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ON THE SIMILARITY LAW FOR FISHING NETS*

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그물漁具의 相似法則에 관하여*

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本研究에서는 그물漁具의 相似를 支配하는 無次元數 K를

$$K=\frac{\nu^n \rho_w v^{2-n}}{d^{1+n}(\rho-\rho_w)}$$

d, ρ: 材料의 直徑 및 密度

ν, ρ_w, v: 물의 動粘性係數, 密度 및 速度

으로 정하고, 여기에서의 直徑의 比를 결정하는 方法에 따라 實物과 模型과의 相似를 完全하게 그리고 近似的으로 만족시키는 條件들을 求하였다. 즉, 完全한 相似의 경우는 直徑의 比를 縮尺比와 같게 하고, 나아가서 다른 모든 치수의 比도 縮尺比와 같게 함으로써 만족된다고 하였으며, 近似的 相似의 경우는 直徑의 比가 縮尺比 $\left(\frac{\lambda_2}{\lambda_1}\right)$와 같지 않아도 된다고 하여, 그물실의 直徑 d, 코의 크기 l 및 콧수 N의 比를

$$\frac{d_2}{d_1}=\frac{l_2}{l_1}=\frac{\lambda_2}{\lambda_1}\cdot\frac{N_1}{N_2}$$

으로, 줄의 直徑 d', 길이 l' 및 密度 ρ'의 比를

$$\frac{d_2'}{d_1'}=\sqrt{\frac{\lambda_2}{\lambda_1}\cdot\frac{d_2}{d_1}\cdot\frac{(\rho_2-\rho_{w2})}{(\rho_1-\rho_{w1})}\cdot\frac{(\rho_1'-\rho_{w1})}{(\rho_2'-\rho_{w2})}}\,,\quad \frac{l_2'}{l_1'}=\frac{\lambda_2}{\lambda_1}$$

로, 부속구의 直徑 d'', 密度 ρ'' 및 數 N''의 比를

$$\frac{N_2''}{N_1''}=\left(\frac{\lambda_2}{\lambda_1}\right)^2\left(\frac{d_2}{d_1}\right)\left(\frac{d_1''}{d_2''}\right)\frac{(\rho_2-\rho_{w2})}{(\rho_1-\rho_{w1})}\frac{(\rho_1''-\rho_{w1})}{(\rho_2''-\rho_{w2})}$$

으로 정하였다. 이렇게 정해진 模型漁具에 대해 流速 v의 比는 $K_1=K_2$로부터

$$\left(\frac{v_2}{v_1}\right)^{2-n}=\left(\frac{\nu_2}{\nu_1}\right)^{-n}\left(\frac{\rho_{w1}}{\rho_{w2}}\right)\frac{(\rho_2-\rho_{w2})}{(\rho_1-\rho_{w1})}\left(\frac{d_2}{d_1}\right)^{1+n}$$

으로 주어지므로, 이를 이용하여 漁具抵抗 D 및 그물감의 다리에서의 張力 τ의 比를

$$\frac{D_2}{D_1}=\frac{d_2(\rho_2-\rho_{w2})}{d_1(\rho_1-\rho_{w1})}\left(\frac{\lambda_2}{\lambda_1}\right)^2$$

$$\frac{\tau_2}{\tau_1}=\frac{d_2 l_2(\rho_2-\rho_{w2})}{d_1 l_1(\rho_1-\rho_{w1})}\cdot\frac{\lambda_2}{\lambda_1}$$

로 정하였다.

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INTRODUCTION

The similarity law for fishing nets had been studied by Tauti[1], Dickson[2], Kawakami[3], Miyazaki[4], Fridman[5], etc., in which the most excellent application of the properties of fishing nets to the law was made by Tauti. He derived the law on the assumption that the forces acting on a segment of a net flexible perfectly are in equilibrium and the water resistance of the forces conforms to the Newton's law irrespective of the Reynolds' number. To this Tauti's law Kawakami added some extensions for ropes and accessaries. But the subsequent studies[6)-13] disclosed that the resistance of fishing nets is not proportional to the square of velocity. This means that the resistance is influenced by the Reynolds' number.

Thus, Miyazaki proposed a method for adding the influence of the Reynolds' number to the Tauti's law by using his experimental result that the water resistance of plane nettings situated perpendicularly to the water flow is in proportion to 1.7th power of the velocity.

