	$3.8 \times 10^{-4}$	$1.9 \times 10^{-4}$
11.8	"	21°37'	8.9	8.3	3.3	4.7	1.9
8.9	"	16°08'	17.7	17.0	4.9	4.6	1.3
6.7	"	12°05'	19.4	19.0	4.1	3.1	0.7
15.5	32.0	28°59'	0	0	0	0	0
15.0	"	27°57'	1.8	1.6	0.8	$0.8 \times 10^{-4}$	$0.43 \times 10^{-4}$
11.0	"	20°07'	10.0	9.4	3.4	1.5	0.54
9.5	"	17°17'	19.8	18.9	5.9	1.6	0.51
8.2	"	14°50'	35.3	34.1	9.0	2.2	0.59
20.0	30.0	41°45'	0	0	0	0	0
"	"	"	23.4	17.5	15.6	$6.5 \times 10^{-4}$	$5.8 \times 10^{-4}$
18.0	"	36°52'	58.8	47.8	35.8	10.0	7.6
17.8	"	36°22'	81.7	65.8	48.5	10.5	7.8
20.0	40.0	30°00'	0	0	0	0	0
"	"	"	18.6	16.1	9.3	$5.3 \times 10^{-4}$	$3.0 \times 10^{-4}$
17.0	"	25°47'	46.4	41.8	20.2	7.2	3.5
11.8	"	17°09'	69.0	66.0	20.3	7.8	2.4
7.0	48.0	8°23'	0	0	0	0	0
6.1	"	7°18'	11.1	11.1	1.43	$67.5 \times 10^{-4}$	$8.7 \times 10^{-4}$
5.0	"	5°59'	12.8	12.8	1.35	21.9	2.3
3.8	"	4°33'	—	—	—	—	—
3.0	"	3°35'	27.9	27.9	1.75	16.0	1.0
10.0	48.0	12°01'	0	0	0	0	0
8.0	"	9°35'	10.4	10.3	1.74	$11.8 \times 10^{-4}$	$2.0 \times 10^{-4}$
7.0	"	8°23'	16.1	16.0	2.36	6.0	0.9
5.0	"	5°59'	—	—	—	—	—
22.6	34.0	41°37'	0	0	0	0	0
15.6	"	27°18'	20.4	17.8	9.2	$10.8 \times 10^{-4}$	$5.6 \times 10^{-4}$
13.6	"	23°35'	73.0	67.0	29.3	11.0	4.8
22.6	34.0	41°37'	0	0	0	0	0
19.7	"	35°25'	32.0	26.1	18.5	$12.6 \times 10^{-4}$	$9.0 \times 10^{-4}$
11.5	"	19°46'	83.0	78.1	28.0	16.8	6.0
13.6	30.3	26°40'					
8.1	"	15°30'					
5.1	"	9°41'					
4.8	"	9°06'					
13.6	30.3	26°40'					
12.1	"	23°32'					
9.0	"	17°17'					
5.9	"	11°13'					
13.6	30.3	26°40'					
"	"	"					
10.6	"	20°28'					
9.2	"	17°48'					
13.6	30.3	26°40'					
"	"	"					
12.5	"	24°21'					
11.3	"	21°52'					



Name and characteristics of Net	Current direction	1. $V$ cm/sec	2. $S_0(1-kV)$	3. $k$	4. $D$ cm	5. $H_0$ cm
(7) (1-a) Middle-Rayer Yellow-tail Set-Net III-Type $B=24.6$ gr $W=5.9$ gr $B/W=4.2$	$ox$	0.0	236.6	0.051	13.6	0.0
		1.8	215.0		"	"
		3.3	197.0		"	"
	$-ox$	0.0	246.0	0.089	13.6	0.0
		1.7	208.6		"	"
		3.2	175.6		"	"
(8) (1-b) Middle-Rayer Yellow-tail Set-Net B-Type $B=45.5$ gr $W=15.7$ gr $B/W=2.9$	$ox$	0.0	478.0	0.023	22.6	0.0
		8.3	387.6		"	2.4
		18.2	279.8		"	0.9
	$-ox$	0.0	501.1	0.017	22.6	0.0
		9.5	421.4		"	4.2
		18.2	348.5		"	0.0
(9) (2-b) Improved Salmon Set-Net A-Type $B=4.0$ gr $W=4.8$ gr $B/W=0.83$	$ox$	0.0	171.2	0.021	15.0	0.0
		4.6	154.6		"	"
		9.2	138.0		"	"
	$oy$	13.8	121.4	0.046	"	"
		18.4	104.8		"	"
		0.0	1064		15.0	0.0
(10) (2-b) Salmon Sea-Bottom Fixed-Net $B=1.4$ gr $W=2.8$ gr $B/W=0.5$	$ox$	4.6	841	0.057	"	"
		9.2	618		"	1.5
		13.8	396		"	"
	$oy$	0.0	1081	0.028	14.0	0.0
		4.0	204.0		"	"
		8.0	178.4		"	"
(11) (2-b) Yellow-tail Sea-Bottom Fixed-Net $B=7.0$ gr $W=8.9$ gr $B/W=0.8$	$ox$	12.1	152.8	0.035	"	"
		16.1	127.5		"	"
		0.0	1081		14.0	0.0
	$oy$	4.0	834	0.035	"	"
		8.0	556		"	"
		12.1	334		"	"
(11) (2-b) Yellow-tail Sea-Bottom Fixed-Net $B=7.0$ gr $W=8.9$ gr $B/W=0.8$	$ox$	0.0	250.0	0.035	15.15	0.0
		4.9	207.6		"	"
		9.7	165.2		"	"
	$oy$	14.5	123.2	0.035	"	"
		19.4	80.4		"	"
		0.0	1229.5		15.15	0.0

Note: ( $ox$ ), the direction of current when the tide comes from the Bag-Net and These three shall be found in Fig. 2-d.

the sand-bag ropes. And in Table III and in Fig. 4, 5 are shown the results of the comparative experiments done on the square net, and on a piece of flat-net. And in Fig. 6 the coefficient of the horizontal and vertical forces composing the whole resistance of the net in this case are shown.

In order to clear the floating-and-sinking-phenomenon of sinkers the following experiments are made. As shown in Fig. 7, the flat-net spread upon the frames is bent at the central line, and then Fluorescein solution is discharged from the upper-stream

6. <i>H</i> cm	7. <i>l</i> cm	8. $\theta$	9. <i>R</i> gr	10. <i>P</i> gr	11. <i>Q</i> gr	12. <i>C<sub>P</sub></i>	13. <i>C<sub>Q</sub></i>
13.6	30.0	26°40'					
"	"	"					
11.7	"	22°42'					
13.6	30.3	26°40'					
"	"	"					
11.2	"	21°41'					
8.1	"	15°30'					
19.0	29.0	40°55'	0	0	0	0	0
12.4	"	25°19'	13.0	11.8	5.58	$8.8 \times 10^{-4}$	$4.2 \times 10^{-4}$
7.0	"	13°58'	39.0	38.9	9.68	8.2	2.1
19.0	29.0	40°55'	0	0	0	0	0
16.6	"	34°53'	33.0	27.1	18.9	$14 \times 10^{-4}$	$9.9 \times 10^{-4}$
8.8	"	17°40'	128.0	122.0	43.8	21.2	7.6
8.0	48.0	9°36'	0	0	0	0	0
6.4	"	7°40'	7.6	7.6	1.02	$14.0 \times 10^{-4}$	$6.2 \times 10^{-4}$
6.1	"	7°18'	11.5	11.5	1.47	19.5	2.5
4.2	"	5°01'	—	—	—	—	—
3.9	"	4°39'	16.7	16.7	1.34	9.4	0.8
10.0	48.0	12°01'	0	0	0	0	0
6.4	"	7°40'	6.5	6.5	0.87	$7.2 \times 10^{-4}$	$1.0 \times 10^{-4}$
4.7	"	5°37'	13.0	13.0	1.28	5.0	0.34
4.0	"	4°47'	—	—	—	—	—
5.3	53.0	5°45'	0	0	0	0	0
4.4	"	4°46'	0.26	0.26	0.02	$1.6 \times 10^{-4}$	$0.13 \times 10^{-4}$
3.6	"	3°54'	0.53	0.53	0.04	0.9	0.06
3.0	"	3°15'	2.1	2.1	0.12	1.9	0.11
2.4	"	2°36'	3.4	3.4	0.15	2.1	0.09
5.5	53.0	5°57'	0	0	0	0	0
3.7	"	4° 0'	0.43	0.43	0.03	$0.65 \times 10^{-4}$	$0.04 \times 10^{-4}$
2.7	"	2°55'	0.9	0.9	0.05	0.45	0.02
2.0	"	2°10'	2.82	2.82	0.12	1.15	0.05
11.4	45.45	14°32'	0	0	0	0	0
10.7	"	13°37'	1.8	1.7	0.4	$7.1 \times 10^{-4}$	$1.7 \times 10^{-4}$
8.7	"	11°03'	4.5	4.4	0.9	5.7	1.1
6.7	"	8°29'	7.4	7.3	1.1	5.6	0.8
6.4	"	8°06'	8.7	8.6	1.2	5.6	0.8
15.0	45.45	19°56'	0	0	0	0	0
"	"	19°16'	5.0	4.8	1.7	$3.9 \times 10^{-4}$	$1.4 \times 10^{-4}$
11.0	"	14° 0'	6.4	6.2	1.6	1.5	0.4
9.5	"	12°04'	11.6	11.3	2.4	1.7	0.4
8.2	"	10°22'	16.0	15.8	2.9	1.9	0.4

Bottom Bag-Net; (—ox), from the Hakoami and Undojyo; (oy), from the Off-shore.

part, and the direction of the flowing solution after it struck against the net and passed through the net-meshes is observed. In the result got, as shown in Fig. 7, at the upper half, there arises an upward current, and at the lower half there arises down-ward current, and at the net-foot and in its neighbourhood there arises down-ward flowing current. Next, as shown in the paragraph (1) of Section II, flat-net with simple construction is used and the force is measured which acts on the sand-bag ropes and on the net-foot, either when the sinkers slid along the water-bottom into



halting state as the net-foot was lifted by the running water, or when the sinkers were detached from the water-bottom, and the following results as shown in Table IV were obtained.

