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Geometry of the Model Purse Seine in Relation to Enclosed Volume during Hauling Operation

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Model experiments for a purse seine were carried out in order to measure the geometry of net shape and to estimate an enclosed volume by using 1/77 scale model purse seine of 12.62 m float line from an offshore mackerel purse seine. A model purse seine was set from a net box of shooting equipments and then pursing and hauling net by hauling equipment. The 3-D geometry shape of the purse seine net during hauling operation was measured by video image processing and tension of purse line by load cell. The 3-D geometry of the model purse seine during hauling operation could be represented with variables such as a ratio of shooting diameter or maximum net depth and a ratio of hauling operation time. Horizontal shapes of float line and lead line were varied from a circle after shooting to an ellipse with pursing and hauling. Projected lateral shape of purse line was observed and formulated as a shape of a water drop. The cross sectional shapes of curved net from two directions were varied such as sine function or polynomial curves. Therefore, enclosed volume of a purse seine in relation to fish school behaviour can be approximated using two main variables from relevant equations.

Key words: model purse seine, hauling, 3-D geometry, enclosed volume

Introduction

A purse seine is a wall of netting equipped with purse rings along its lower edge and purse line passing through the purse rings to close off the space surrounded by the purse seine from below. Thus, a bowl-like net space is created in which fish school is enclosed and prevented from escaping. The design of a purse seine must be based on the relationship among the size of the fish school and the size of the net, the distance at which the fish can detect the purse seine under environmental conditions of fishing ground. The main points for successful operation are net configuration of surrounded wall and behaviour of fish school to purse seine from shooting to pursing as enclosed even until hauling.

Girenko (1957) has represented schematic plan view and lateral view of full scale purse seine without formulation. The partial net shape and tension of the purse line during pursing were investigated in field using commercial nets by Azvolinskii et al. (1975) and Ben-Yami (1994) and using a model purse seine by Inoue (1954), Iitaka (1956, 1958), Konagaya (1971), Liu et al. (1984), Shimozaki et al. (1988) and Park et al. (1999).

The responses of fish in relation to purse seine were observed in the field using full scale net by Misund (1992, 1993) and using model purse seine by Park et al. (1997). The relationship between performance of a purse seine and fishing capability was studied by Bag (1986), Bag et al. (1986), Kim and Huh (1987), Park (1991) and Misund et al. (1992).

Ben-Yami (1994) and Kim (1999) described the volume of a surrounded purse seine as cylinder after shooting until the end of pursing. However their approximations under assumption of the cylindrical shape is far from real shape even under static water condition. Therefore 3-dimensional geometry of net walls in action of a purse seine as by measurement or mathematical analysis is necessary to formulate space volume as a factor affects fish behaviour and to reach more successful catch. In addition, it also helps to understand the performance of a purse seine in relation to environmental conditions such as the gate phenomenon when pursing and together floats when hauling net as well as in concerning to the design of a purse seine.

The purposes of this study are to measure the shape of a model purse seine such as floats line and lead line, and curved net shape during hauling operation in relation to the 3-dimensional geometry in order to formulate performance of net and to approximate enclosed volume of a purse seine. The model experiments were carried out in the static water tank with shooting and hauling equipments using model purse seine from February to March, 2000.

Materials and Methods

The model purse seine adapted for water tank space was made as 1/77 scale net with length of float line 12.62 m as shown in Fig. 1 from an offshore mackerel purse seine as a prototype net with length of float line 972 m (National Fisheries Research & Development Agency, 1989) according to the similarity methods for fishing gear by Tauti (1934). The ratio of water flow in model experiment was 1/1.287 as using a ratio of netting twine diameter 1/2.108 from mean value of full scale net. Therefore, a ratio of force in the model experiment was 1/9,821 and a ratio of operating time was 1/60.