However, the water resistance is not always in proportion to only 1.7th power of the velocity and varies according to the attitude of the nettings to the water flow[14]. This gives that the Miyazaki's method can not be applied to fishing nets taking a variety of attitude to the water flow. Therefore, the similarity law for fishing nets is newly derived here. In view of the case in which the selection of model materials for satisfying the law is impossible, an approximate similarity is also considered.

GROUND OF SIMILARITY

Fishing nets are so flexible in actual that their shape in water is determined mainly by the external forces, i.e., the water resistance and the apparent weight, acting on them. Hence, the segments of a fishing net, if employed in fishing, will be all subjected to the two forces. Supposing, as Tauti does, that the segments are set in water of a constant velocity or moving through water at a constant velocity, the water resistance and the apparent weight will equilibrate with the internal force or the tens ion occurred in the segments and at the same time the shape of the segments will be determined (Fig. 1). Therefore, equalizing the ratio between the water resistance and the apparent weight in all corresponding segments of the full-scale and the model net will give the ratio of the tension same in all the segments and make the shape of the corresponding segments similar.

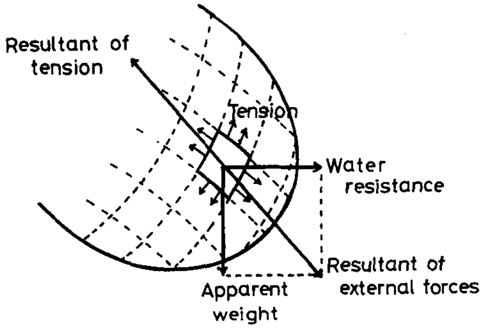

Fig. 1. Equilibrium of forces in the segment of fishing nets.

The water resistance D and the apparent weight W of the segment, its area S and volume V, may be given by

$$D=\frac{1}{2}C_D\,\rho_w\,S\,v^2 \qquad (1)$$

and

$$W=V(\rho-\rho_w), \qquad (2)$$

respectively, where C_D is the coefficient of resistance, ρ_w is the density of the water, v is the relative velocity of the segment to the water, and ρ is the density of the materials constituting the segment. The coefficient C_D, a function of the Reynolds' number, can be expressed as

$$C_D=a\left(\frac{dv}{\nu}\right)^{-n} \qquad (3)$$

not only in nettings[15], but also in ropes[13] and accessaries[16], where d is the diameter of the materials, ν is the kinematic viscosity of the water, and a and n are constants. The values of a and n are decided by the shape of the segments, i. e., in case of nettings by the ratio of the diameter d to the length l of a bar, the mesh-opening angle φ, and the angle θ to the water flow, and in case of ropes and accessaries by θ.[15)-17)] On the other hand, the volume V may be represented by

$$V=bdS, \qquad (4)$$

where b is a constant. Therefore, equation (1) and (2) may be rewritten as

$$D=\frac{a}{2}\left(\frac{dv}{\nu}\right)^{-n}\rho_w\, S\, v^2 \qquad (5)$$

and

$$W=bdS(\rho-\rho_w), \qquad (6)$$

respectively, and the dimensionless number K given by the ratio of D to W may be expressed as

$$K=\frac{\nu^n\ \rho_w\ v^{2-n}}{d^{1+n}(\rho-\rho_w)}, \qquad (7)$$

because the constants are neglected from the reason why the full-scale and the model net should be equal in values of d/l, φ and θ. Consequently, the similarity of the two nets will be made when they are equal in values of d/l, φ, θ, and K. The equality of K should be kept simultaneously in nettings, ropes, and accessaries, so that the ratio of d between the two nets should be equal in the three kinds of materials. But the ratio of d of ropes between the two nets is bound to equal the scale ratio, and so the ratios of d of nettings and accessaries should be also equal to the scale ratio. If this equalization is accomplished, a perfect similarity may be obtained. However, the equalization ascribes a great deal of difficulties in actual modeling and so often makes the model experiment impossible. But disregarding the severity in ropes, the ratio of d can be determined arbitrary irrespective of the scale ratio and the modeling becomes very easy. On the other hand, this method will invite a error due to the disagreement among the three kinds of meterials. It may be therefore desirable that the similarity of the full-scale and the model net is considered in the two cases as follows: the case in which the ratio of d between the two nets is equal to the scale ratio and the case not so. The former will be led to the perfect similarity and the latter to the approximate similarity.