Table III. Various conditions showing the specific

Name and characteristics of Net	1. Velocity cm/sec	2. Projected area cm <sup>2</sup> $S_0(1-kV)$	3. Coefficient of deforma- tion $k$	4. Depth $D$ cm	5. Distance of sinker-site from bottom $H_0$ cm	6. Distance of body-site from bottom $H$ cm	7. Length of sand-Bag rope $l$ cm	8. $\sin^{-1}(\frac{H}{l})$ $\theta$	9. Force acting on the rope $R$ gr	10. Horizontal force $R \cos \theta$ $P$ gr
Square-Net A Sum Total Buoyancy $B=3.4$ gr  Sum Total Under-water- weight $W=6.8$ gr $B^*/W=0.5$  30 cm $\times$ 30 cm $\times$ 30 cm	0.0	723	0.034	30.0	0.0	27.3	60.0	27°04'	0	0
	5.12	598		"	"	19.5	"	18°58'	2.1	2.0
	10.25	473		"	"	11.5	"	11°03'	10.7	10.5
	15.35	348		"	"	7.6	"	7°17'	25.1	24.9
	20.50	222		"	"	5.5	"	5°16'	40.6	39.6
	0.0	659	0.031	30.0	0.0	27.7	90.0	17°55'	0	0
	5.12	555		"	"	20.8	"	13°22'	3.3	3.2
	10.25	451		"	"	12.7	"	8°07'	13.7	13.6
	15.35	347		"	"	9.0	"	5°46'	23.9	23.8
	20.50	243		"	"	5.5	"	4°09'	39.6	39.5
	0.0	628	0.033	30.0	0.0	27.8	120.0	13°24'	0	0
	5.12	618		"	"	22.1	"	10°37'	4.9	4.8
	10.25	463		"	"	13.5	"	6°28'	13.2	13.1
	15.35	301		"	"	8.7	"	4°10'	26.6	26.5
	20.50	226		"	"	6.9	"	3°18'	40.3	40.2
Square-Net B  $B=6.8$ gr  $W=6.8$ gr $B^*/W=1.0$  30 cm $\times$ 30 cm $\times$ 30 cm	0.0	600	0.028	30.0	0.0	28.0	60.0	27°49'	0	0
	5.12	515		"	"	20.2	"	19°40'	5.3	5.1
	10.25	429		"	"	12.7	"	12°13'	16.6	16.2
	15.35	344		"	0.1	8.9	"	8°32'	34.3	33.9
	20.50	258		"	0.5	6.8	"	6°30'	48.2	47.1
	0.0	599	0.022	30.0	0.0	28.4	90.0	18°24'	0	0
	5.12	531		"	"	25.4	"	16°24'	4.4	4.3
	10.25	462		"	"	15.3	"	9°47'	20.0	19.7
	15.35	394		"	"	10.8	"	6°54'	32.5	32.2
	20.50	325		"	0.3	8.5	"	5°25'	48.1	48.0
	0.0	681	0.027	30.0	0.0	28.4	120.0	13°41'	0	0
	5.12	589		"	"	26.1	"	12°34'	3.5	3.4
	10.25	496		"	"	16.7	"	8° 0'	16.5	16.3
	15.35	404		"	0.1	12.1	"	5°47'	34.5	34.2
	20.50	311		"	0.3	9.6	"	4°35'	48.2	48.0
Square-Net C  $B=6.8$ gr  $W=3.4$ gr $B^*/W=2.0$  30 cm $\times$ 30 cm $\times$ 30 cm	0.0	705	0.03	30.0	0.0	28.2	60.0	28°02'	0	0
	5.12	598		"	"	22.1	"	21°37'	4.7	4.4
	10.25	491		"	0.5	13.1	"	12°37'	18.2	17.7
	15.35	385		"	1.1	9.5	"	9°07'	35.0	34.5
	20.50	277		"	1.3	7.3	"	6°59'	53.2	52.8
	0.0	687	0.03	30.0	0.0	28.0	90.0	18°07'	0	0
	5.12	583		"	"	23.1	"	14°52'	4.6	4.5
	10.25	478		"	0.4	14.8	"	9°28'	15.9	15.7
	15.35	374		"	1.1	11.0	"	7°02'	34.0	33.6
	20.50	269		"	1.8	9.0	"	5°44'	52.0	52.0
	0.0	638	0.03	30.0	0.0	28.3	120.0	13°38'	0	0
	5.12	545		"	"	23.9	"	11°29'	5.7	5.6
	10.25	451		"	0.8	15.4	"	7°22'	19.8	19.7
	15.35	358		"	3.3	12.7	"	6°05'	32.6	32.4
	20.50	264		"	3.0	10.6	"	5°04'	52.2	52.0



By this experimental result, it is ascertained that in the net which attached itself to the water-bottom in spite of the sliding of the sinkers, besides the force acting on the sand-bag ropes there is another kind of force acting on the net-foot.

characters of the Net.

11.	12.		13.		14.	15.	16.	17.	18.	19.	20.	21.	22.
Vertical force $R_{\text{Sink}}$ $Q$ gr	Sink floater		Detached sinker		Under-water Buoyancy $B=(b-d)$ gr	Lift $(Q-B)=h$ gr	Resultant of $R$ and $b$ $a$ or $a'$ gr	Hydrodynamic force $e$ gr	Direction of Hydrodynamic force $\phi$	Horizontal component of $e$ $f$ gr	Horizontal coefficient of $R$ $C_P$	Vertical coefficient of $R$ $C_Q$	Coefficient of Lift $C_h$
	Num-ber	Buoyancy $b$ gr	Num-ber	Under-water weight $d$ gr									
0	0		0										
0.67	8	* 3.4	"	1.4	2.0	-1.33	3.4	2.4	-33°38'	2.0	$2.6 \times 10^{-4}$	$0.9 \times 10^{-4}$	$1.70 \times 10^{-4}$
2.05	"	"	"	"	"	+0.05	10.6	10.1	0°	10.5	4.2	0.8	0
3.18	"	"	"	"	"	+1.18	24.9	24.9	+ 2°43'	24.9	6.1	0.8	0.29
3.73	"	"	"	"	"	+1.73	40.2	40.2	+ 2°28'	40.2	8.4	0.8	0.37
0	0		0										
0.77	8	* 3.4	"	1.4	2.0	-1.23	4.6	3.5	-20°51'	3.5	$4.4 \times 10^{-4}$	$1.0 \times 10^{-4}$	$1.70 \times 10^{-4}$
1.94	"	"	"	"	"	-0.06	13.6	13.3	0°	13.5	5.6	0.8	0
2.36	"	"	"	"	"	+0.36	23.8	23.8	+ 0°52'	23.8	5.8	0.6	0.09
2.89	"	"	"	"	"	+0.89	39.5	39.4	+ 1°18'	39.4	7.7	0.6	0.18
0	0		0										
0.90	8	* 3.4	"	1.4	2.0	-1.10	5.4	4.5	-15°11'	4.8	$6.6 \times 10^{-4}$	$1.1 \times 10^{-4}$	$1.60 \times 10^{-4}$
1.50	"	"	"	"	"	-0.50	13.3	12.9	- 2°13'	13.2	5.6	0.7	0.21
1.93	"	"	"	"	"	-0.07	26.6	26.4	0°	26.6	6.7	0.5	0
2.32	"	"	"	"	"	+0.32	40.2	40.2	+ 0°27'	40.2	8.6	0.5	0.07
0	0		0										
1.80	7	* 5.95	"	1.4	4.55	-2.75	6.5	5.7	-28°52'	5.0	$7.6 \times 10^{-4}$	$2.7 \times 10^{-4}$	$4.10 \times 10^{-4}$
3.50	8	* 6.8	"	"	5.4	-1.90	16.6	16.5	-11°01'	16.3	7.2	1.6	0.80
5.10	"	"	1	2.25	4.55	+0.55	33.9	34.0	+ 0°55'	33.9	8.4	1.2	0.14
5.50	"	"	"	"	"	+0.95	47.9	47.9	+ 1°08'	47.9	8.7	1.1	0.18
0	0		0										
1.30	7	* 5.95	"	1.4	4.55	-3.25	6.3	5.4	-37°01'	4.2	$6.2 \times 10^{-4}$	$1.9 \times 10^{-4}$	$4.70 \times 10^{-4}$
3.40	8	* 6.8	"	"	5.4	-2.00	20.0	19.1	- 6°01'	19.7	8.1	1.4	0.78
3.90	"	"	"	"	"	-1.50	32.4	32.3	- 2°40'	32.4	6.9	0.8	0.32
4.90	"	"	1	2.25	4.55	+0.35	47.9	47.9	+ 0°23'	47.9	7.0	0.7	0.05
0	0		0										
0.80	5	* 4.25	"	1.4	2.85	-2.05	4.9	4.0	-30°50'	3.4	$4.4 \times 10^{-4}$	$1.0 \times 10^{-4}$	$2.70 \times 10^{-4}$
2.60	7	* 5.95	"	"	4.55	-1.95	16.7	16.5	- 6°47'	16.3	6.3	1.0	0.75
3.60	8	* 6.8	1	2.25	"	-0.95	34.4	34.0	- 1°35'	34.3	7.2	0.8	0.20
3.90	"	"	1	"	"	-0.65	48.1	48.0	- 0°46'	48.1	7.3	0.6	0.10
0	0		0										
1.73	5	* 4.25	3	2.65	1.6	+0.13	4.5	4.4	+ 1°18'	4.3	$5.6 \times 10^{-4}$	$2.2 \times 10^{-4}$	$0.13 \times 10^{-4}$
4.00	7	* 5.95	4	3.1	2.85	+1.15	17.8	17.8	+ 3°48'	17.8	6.9	1.6	0.46
5.60	8	* 6.8	5	3.53	3.27	+2.33	34.6	34.1	+ 3°59'	34.6	7.6	1.2	0.52
6.50	"	"	3	2.65	4.15	+2.35	52.8	52.8	+ 2°33'	52.6	9.1	1.1	0.40
0	0		0										
1.24	5	* 4.25	3	2.65	1.6	-0.36	4.8	4.5	- 4°36'	4.4	$5.9 \times 10^{-4}$	$1.6 \times 10^{-4}$	$0.47 \times 10^{-4}$
2.60	7	* 5.95	4	3.1	2.85	-0.25	15.8	15.7	- 0°55'	15.7	6.2	1.1	0.10
4.20	8	* 6.8	6	4.0	"	+1.35	33.7	33.8	+ 2°18'	33.7	7.6	1.0	0.30
5.20	"	"	8	5.2	1.6	+3.60	51.8	51.8	+ 3°59'	51.8	9.2	1.0	0.67
0	0		0										
1.13	5	* 4.25	4	3.1	1.15	0.00	5.7	5.6	0°	5.5	$7.8 \times 10^{-4}$	$1.5 \times 10^{-4}$	0
2.60	7	* 5.95	5	3.53	2.42	+0.18	19.7	19.6	+ 4°58'	19.7	8.3	1.1	$0.72 \times 10^{-4}$
3.50	8	* 6.8	8	5.2	1.6	+1.90	32.4	32.5	+ 3°32'	32.4	7.7	0.9	0.45
4.60	"	"	"	"	"	+3.00	52.0	52.0	+ 3°18'	52.0	9.4	0.9	0.36



Name and characteristics of Net	1. $V$ cm/sec	2. $S_0(1-kV)$	3. $k$	4. $D$ cm	5. $H_0$ cm	6. $H$ cm	7. $l$ cm	8. $\theta$	9. $R$ gr	10. $P$ gr
Flat-Net A  $B=3.4$ gr	0.0	630	0.04	30.0	0.0	28.8	60.0	28°41'	0	0
	5.12	502		"	"	27.3	"	27°04'	6.9	6.2
	10.25	373		"	"	21.9	"	21°04'	11.1	10.3
	15.35	245		"	"	15.8	"	15°16'	13.9	13.3
	20.50	115		"	"	10.8	"	10°22'	25.0	24.6
$W=6.8$ gr  $B^*/W=0.5$	0.0	599	0.04	30.0	0.0	28.2	90.0	18°16'	0	0
	5.12	474		"	"	27.3	"	17°39'	7.0	6.7
	10.25	349		"	"	23.9	"	15°26'	10.1	9.8
	15.35	225		"	"	16.1	"	10°18'	15.6	15.35
	20.50	100		"	"	12.6	"	8°03'	24.5	24.24
30 cm×30 cm	0.0	610	0.04	30.0	0.0	27.9	120.0	13°27'	0	0
	5.12	487		"	"	27.0	"	13° 0'	3.8	3.7
	10.25	363		"	"	24.0	"	11°33'	7.2	7.0
	15.35	240		"	"	17.0	"	8°09'	14.1	14.0
	20.50	117		"	"	13.6	"	6°30'	22.3	22.2
Flat-Net B  $B=6.8$ gr	0.0	660	0.04	30.0	0.0	27.5	60.0	27°17'	0	0
	5.12	523		"	"	27.2	"	26°58'	6.3	5.62
	10.25	387		"	"	24.7	"	24°19'	12.5	11.4
	15.35	250		"	"	18.4	"	17°51'	22.3	21.2
	20.50	113		"	1.0	14.4	"	13°53'	32.8	31.7
$W=6.8$ gr  $B^*/W=1.0$	0.0	664	0.04	30.0	0.0	27.5	90.0	17°47'	0	0
	5.12	528		"	"	27.2	"	17°36'	4.7	4.3
	10.25	391		"	"	24.9	"	16°04'	8.8	8.4
	15.35	256		"	0.1	20.6	"	13°14'	17.6	17.1
	20.50	118		"	0.3	16.3	"	10°26'	28.3	27.8
30 cm×30 cm	0.0	696	0.04	30.0	0.0	27.3	120.0	13°09'	0	0
	5.12	547		"	"	27.0	"	13° 0'	2.1	2.05
	10.25	398		"	"	25.0	"	12°13'	6.3	6.2
	15.35	250		"	0.4	21.1	"	10°08'	15.3	15.3
	20.50	100		"	0.2	17.5	"	8°23'	24.8	24.4
Flat-Net C  $B=6.8$ gr	0.0	627	0.044	30.0	0.0	28.0	60.0	27°49'	0	0
	5.12	486		"	"	27.5	"	27°17'	7.4	6.6
	10.25	345		"	0.8	24.8	"	24°25'	14.5	13.2
	15.35	205		"	4.1	21.1	"	20°35'	21.1	19.8
	20.50	64		"	4.6	17.0	"	16°28'	27.6	26.4
$W=3.4$ gr  $B^*/W=2.0$	0.0	639	0.043	30.0	0.0	27.8	90.0	17°59'	0	0
	5.12	499		"	"	27.7	"	17°55'	7.5	6.8
	10.25	358		"	1.4	25.2	"	16°15'	14.4	13.8
	15.35	219		"	7.3	23.9	"	15°24'	20.9	19.8
	20.50	78		"	9.4	22.3	"	14°21'	26.8	25.9
30 cm×30 cm	0.0	648	0.044	30.0	0.0	27.7	120.0	13°21'	0	0
	5.12	503		"	"	25.6	"	12°19'	6.6	6.4
	10.25	358		"	1.7	25.6	"	12°19'	12.8	12.0
	15.35	213		"	7.0	24.4	"	11°44'	19.9	19.5
	20.50	67		"	10.8	23.6	"	11°20'	27.0	26.4