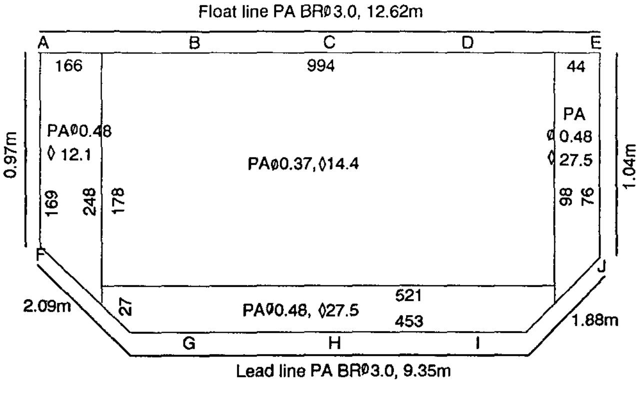

Fig. 1. Design of 1/77 model purse seine from a mackerel purse seine. The letters A through J were quarterly positioned in order to represent net geometry along with float line and lead line respectively.

Total 168 model floats of cylindrical foam plastic with diameter 2 cm, length 3.5 cm and buoyancy 4.85 g were attached to float line as total buoyancy 815 g. The aluminium chain 13.32 m as weight in water 240.2 g, 44 larger iron rings (ϕ 2.3 cm, weight 4.40 g) and 49 smaller rings (ϕ 1.3 cm, weight 1.88 g) were connected to 13.32 m lead line as total weight 526 g.

The experimental water tank made of iron was L 5.0×B 5.0×D 5.0 m (water depth 4.75 m) in the College of Marine Science, Tongyoung. The experimental shooting and hauling equipments (made by Dongwon Scientific System, Pusan) were set using iron frames on the water tank as shown in Fig. 2. The shooting equipment was consisted with an electric motor (M1) with a reduced gear and rotating beam as adjustable length 1.95 m attached net box L 37×B 36×D 21 cm. The hauling equipment above 0.4 m from water surface was consisted with an electric motor M2 with reduced pulley for

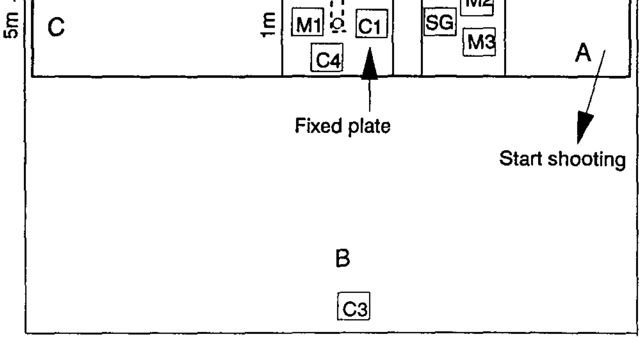

Fig. 2. A plan view of an experimental set-up with shooting and hauling equipment for a model purse seine (not to scale). M1 is motor and gear for shooting, M2 for pursing and M3 for hauling net, and C1 is an air video camera for plan view, C2 and C3 are underwater video cameras for lateral views and C4 for upper view from bottom of tank. The letters A, B, C, D and E are net tracks when shooting (refer to Fig. 1).

pursing and M3 for hauling net on the movable plate 1×1 m with rollers on the frame rails. All electric motors were AC220V, 90W, 1,550 rpm and digitally controlled speed.

The dimension of pursing drum made of stainless steel was outer diameter 12 cm, inner diameter 7 cm, outer width 15 cm and inner width 13.5 cm. The dimension of a V-groove net drum made of stainless steel with rubber surfaces was outer diameter 17.5 cm, inner diameter 7.5 cm, outer width 9 cm and inner width 6.5 cm.

The net stacked in the net box just above water surface was shot from bunt part into water according to 6 rpm rotation of a shooting beam clockwise until wing end tracking nearly a circle taking about 10 s. The pursing speed of the drum 100 rpm taking for about 15 s with both purse line was 37 cm/s. The hauling net speed by the drum with 60 rpm taking about 45 s from wing part of a purse seine was 36 cm/s approximately. Total time for hauling operation was about 80 s from the start of pursing to end of hauling net including purse line connecting 10 s and preparing net hauling 10 s. Tension of the purse line threaded into a v-grooved roller with diameter 3.5 cm before pursing drum was measured by load cell and its data were saved PC via A/D converter considering a roller efficiency and directional calibration.