PERFECT SIMILARITY

Now the full-scale and the model net are distinguished by the subscript 1 and 2. If the linear sizes of the two nets are given by λ_1 and λ_2, respectively, the ratio λ_2/λ_1 becomes the scale ratio and the square of the scale ratio becomes equal to the area ratio of the two nets. The area ratio should be equal in all corresponding segments. Thus giving the superscript "′" and "″" to ropes and accessaries in order to distinguish with nettings having no superscript, the following equation is obtained:

$$\frac{S_2}{S_1}=\frac{S_2'}{S_1'}=\frac{S_2''}{S_1''}=\left(\frac{\lambda_2}{\lambda_1}\right)^2, \qquad (8)$$

or

$$\frac{d_2l_2N_2^2}{d_1l_1N_1^2}=\frac{d_2'l_2'}{d_1'l_1'}=\frac{d_2''^2N_2''}{d_1''^2N_1''}=\left(\frac{\lambda_2}{\lambda_1}\right)^2 \qquad (9)$$

where d, l, and N are the diamenter of a bar twine, its length, and the number of meshes in breadth or length of nettings, d' and l' are the diameter and the length of ropes, and d'' and N'' are the diameter and the number of accessaries, respectively, in the segments. For the perfect similarity, the ratio of the diameter and so of the length should be equal to the scale ratio as mentioned above, i. e.,

$$\frac{d_2}{d_1}=\frac{l_2}{l_1}=\frac{d_2'}{d_1'}=\frac{l_2'}{l'_1}=\frac{d_2''}{d_1''}=\frac{\lambda_2}{\lambda_1}, \qquad (10)$$

so that

$$\left.\begin{aligned}\frac{d_1}{l_1}&=\frac{d_2}{l_2}\\ \varphi_1&=\varphi_2\\ N_1&=N_2\\ N_1''&=N_2''\end{aligned}\right\}. \qquad (11)$$

Simultaneously, the value of the dimensionless number K should be equal in the two nets, i. e.,

$$K_1=K_2 \qquad (12)$$

or

$$\left(\frac{v_2}{v_1}\right)^{2-n}=\left(\frac{\nu_2}{\nu_1}\right)^{-n}\cdot\left(\frac{\rho_{w1}}{\rho_{w2}}\right)\frac{(\rho_2-\rho_{w2})}{(\rho_1-\rho_{w1})}\cdot\left(\frac{\lambda_2}{\lambda_1}\right)^{1+n}. \qquad (13)$$

If this equation is satisfied, $\theta_1=\theta_2$ will be done simultaneously. But the equation should be satisfied not only in nettings, but also in ropes and accessaries. Thus, the following equation should be satisfied:

$$\frac{(\rho_2-\rho_{w2})}{(\rho_1-\rho_{w1})}=\frac{(\rho_2'-\rho_{w2})}{(\rho_1'-\rho_{w1})}=\frac{(\rho_2''-\rho_{w2})}{(\rho_1''-\rho_{w1})}. \tag{14}$$

When the two nets are in relation as mentioned above, the ratio D_2/D_1 of the water resistance between them may be in the form:

$$\frac{D_2}{D_1}=\left(\frac{\nu_2}{\nu_1}\right)^n\left(\frac{\rho_{w2}}{\rho_{w1}}\right)\left(\frac{\lambda_2}{\lambda_1}\right)^{2-n}\left(\frac{v_2}{v_1}\right)^{2-n}$$

$$=\frac{(\rho_2-\rho_{w2})}{(\rho_1-\rho_{w1})}\left(\frac{\lambda_2}{\lambda_1}\right)^3 \tag{15}$$

from the equation (5), (10), and (13), and this ratio should be equal to the weight ratio W_2/W_1 and the tension ratio T_2/T_1, respectively. That is,

$$\frac{D_2}{D_1}=\frac{W_2}{W_1}=\frac{T_2}{T_1}. \tag{16}$$

or

$$\frac{(\rho_2-\rho_{w2})}{(\rho_1-\rho_{w1})}\left(\frac{\lambda_2}{\lambda_1}\right)^3=\frac{N_2\tau_2(\cos\varphi_2+\sin\varphi_2)}{N_1\tau_1(\cos\varphi_1+\sin\varphi_1)} \tag{17}$$

from Fig. 2. Substituting $N_1=N_2$ and $\varphi_1=\varphi_2$, the ratio τ_2/τ_1 of the tension in a bar becomes