Mark \* Shows the occasion when the whole buoys of net were sunken

#### IV. Discussion of the Experimental Result.

##### (1) On the coefficient of deformation $k$

Now, when the current velocity varies, the net-deformation, as shown in Fig. 3 and 4, varies too. And then let the projected-area before the deformation be  $S_0$  and that under a given velocity  $V$  be  $S$ , and assuming that the relationship between the current

11. $Q$ gr	12. $b$ gr	13. $d$ gr	14. $B=(b-d)$	15. $(Q-B)=h$	16. $a$ or $a'$ gr	17. $e$ gr	18. $\phi$	19. $f$ gr	20. $C_P$	21. $C_Q$	22. $C_h$
0	0	0									
3.18	3	1.14	0.35	0.8	+ 2.38	6.4	+ 21°50'	6.2	$9.4 \times 10^{-4}$	$4.8 \times 10^{-4}$	$3.60 \times 10^{-4}$
4.05	9	* 3.4	"	3.05	+ 1.00	10.3	+ 5°34'	10.3	5.3	2.1	0.50
4.02	"	* "	"	"	+ 0.97	13.4	+ 4°09'	13.4	4.5	1.3	0.34
4.50	"	* "	"	"	+ 1.45	24.6	+ 3°23'	24.6	10.1	1.9	0.60
0	0	0									
2.13	3	1.14	0.35	0.8	+ 1.34	6.7	+ 11°32'	6.7	$10.7 \times 10^{-4}$	$3.4 \times 10^{-4}$	$2.15 \times 10^{-4}$
2.63	9	* 3.4	"	3.05	- 0.42	9.8	- 2°27'	9.8	5.3	1.5	0.23
2.82	"	* "	"	"	- 0.23	15.3	- 0°52'	15.3	5.8	1.1	0.08
3.39	"	* "	"	"	+ 0.34	24.3	+ 0°48'	24.3	11.6	1.6	0.16
0	0	0									
0.86	3	1.14	0.35	0.8	+ 0.06	3.7	+ 0°56'	3.7	$5.8 \times 10^{-4}$	$1.4 \times 10^{-4}$	$0.16 \times 10^{-4}$
1.42	9	* 3.4	"	3.05	- 1.63	7.3	- 12°53'	7.1	3.7	0.5	0.85
1.96	"	* "	"	"	- 1.09	14.0	- 4°29'	14.0	4.9	1.1	0.38
2.50	"	* "	"	"	- 0.55	22.2	- 1°25'	22.2	9.1	1.0	0.23
0	0	0									
2.86	3	2.28	0.35	1.93	+ 0.93	5.6	+ 9°33'	5.6	$8.2 \times 10^{-4}$	$4.2 \times 10^{-4}$	$1.40 \times 10^{-4}$
5.14	7	5.3	"	4.95	+ 0.19	11.4	+ 0°57'	11.4	5.6	2.5	0.10
6.90	9	* 6.8	"	6.45	+ 0.45	21.2	+ 1°13'	21.2	7.2	2.3	0.15
7.90	"	* "	"	5.69	+ 2.21	31.9	+ 3°58'	31.8	13.3	3.3	0.90
0	0	0									
1.42	3	2.28	0.35	1.93	- 0.51	4.5	- 6°30'	4.4	$6.2 \times 10^{-4}$	$1.9 \times 10^{-4}$	$0.74 \times 10^{-4}$
2.40	7	5.3	"	4.95	- 2.25	8.9	- 16°19'	8.4	4.1	1.2	1.20
4.00	9	* 6.8	1	5.69	- 1.69	17.2	- 5°38'	17.1	5.7	1.3	0.56
5.10	"	* "	2	4.95	+ 0.15	27.8	+ 0°19'	27.6	11.2	2.0	0.06
0	0	0									
0.47	3	2.28	0.35	1.93	- 1.46	2.7	- 32°41'	2.0	$2.9 \times 10^{-4}$	$0.7 \times 10^{-4}$	$2.00 \times 10^{-4}$
1.34	7	5.3	"	4.95	- 3.61	7.3	- 29°40'	6.2	3.0	0.6	1.70
2.74	9	* 6.3	2	"	- 2.21	15.5	- 8°12'	15.3	5.2	0.9	0.75
3.60	"	* "	4	3.45	+ 0.15	24.5	+ 3°30'	24.5	11.6	1.7	0.07
0	0	0									
3.40	3	2.28	0.35	1.93	+ 1.47	6.7	+ 12°40'	6.6	$10.4 \times 10^{-4}$	$5.2 \times 10^{-4}$	$2.30 \times 10^{-4}$
6.06	9	* 6.8	9	3.05	+ 3.01	13.0	+ 13°07'	13.0	7.3	3.3	1.60
7.50	"	* "	"	"	+ 4.45	19.6	+ 12°46'	19.6	8.2	3.1	1.80
7.90	"	* "	"	"	+ 4.85	26.5	+ 10°26'	26.5	19.7	5.9	3.60
0	0	0									
2.30	3	2.28	0.35	1.93	+ 0.37	7.1	+ 2°59'	7.1	$10.4 \times 10^{-4}$	$3.4 \times 10^{-4}$	$0.56 \times 10^{-4}$
4.04	7	5.3	9	1.55	+ 2.49	13.9	+ 10°19'	13.8	7.3	2.1	1.30
5.56	8	6.1	"	2.35	+ 3.21	20.0	+ 9°12'	19.9	7.7	2.2	1.25
6.70	9	6.8	"	3.05	+ 3.65	26.0	+ 6°33'	25.9	15.8	4.1	2.23
0	0	0									
1.40	3	2.28	0.35	1.93	- 0.53	6.5	- 4°36'	6.5	$9.7 \times 10^{-4}$	$2.3 \times 10^{-4}$	$0.81 \times 10^{-4}$
2.70	5	3.8	9	0.05	+ 2.65	21.7	+ 12°02'	12.5	6.4	1.4	1.40
4.05	7	5.3	"	1.55	+ 2.50	19.8	+ 7°18'	19.6	7.8	1.6	1.00
5.30	"	"	"	"	+ 3.75	26.5	+ 8°03'	26.5	18.7	3.8	2.66

under the water.

velocity and the projected-area of the deformation varies linealy, the equation is obtained,

$$S=S_0(1-kV) \dots\dots\dots(a)$$

The coefficient of deformation  $k$  is calculated from the experimental data. Then the results, or  $k$  concerning each net are shown in Table II and III. Fig. 8 and 9 are representative ones.



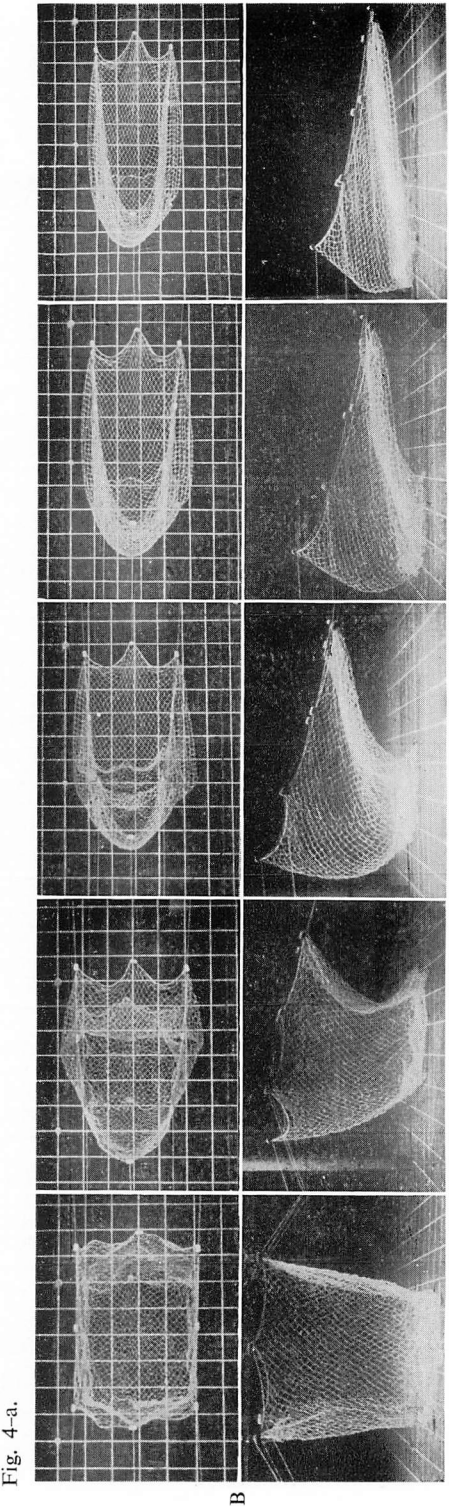
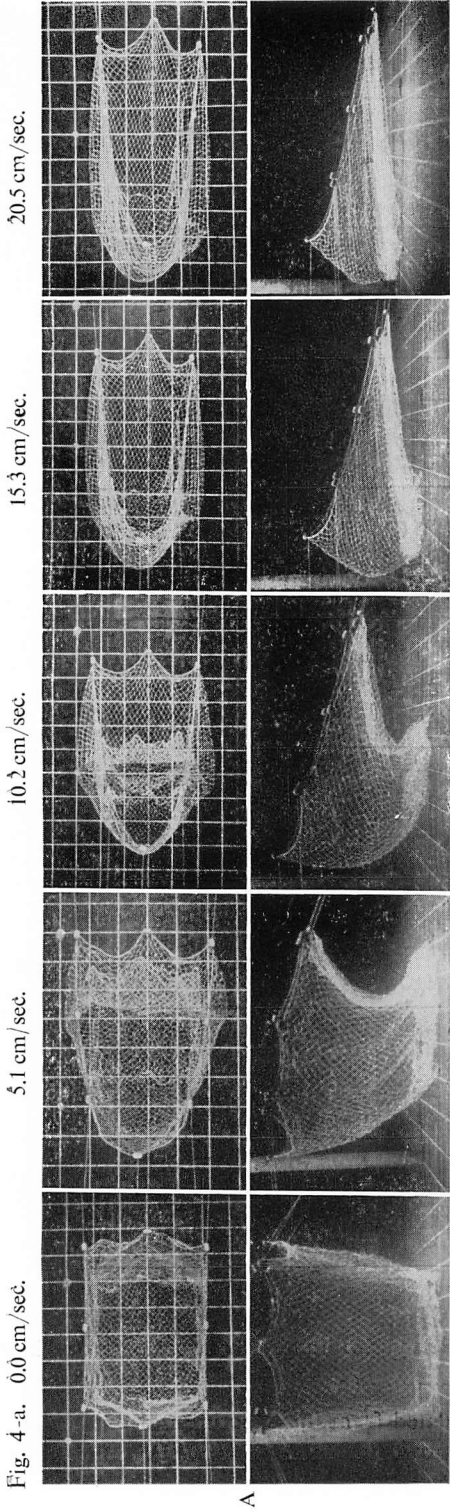


Fig. 4-a.

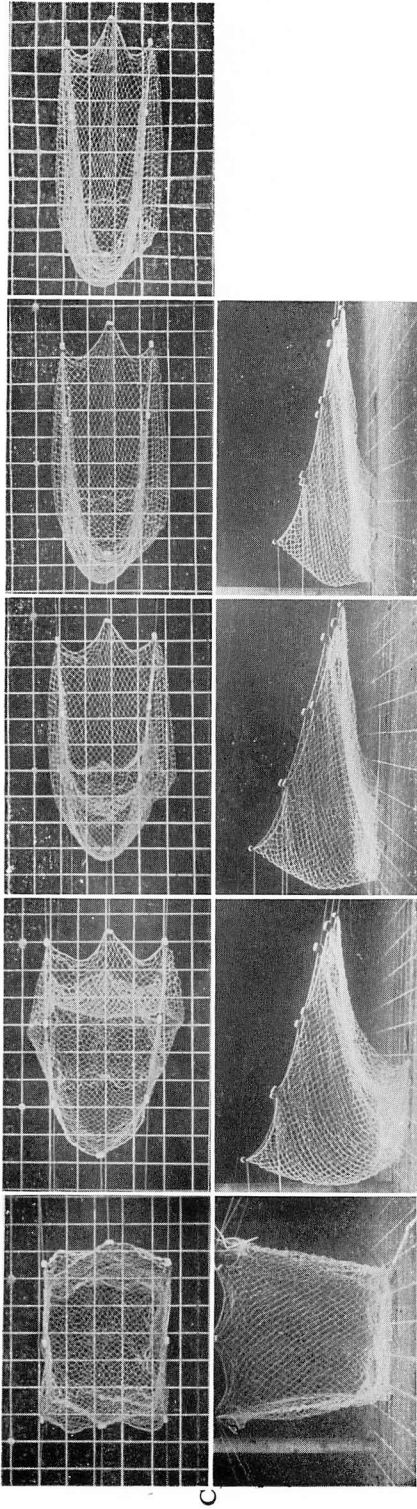


Fig. 4-a. Deformation of Square-Net characterized by the Current velocity (cm/sec).  $B/W=1/2$ , Depth=30 cm, Length of sand-bag rope of Net,  $A=60$  cm, that of  $B=90$  cm, that of  $C=120$  cm.

Fig. 4-b.

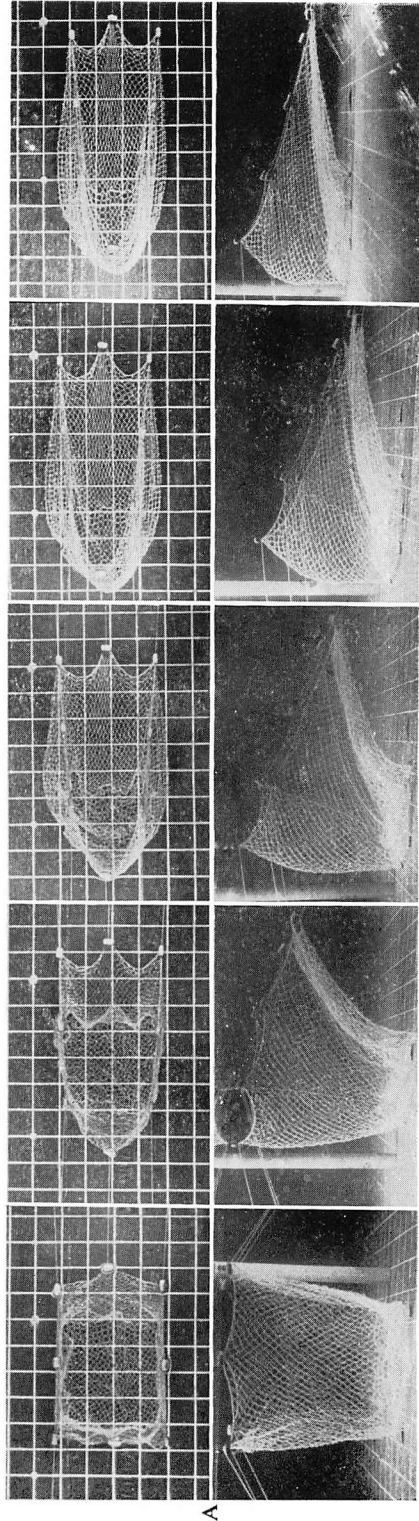




Fig. 4-b.

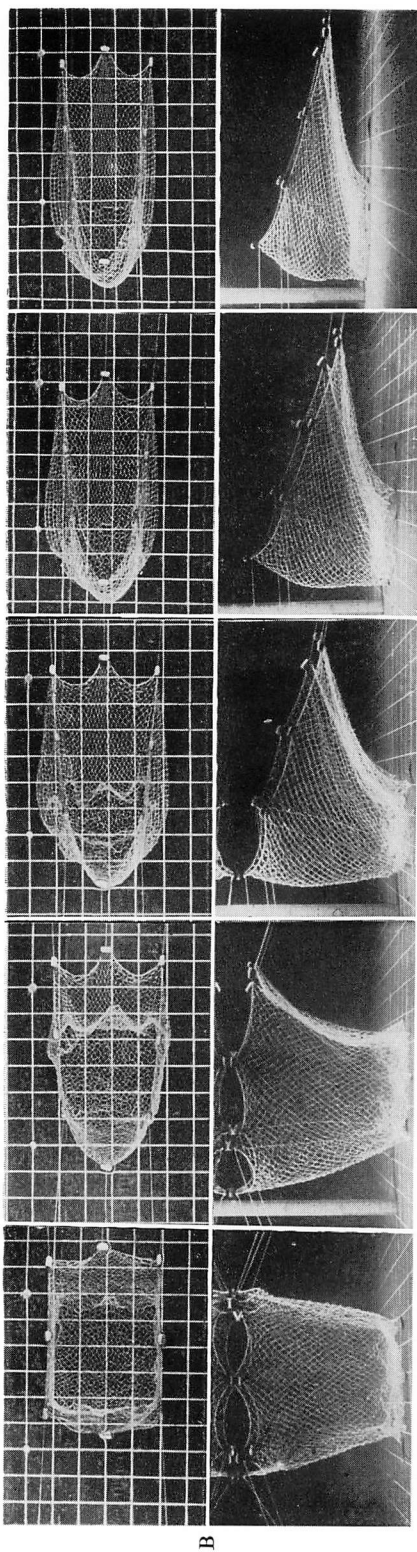


Fig. 4-b.

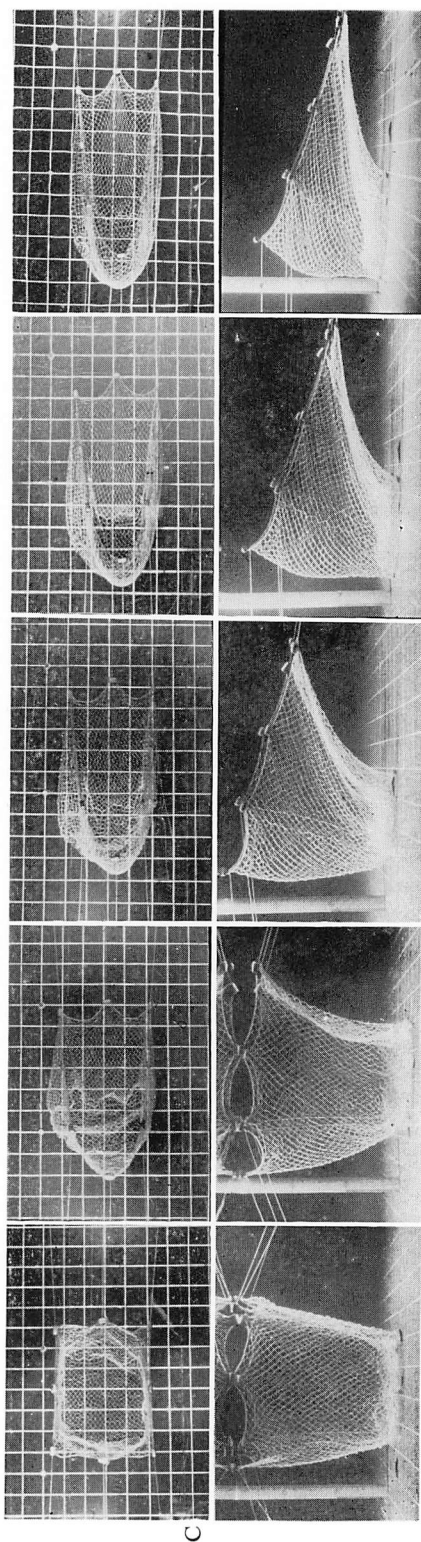


Fig. 4-b. Deformation of Square-Net characterized by the Current velocity (cm/sec).  $B/W=1/1$ , Depth=30cm,  
Length of sand-bag rope of Net,  $A=60$  cm. that of  $B=90$  cm. that of  $C=120$  cm.

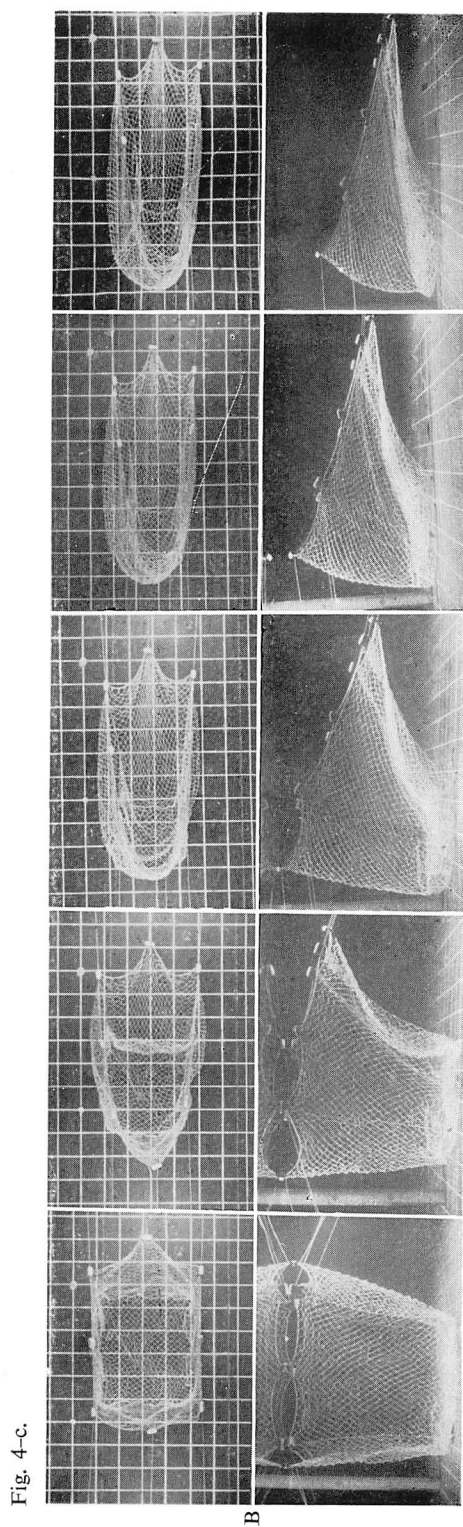
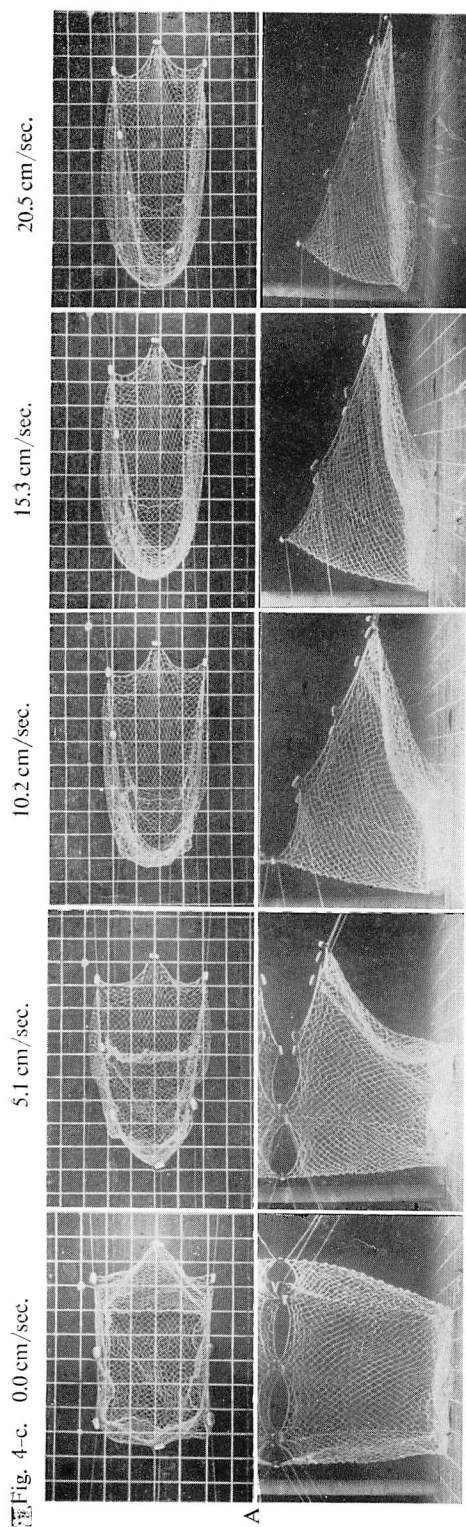




Fig. 4-c.