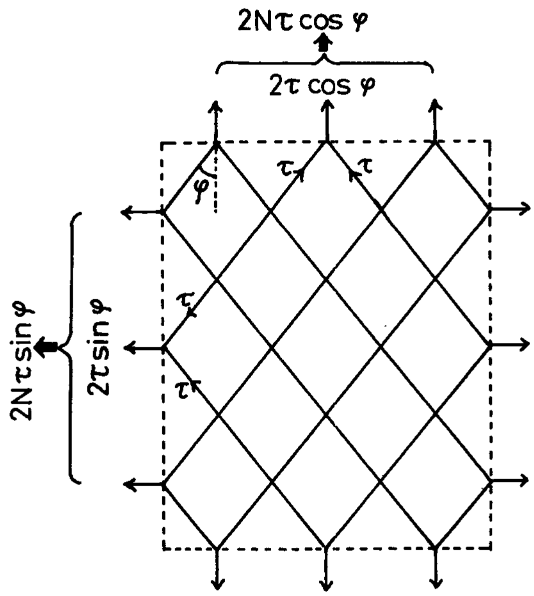

Fig. 2. Tension in the netting segment.

$$\frac{\tau_2}{\tau_1}=\frac{(\rho_2-\rho_{w2})}{(\rho_1-\rho_{w1})}\left(\frac{\lambda_2}{\lambda_1}\right)^3. \tag{18}$$

In case in which the net shape is changed with time t, the ratio t_2/t_1 may be in the form:

$$\frac{t_2}{t_1}=\frac{\lambda_1}{\lambda_2}\cdot\frac{v_2}{v_1}$$

$$=\frac{\lambda_1}{\lambda_2}\left\{\left(\frac{\nu_2}{\nu_1}\right)^{-n}\left(\frac{\rho_{w1}}{\rho_{w2}}\right)\frac{(\rho_2-\rho_{w2})}{(\rho_1-\rho_{w1})}\left(\frac{\lambda_2}{\lambda_1}\right)^{1+n}\right\}^{\frac{1}{2-n}}. \tag{19}$$

These results mentioned above may be regarded to be perfect conditions for the similarity. If these conditions are not satisfied although in a small measure, the similarity will not be obtained. Hence, the practical procedure of the model experiment may be ordered as follows:

1) First determine the scale ratio λ_2/λ_1.

2) Next determine the densities ρ, ρ', and ρ'' of the model materials by equation (14) and equalize the ratios of their sizes to the scale ratio λ_2/λ_1 as shown in equation (10).

3) Test the resistance D_2 and investigate the value of n_2 from

$$D_2 \propto v_2^{2-n_2}$$

4) If n_2 is obtained ($n_1=n_2\equiv n$), calculate the velocity ratio v_2/v_1 by equation (13).

5) Convert the resistance D and the tension τ of a bar from the model to the full-scale by equation (15) and (18).

6) In case in which the net shape is changed with time t, determine the time ratio t_2/t_1 by equation (19).

APPROXIMATE SIMILARITY

The necessity of the approximate similarity is due mainly to the difficulties of equalizing the ratio of the diameter of materials to the scale ratio or satisfying equation (10). However considering only nettings among the three kinds of materials, the ratio of the diameter of netting twines between the full-scale and the model net can be determined arbitrary irrespective of the scale ratio. That is, taking out only

$$\frac{l_2N_2}{l_1N_1}=\frac{\lambda_2}{\lambda_1} \tag{20}$$

from equation (9) and permitting $N_1 \neq N_2$, it is obtained that

$$\frac{d_2}{d_1}=\frac{l_2}{l_1}=\frac{\lambda_2}{\lambda_1}\cdot\frac{N_1}{N_2} \tag{21}$$

and then $d_1/l_1=d_2/l_2$ and $\varphi_1=\varphi_2$ are satisfied. Thus, $K_1=K_2$ becomes

$$\left(\frac{v_2}{v_1}\right)^{2-n}=\left(\frac{\nu_2}{\nu_1}\right)^{-n}\left(\frac{\rho_{w1}}{\rho_{w2}}\right)\frac{(\rho_2-\rho_{w2})}{(\rho_1-\rho_{w1})}\left(\frac{d_2}{d_1}\right)^{1+n}. \tag{22}$$

This equation can not be applied simultaneously to ropes and accessaries because of the dissatisfaction of equation (10). However, the main function of ropes and accessaries in fishing nets is not in resistance, but in weight, and their resistance is significantly small in comparison with the resistance of the nettings constituting the main body of fishing nets. Therefore satisfying

$$\frac{W_2}{W_1}=\frac{W_2'}{W_1'}=\frac{W_2''}{W_1''} \tag{23}$$

or

$$\frac{d_2^2 l_2 N_2^2(\rho_2-\rho_{w2})}{d_1^2 l_1 N_1^2(\rho_1-\rho_{w1})}=\frac{d_2'^2 l_2'(\rho_2'-\rho_{w2})}{d_1'^2 l_1'(\rho_1'-\rho_{w1})}=\frac{d_2''^3 N_2''(\rho_2''-\rho_{w2})}{d_1''^3 N_1''(\rho_1''-\rho_{w1})} \tag{24}$$