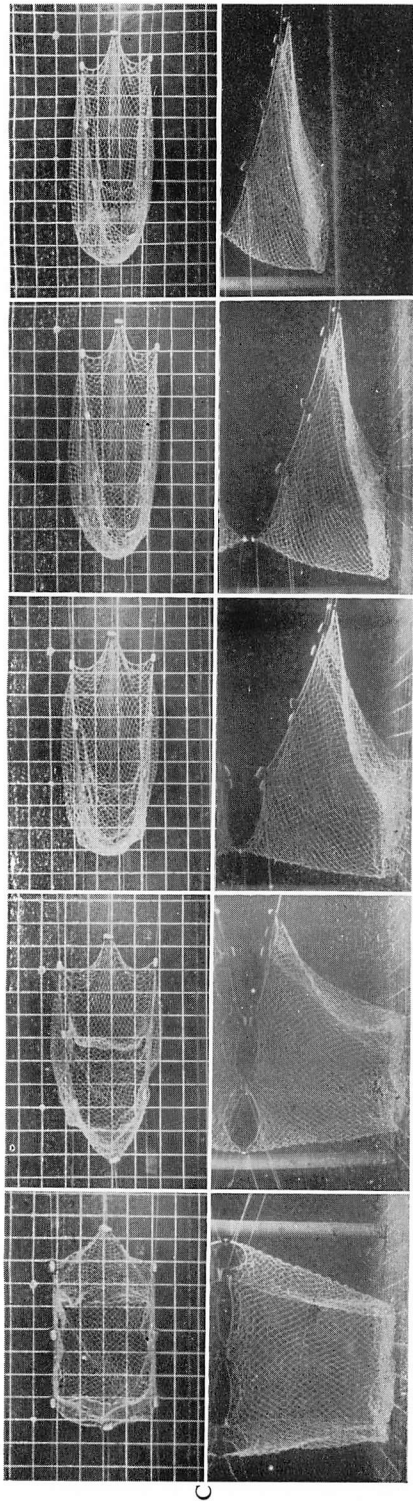
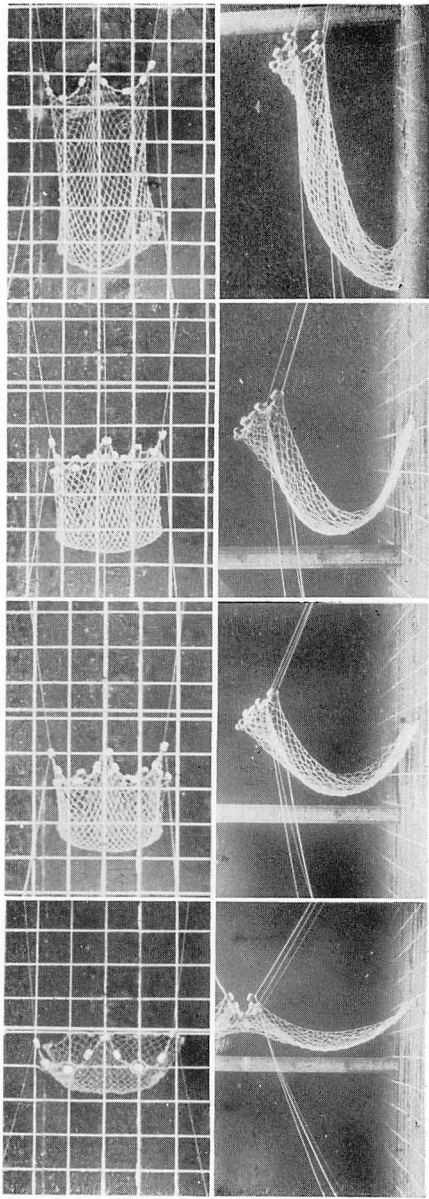


Fig. 4-c. Deformation of Square-Net characterized by the Current velocity (cm/sec).  $B/W=2/1$ , Depth=30 cm, Length of sand-bag rope of Net, A=60 cm. that of B=90 cm. that of C=120 cm.

Fig. 5-a. 0.0 cm/sec.



A

Fig. 5-a.

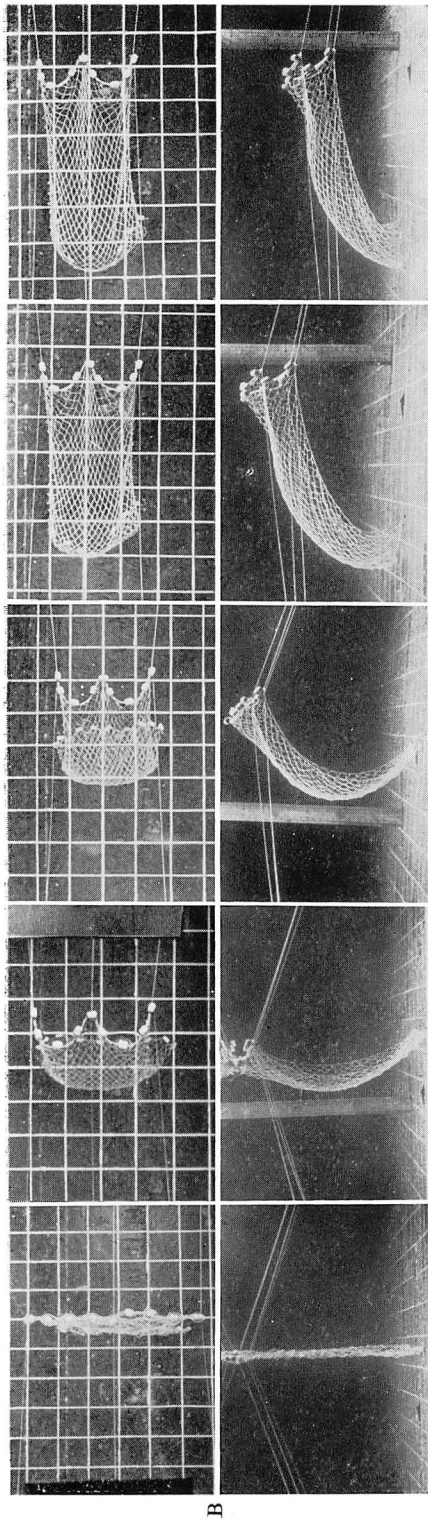


Fig 5-a.

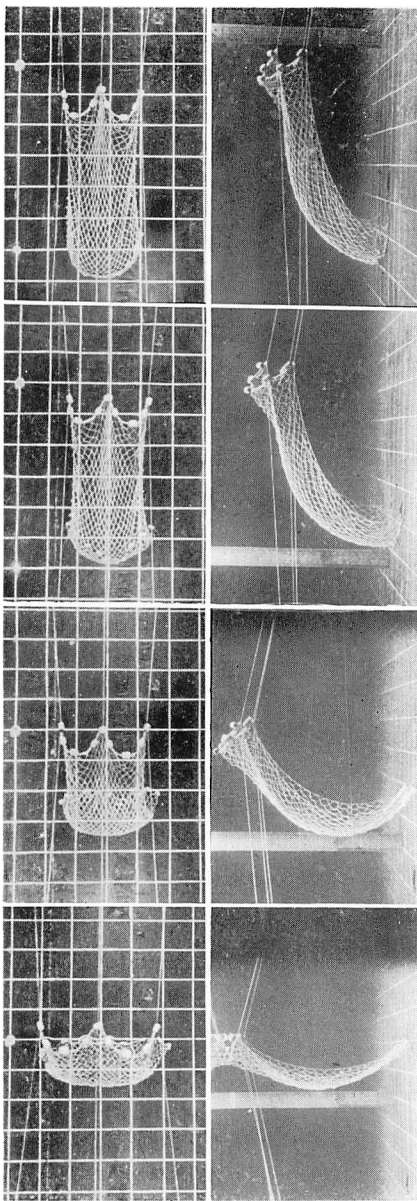


Fig. 5-a. Deformation of Flat-Net characterized by the Current velocity (cm/sec).  $B/W=1/2$ , Depth=30 cm, Length of sand-bag rope of Net,  $A=60$  cm. that of  $C=120$  cm.



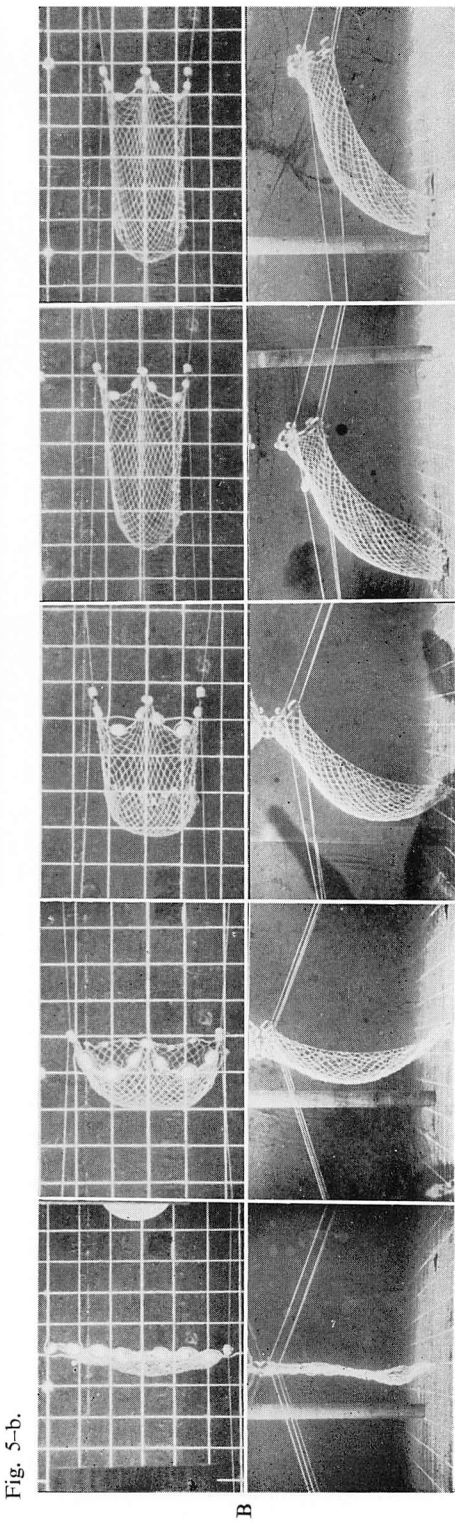
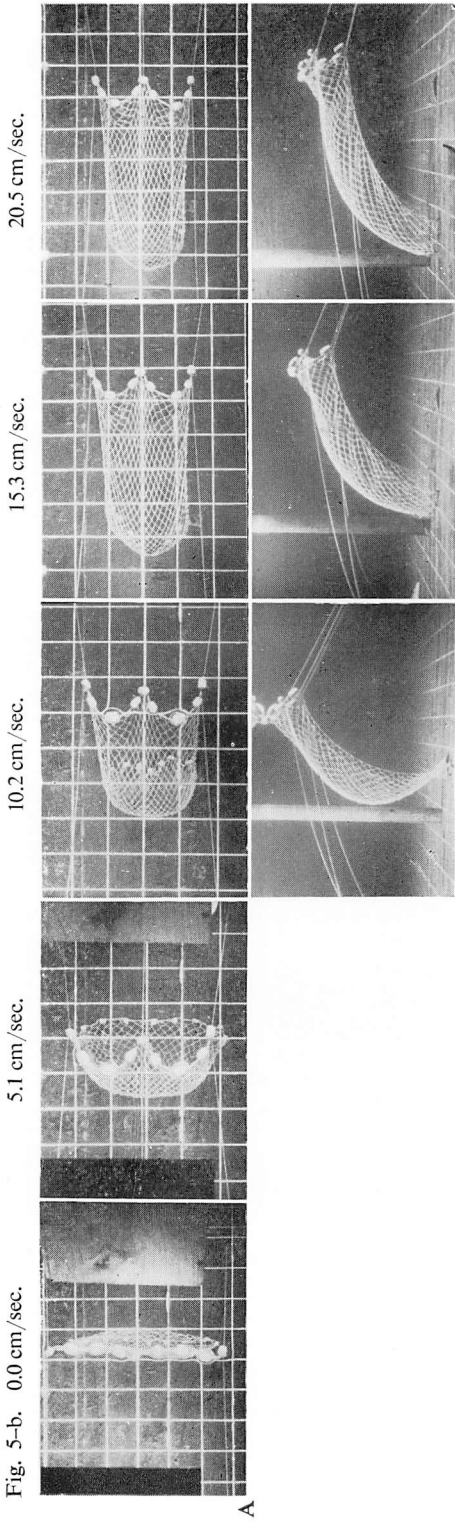


Fig. 5-b.

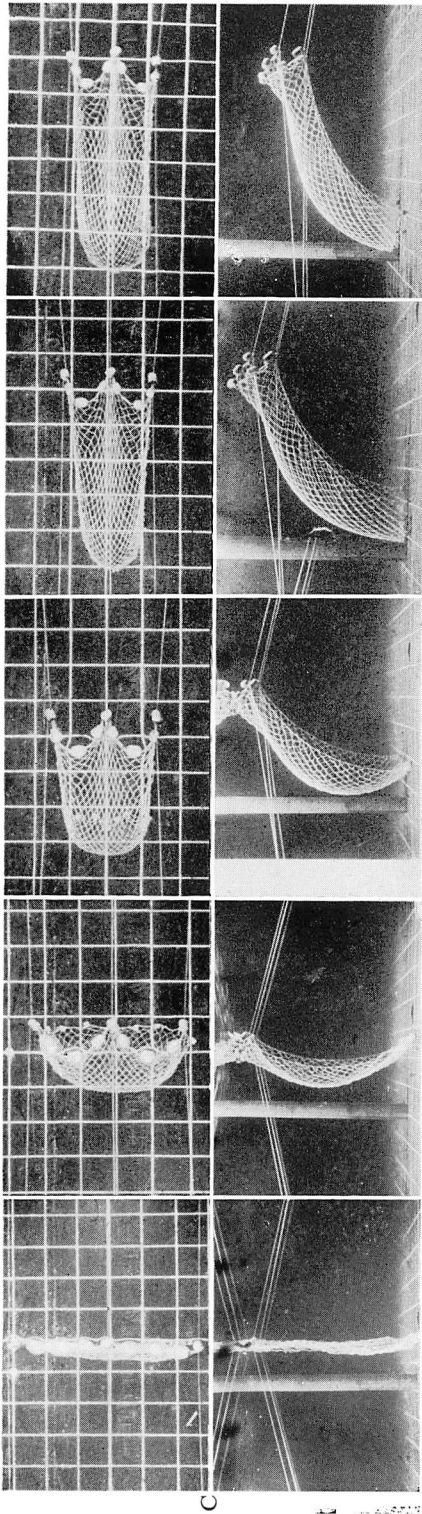
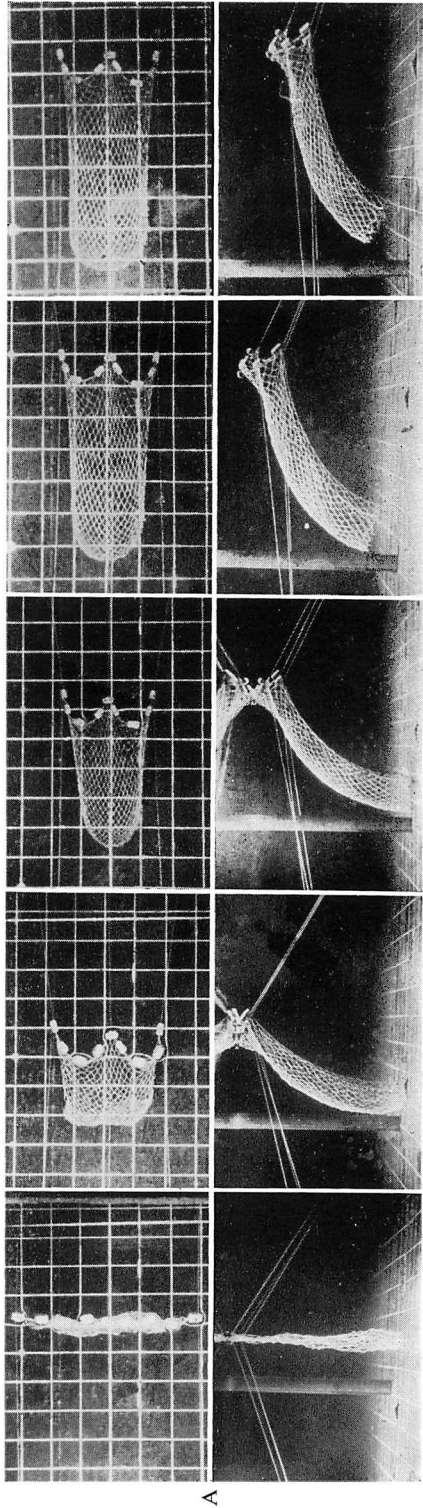


Fig. 5-b. Deformation of Flat-Net characterized by the Current velocity (cm/sec).  $B/W=1/1$ , Depth=30 cm, Length of sand-bag rope of Net,  $A=60$  cm, that of  $B=90$  cm, that of  $C=120$  cm.

Fig. 5-c.



0.0 cm/sec.

5.1 cm/sec.

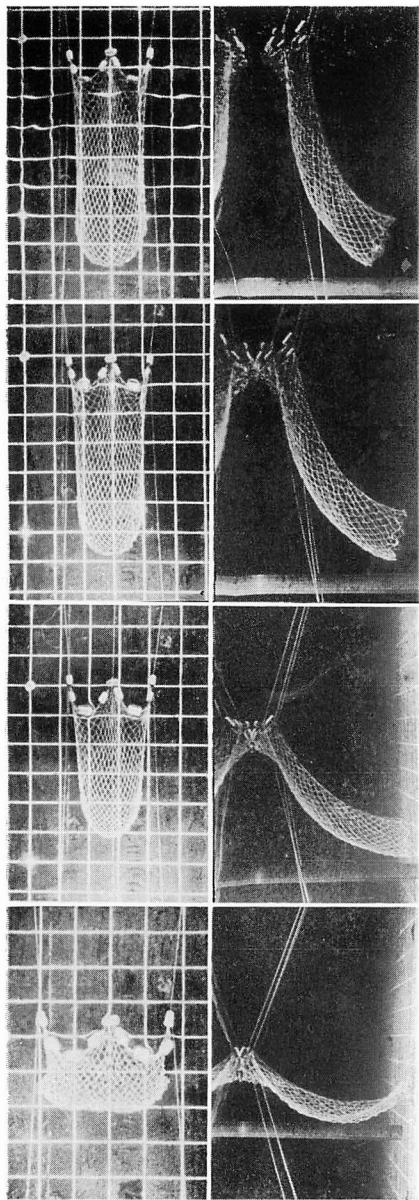
10.2 cm/sec.

15.3 cm/sec.

20.5 cm/sec.

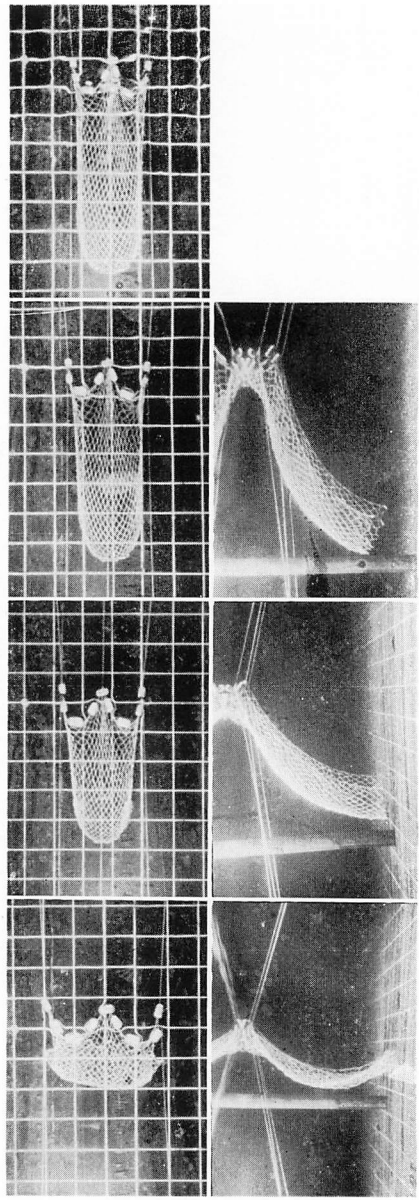


Fig. 5-c.