and disregarding the error in resistance will not invite so significant difference. Thus, the following equations are obtained:

$$\frac{l_2'}{l_1'}=\frac{\lambda_2}{\lambda_1}, \tag{25}$$

$$\frac{d_2'}{d_1'}=\sqrt{\frac{\lambda_2}{\lambda_1}\frac{d_2}{d_1}\frac{(\rho_2-\rho_{w2})}{(\rho_1-\rho_{w1})}\frac{(\rho_1'-\rho_{w1})}{(\rho_2'-\rho_{w2})}}, \tag{26}$$

and

$$\frac{N_2''}{N_1''}=\left(\frac{\lambda_2}{\lambda_1}\right)^2\left(\frac{d_2}{d_1}\right)\left(\frac{d_1''}{d_2''}\right)^3\frac{(\rho_2-\rho_{w2})}{(\rho_1-\rho_{w1})}\frac{(\rho_1''-\rho_{w1})}{(\rho_2''-\rho_{w2})}. \tag{27}$$

When the full-scale and the model net are in relation as mentioned above, the resistance ratio D_2/D_1, the tension ratio τ_2/τ_1, and the time ratio t_2/t_1 may be given by

$$\frac{D_2}{D_1}=\left(\frac{\nu_2}{\nu_1}\right)^n\left(\frac{\rho_{w2}}{\rho_{w1}}\right)\left(\frac{d_2}{d_1}\right)^{-n}\left(\frac{\lambda_2}{\lambda_1}\right)^2\left(\frac{v_2}{v_1}\right)^{2-n}=\frac{d_2(\rho_2-\rho_{w2})}{d_1(\rho_1-\rho_{w1})}\left(\frac{\lambda_2}{\lambda_1}\right)^2, \tag{28}$$

$$\frac{\tau_2}{\tau_1}=\frac{d_2(\rho_2-\rho_{w2})}{d_1(\rho_1-\rho_{w1})}\left(\frac{\lambda_2}{\lambda_1}\right)^2\frac{N_1(\cos\varphi_1+\sin\varphi_1)}{N_2(\cos\varphi_2+\sin\varphi_2)}=\frac{d_2 l_2(\rho_2-\rho_{w2})}{d_1 l_1(\rho_1-\rho_{w1})}\frac{\lambda_2}{\lambda_1}, \tag{29}$$

and

$$\frac{t_2}{t_1}=\frac{\lambda_1}{\lambda_2}\frac{v_2}{v_1}=\frac{\lambda_1}{\lambda_2}\left\{\left(\frac{\nu_2}{\nu_1}\right)^{-n}\left(\frac{\rho_{w1}}{\rho_{w2}}\right)\frac{(\rho_2-\rho_{w2})}{(\rho_1-\rho_{w1})}\left(\frac{d_2}{d_1}\right)^{1+n}\right\}^{\frac{1}{2-n}}. \tag{30}$$

Summarizing these results will give the practical procedure of the approximate model experiment as follows:

1) Determine the scale ratio λ_2/λ_1.

2) Determine the fiber material or the density ρ of netting twines arbitrary and then their diameter d, the mesh size l, and the mesh number N by equation (21).

3) Determine the diameter d', the length l', and the density ρ' of ropes by equation (25) and (26).

4) Determine the diameter d'', the density ρ'', and the number N'' of accessaries by equation (27).

5) Test the resistance D_2 and investigate the value of n_2 from

$D_2 \propto v_2^{2-n_2}$.

6) If n_2 is obtained ($n_1=n_2\equiv n$), calculate the velocity ratio v_2/v_1 by equation (22).

7) Convert the resistance D and the tension τ from the model to the full-scale by equation (28) and (29).

8) In case in which the net shape is changed with time t, determine the time ratio t_2/t_1 by equation (30).

The approximate modeling by these procedure will always produce a error. The error is due to the disagreement of ropes and accessaries with nettings, but the disagreement is in principle ascribed to the difficulty of equalizing the diameter ratio of netting twines to the scale ratio. If the scale ratio is selected larger, the above equalization will become easier and the error occurred owing to ropes and accessaries will become smaller. Consequently, the error may be larger in smaller scale ratio. However, there are no sufficient data on the scale effect. It may be therefore desirable that the scale ratio is selected largily so far as circumstances permit.

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