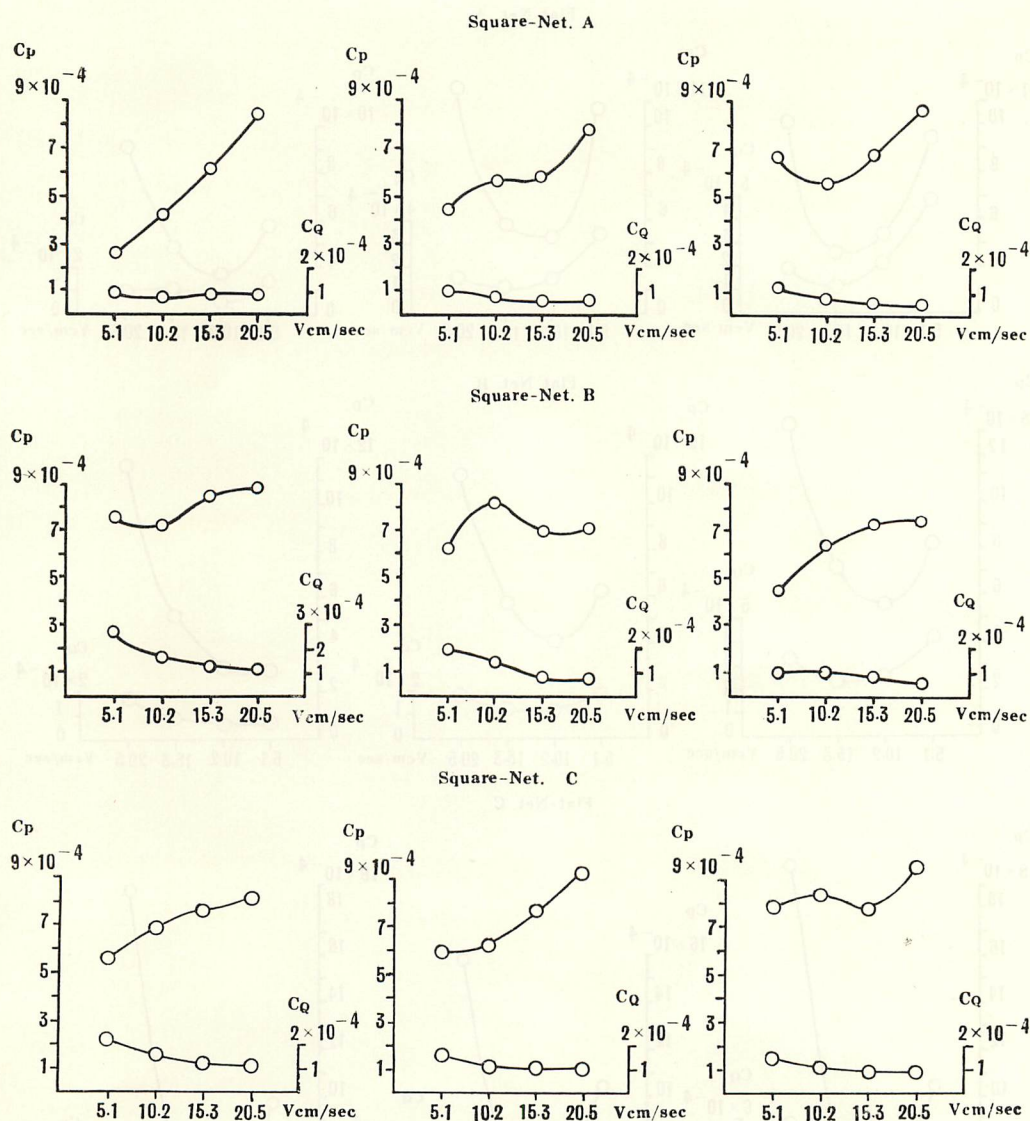
B

Fig. 5-c.



C

Fig. 5-c. Deformation of Flat-Net characterized by the Current velocity (cm/sec).  $B/W=2/1$ , Depth=30 cm, Length of sand-bag rope of Net, A=60 cm, that of B=90 cm, that of C=120 cm.

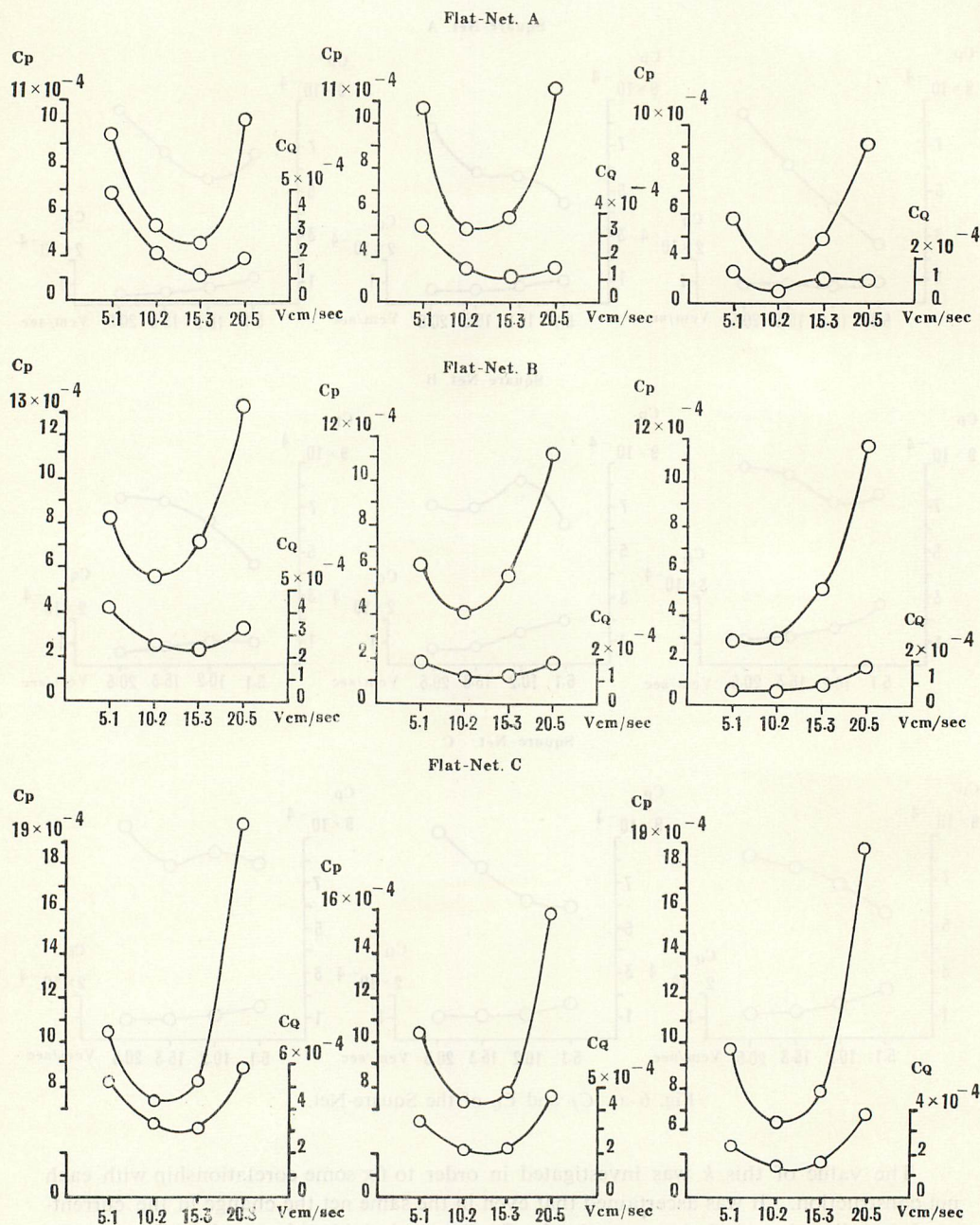

Fig. 6-a.  $C_p$  and  $C_q$  of the Square-Net.

The value of this  $k$  was investigated in order to fix some corelationship with each net-construction. It was ascertained that even in the same net the change in the current-receiving direction, and the range in the floating and sinking force of the floaters and sinkers have some effects on the variation of  $k$  (Refer, each Net in Table II).

In short, in the same net,  $k$  is constant in spite of the variation in the current velocity  $V$ . But in the case when net-shape changes in accordance with the current direction,  $k$  as deformation coefficient changes also.

The experiments show that, even if the direction in which the net is brought to confront to the running water-current changes,  $k$  is within the range of 0.01~0.09,



Fig. 6-b.  $C_P$  and  $C_Q$  of the Flat-Net.

According to the frequency distribution, as shown in Table V, both in 0.035 and in 0.025 the frequency remains the same, in 0.045 comes the next one. Therefore, the range of  $k$  is about 0.025~0.045, (provided that the current velocity is in or less than 18.0 cm/sec) and the mean value of  $k$  is determined to be 0.037.

Table IV. Dragging force to the Sinker-site.

Characteristics of Flat-Net	Velocity cm/sec	Force acting on the sand- bag rope gr	Force acting on the sinker-site R'			Vertical dis- tance of buoy- site from the bottom H cm	$\sin^{-1}(\frac{H}{l})$	Condition
			Left gr	Right gr	Total gr			
Buoyancy 3.4 gr	5.1	5.5	2.5	2.0	4.5	21.8	22° 0'	3 floaters sink completely, 6 floaters sink under water partially.
Under-water-weight 6.8 gr	10.2	13.5	2.5	2.0	4.5	16.5	17° 0'	All of the floaters sink completely under water. Sinkers remain attached to the bottom.
Height of Net 28.0 cm	15.3	23.5	3.5	2.0	5.5	11.5	11° 30'	Ibid.
Depth 22.5 cm	20.5	31.0	4.5	1.0	5.5	9.0	9° 15'	Sinkers are about to float.
Length of sand-bag rope l=56.0 cm	25.6	52.5	6.8	0.0	6.8	7.0	7° 30'	Sinkers begin to lift and lower themselves.
Buoyancy 6.8 gr	10.2	13.0	2.0	3.5	5.5	20.0	21°	
Under-water-weight 6.8 gr	15.3	26.0	3.0	2.8	5.8	16.5	17°	All the sinkers begin to lift, leaving only one sinker on the left side attached to the bottom.
Height of Net 28.0 cm	20.5	32.0	3.0	2.8	5.8	13.0	13°	All the sinkers, especially those on the right side begin to lift.
Depth 28.0 cm	25.6	40.0	6.0	2.8	8.8	11.0	11°	Ibid.
Length of sand-bag rope l=56.0 cm								



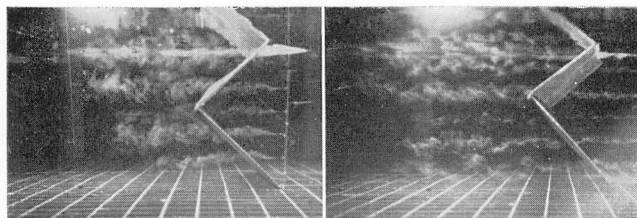
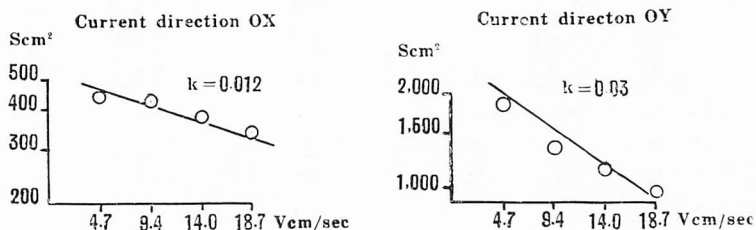
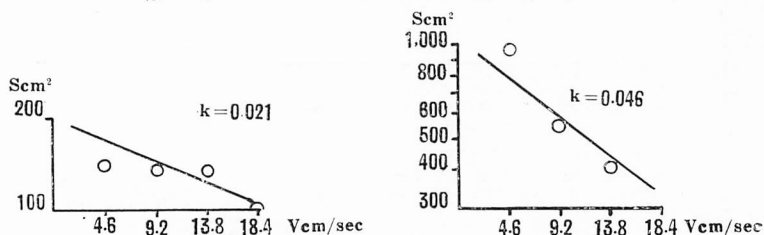


Fig. 7. Current through the Net.

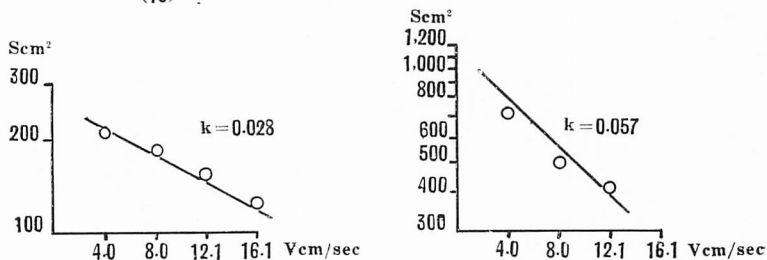
## (1) Soko-Hisago-Ami. (1-a)



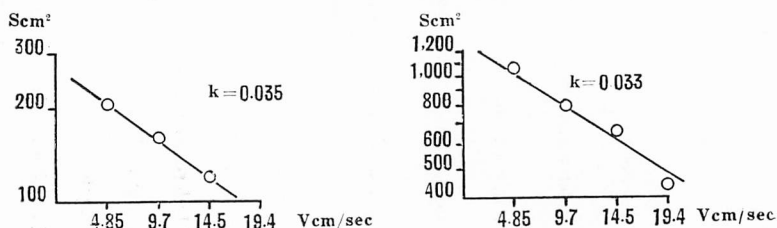
## (3) Improved Salmon Set-Net, B-Type (1-a)



## (10) Salmon Sea-Bottom Fixed-Net (2-b)



## (11) Yellow-tail Sea-Bottom Fixed-Net (2-b)

Fig. 8. The coefficient of deformation  $k$ .

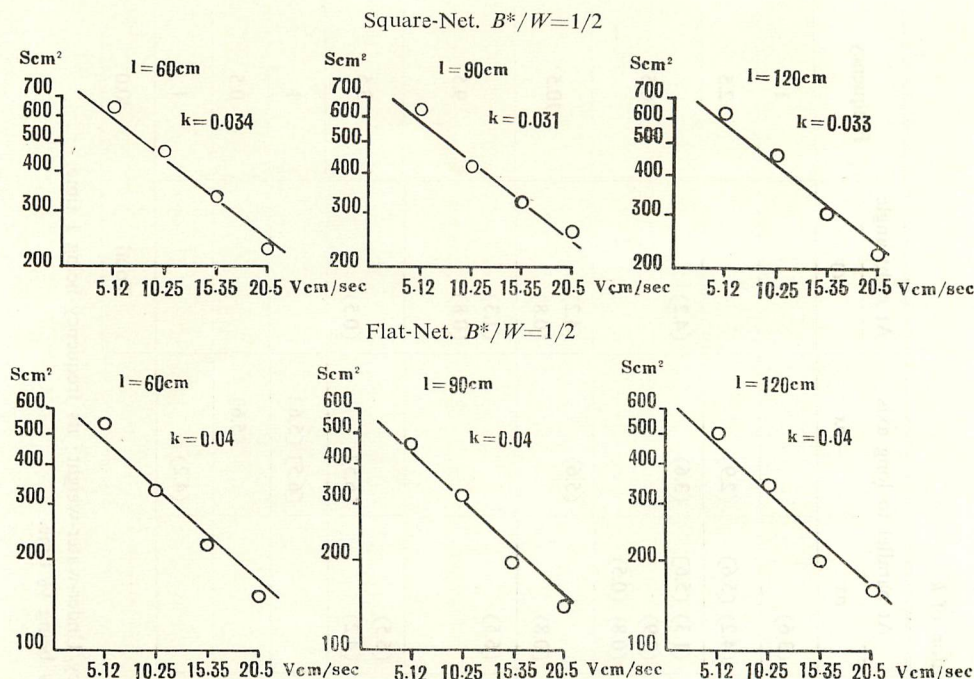


Fig. 9. The coefficient of deformation  $k$ .

(2) On the resistance coming from other factors than deformation

If the coefficient of deformation  $k$  in the fixed-net is defined as in the above mentioned paragraph, we get the general equation on the resistance

$$R = \frac{\rho}{2} S_0 (1 - kV) V^2 \Phi(Re, Fr, D/L) \dots\dots\dots (b)$$

As mentioned in Fig. 3, 4 and 5, the experimental result shows that net deformation and resistance are caused by the variation in the current-velocity. Besides the net itself, to the net-construction there are many accessories attached; floater, sinker, sand-bag ropes, and others, and the whole construction is fixed to the water-bottom by the sand-ropes tied with sand-bags. Accordingly, besides the net-deformation, such accessories as mentioned above and each combination of these factors, also bring about the resistance. Then it is quite natural to assume that in the equation (b),  $(1 - kV)$  is, as shown in formula (a), the element working upon the net-deformation as a whole. And  $\Phi(Re, Fr, D/L)$  is the factor which is to be derived from other factors than the deformation. Therefore, in case of the fixed-net, and when the current velocity  $V$  lies within 18.0 cm/sec, the author considers that  $\Phi(Re, Fr, D/L) = C$  (const.) is properly expressed; and then the current resistance comes to be expressed in the following equation

$$R = C \frac{\rho}{2} S_0 (1 - kV) V^2 \dots\dots\dots (b')$$

In the model experiment, as shown in Table II, III, the resistance acting on the whole net-body  $R$  is counted from the sum of the tension upon each sand-bag rope.

Then after resolving the resistance into the horizontal component  $P = R \cos \theta$  and the vertical component  $Q = R \sin \theta$ , the coefficient of these two component  $C_P$  and  $C_Q$  were counted. Of course, between these  $P$ ,  $Q$ ,  $C_P$  and  $C_Q$ , the following relationship is to exist.



Table V. Frequency distribution of  $k$ 

Coefficient of deformation <i>k</i>	Middle value	Square-Net	Flat-Net	Current direction Character- istics of Net	At parallel to long axis		At right angle <i>oy</i>	Frequency
					<i>ox</i>	— <i>ox</i>		
0.00 — 0.01	0.005			1—a	(3.6)			1
0.01 — 0.02	0.015			1—a	(4.2) [5.6]	(2.9)		2.5
0.02 — 0.03	0.025	(1.0) (1.0) (1.0) [2.0] [2.0] [2.0]		1—a	(1.3) [5.6]	(3.6)	(4.2)	10.5
				1—b 2—b	(2.9) (0.8) (0.5)			
0.03 — 0.04	0.035	(0.5) (0.5) (0.5) [2.0] [2.0] [2.0]	[0.5] [0.5] [0.5] [1.0] [1.0]	1—a	(0.8)	(5.6)	(4.2) (0.8)	10.5
				2—b				
0.04 — 0.05	0.045		[0.5] [0.5] [0.5] [1.0] [1.0] [1.0] (2.0) (2.0) (2.0)	1—a	(6.5)		(1.3) (0.8)	9.5
				2—b				
0.05 — 0.06	0.055			1—a	(6.5)		(0.5)	3.5
				2—b	(4.2)	[6.5]		
0.06 — 0.07	0.065			1—a		[6.5] [5.6]		1
0.07 — 0.08	0.075			1—a		[5.6]		0.5
0.08 — 0.09	0.085			1—a		(4.2)		1
Total								40.0

Note : Numerals in round brackets ( ) the show, Value of Buoyancy/Under-water-weight; its frequency being 1 time and those in crotchets [ ] show, the same one; its frequency being  $\frac{1}{2}$  time.

$$\text{Horizontal force } P = \frac{\rho}{2} S_0 (1 - kV) V^2 C_P$$

$$\text{Coefficient of the horizontal force } C_P = \frac{P}{(\frac{1}{2} \rho S V^2)}$$

$$\text{Vertical force } Q = \frac{\rho}{2} S_0 (1 - kV) V^2 C_Q$$

$$\text{Coefficient of the vertical force } C_Q = \frac{Q}{(\frac{1}{2} \rho S V^2)}$$

$$\text{Coefficient of the force } C = (C_P^2 + C_Q^2)^{1/2} \dots\dots\dots (c)$$

Now, according to the experiment the resistance coefficient  $C_P$  and  $C_Q$  as shown, in Table II and III, are in the range  $1.0 \times 10^{-4} \sim 21.0 \times 10^{-4}$  and  $0.5 \times 10^{-4} \sim 9.5 \times 10^{-4}$  respectively.

Although, even in the same net, these resistance coefficients are different in each current velocity, such variations as mentioned above are considered small enough to be neglected, and so, after counting the mean value fixed at each different current velocity, the results shown in Table VI and Fig. 10 are obtained.

Table VI. Average value of  $C_P$ ,  $C_Q$ , and  $C$

$V$ cm/sec	$C_P$	$C_Q$	$C$
5.1	$5.9 \times 10^{-4}$	$1.9 \times 10^{-4}$	$6.3 \times 10^{-4}$
10.2	4.9	1.7	6.6
15.3	5.8	1.3	5.9
20.5	7.6	2.7	10.4

Now,  $C$  in the above Table is the coefficient coming from the factors except the deformation of the net, and it is regarded to be nearly constant under the current velocity below about 18.0 cm/sec. And  $C$  is almost equal to  $C_P$ . In case of  $C_Q$ , as to be discussed later, as the buoyancy of the floater is involved in the vertical force,  $C_Q$  is not the lift-coefficient treated in the hydrodynamics.

$$\text{Hence, by using } R = C \frac{\rho}{2} S_0 (1 - kV) V^2,$$

the approximate value of the current resistance of any fixed-net at the given current velocity is to be counted easily.

### (3) Floating-and-sinking-phenomenon of the Sinker

Now,  $Q$  is the vertical component of the force to the sand-bag rope, and  $B$  the force got by reducing the weight of the sinker and the net in water from the buoyancy of the floater under water.

As to the relationship between  $Q$  and  $B$  there are two cases, viz. the one when  $Q$  is smaller than  $B$ , and the other when  $Q$  is larger than  $B$ . As to the former, at the section  $b$ , in the 12th line of Table III, it is denoted with \*;  $(Q - B)$  in the 15th line is negative.

The cause of such a phenomenon as this is assumed to be due to the deformation

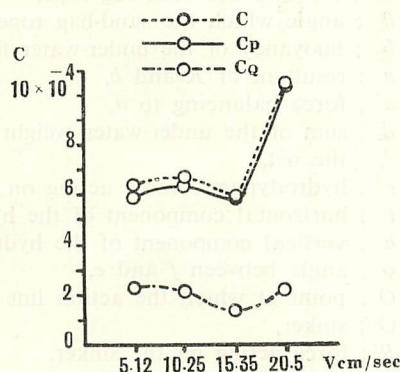


Fig. 10. Average value of  $C$ ,  $C_P$  and  $C_Q$ .







coefficient of horizontal resistance  $C_P$  is equal to the coefficient of horizontal component of the hydrodynamic force.

iii) The vertical component  $h$  of the hydrodynamic force, may be considered as the lift of the hydrodynamic force. This magnitude decreases when the current velocity increases. By the way, as  $C_Q$  is counted, basing on the vertical force acting on the sand-bag rope, so, it is not the so called the coefficient of the lift. But in the fixed-net the horizontal resistance is dominant, so, there may be not so much difference between  $C_Q$  and  $C_h$ , as shown in the 22nd line, Table III.

b) On  $B^*/W$  and the length of the sand-bag rope

Whether the net-foot detaches itself completely from the water-bottom or not is generally determined by whether  $(Q-B) = h$  is positive or negative. In the net where the ratio between floating power  $B^*$  and sinking power  $W$ , viz,  $B^*/W$  is equal to 2,  $h$  is positive. This may be described in another expression, namely the result of  $\chi^2$ -test on the flat-net  $C$  (Table III) is highly significant, and that of  $\chi^2$ -test on the square-net  $C$  is significant. When,  $h$  of the net, where the value of  $B^*/W$  is equal to 1 or 0.5, is negative, the net-foot remains attached to the water-bottom.

In short, from the above experimental results, the following may be described. When  $B^*/W$  is large, the net-foot detaches itself from the water-bottom easily. When  $B^*/W$  becomes small, the net-foot does not easily detach itself from the bottom, and the smaller becomes  $B^*/W$  the harder becomes the net-foot-detachment from the water-bottom.

Besides the value of  $B^*/W$ , the fact whether the net-foot detaches itself from the water-bottom or not has relationship with the length of the sand-bag rope, viz, the longer is the sand-bag rope the easier becomes the net-foot detachment from the water-bottom, as shown Fig. 4 and 5. In this experiment, when  $B^*/W=1$ , this is to be numerically observed as shown in the 13th line, Table III.

c) As shown in Table IV, while all the sinkers of the net-foot remain attached to the water-bottom, as to the resistance, in addition to the force to the sand-bag rope, there is a force to the net-foot, and so, the occasion when the net-foot remains attached to the water-bottom is now considered. In Fig. 11-b, the force  $R'$  to the sinkers, increases as the current velocity increases. (See Table IV). And the sum of the horizontal component of  $a'$  and that of  $r'$  is the horizontal component of the force acting on the net. When the net-foot remains attached to the water-bottom, the sinker is pressed downward. Then, it may be easily assumed that the vertical component of the resistance to the net-foot does not work to blow up the net-foot. And moreover, as stated above, whether the net-foot detaches itself from the water bottom or not has a relationship with the value of  $B^*/W$ . But in this experiment it is difficult to measure the angle which the net-foot makes with the horizontal line when the net-foot remains attached to the bottom in the running water. This difficulty may be due to the fact that the used tension pickup is larger than the sinker.

Then, in order to make any further research on the floating and sinking phenomenon of the net-foot, it seems to be necessary to make the experiment with the tension pickup reduced into minor type, and under the conditions in which the value of  $B^*/W$  is let to change variously.

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