The plan view of the purse seine was observed by air camera C1 (SAMSUNG CCD camera, BW 360 ED) fixed at 4 m above of water surface. Lateral view at water depth 1 m from hauling position (A~F and E~J position of the net design, refer to Fig. 1) by underwater camera C2 (KONGSBERG SIMRAD, SIT camera, OE 1324, diagonal angle of view 88°), and lateral view to B~G position of net design by underwater camera C3 (DeepSea Power and Light Inc., M1050, angle of view in horizontal 77°×vertical 59°), and upper view from a bottom center of the tank by C4 (KOWA CORP., sphere CCD camera, angle of view in horizontal 72°× vertical 54°). The video recorder was one Samsung world recorder and three LG LV-R33.

The calibration of the position in observed video images of net was carried out using 2 m long black and white stripped bar hanging vertically at many horizontal positions of the upper frame in refer to Hasegawa and Soeda (1984) and Kim (1996). 3-dimensional coordinates for underwater net geometry were defined with X-axis as A~C or E~C direction of purse seine net in operation from hauling position, and Z-axis as B~D direction, and Y-axis as depth. The shape of the purse seine was measured from observed video images for 17 operations of shooting and hauling in the monitor using OHP film as 2-dimensional coordinates from each camera in order to convert resultant 3-dimensional coordinates.

Results and discussion

1. Horizontal geometry of the float line

Horizontal geometry in X~Z coordinates of the float line was observed as a circle just after shooting shown maximum diameter (D_m) about 3.7 m similar to a diameter by the length of float line as a circumference. After that ratio of a mean diameter of float line to D_m=3.7 m was gradually decreased and distorted arc of float line as shown an ellipse sinking and pursing (Ben-Yami, 1994). With hauling operation is going on, diameter in X-axis (A~C of float line in Fig. 1) was decreased more than the diameter in Z-axis (B~D of float line)

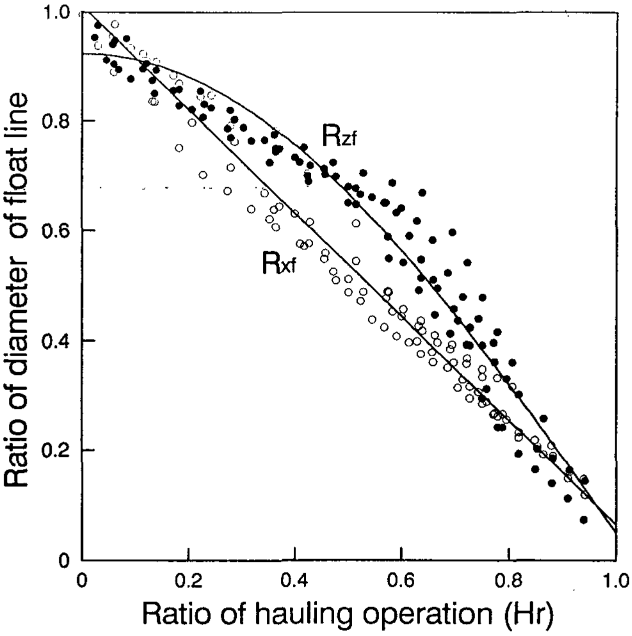

Fig. 3. Ratios of diameters to maximum diameter 3.7 m of model float line in X-axis R_{xf} (circle symbols) and in Z-axis R_{zf} (filled circle symbols) after shooting in accordance with ratios of total hauling operation H_r.

because hauling points moved on to X-axis. The relationship between the ratio of diameters of float line when depth $Y_f=0$ and a ratio (H_r) of hauling operation time to total operation time 80 s was shown in Fig. 3 and their relationship can be represented as following equations;

$$R_{xf}=1.011-0.947H_r$$
(number of data $n=107$, correlation coefficient $r=0.988$)
$$R_{zf}=0.049+0.875\cos(0.5\pi H_r)$$
($n=107$, $r=0.976$) (1)

where R_{xf} is a ratio of diameter to $D_m=3.7$ m in X-axis direction and R_{zf} is a ratio of diameter in Z-axis direction. The ratio of diameter of float line such as R_{xf} or R_{zf} when end of pursing about $H_r \fallingdotseq 0.2$ in this experiments was similar to the result of model experiments by Bag (1986) while larger than those of measurements by Girenko (1957).

2. Geometry of the lead line and purse line

The projected horizontal geometry of lead line as an upper view from bottom was varied from as a circle just after shooting, to as an ellipse and to as a shape of water drop during pursing as shown in Fig. 4 similar to the results of Girenko (1957) and Liu et al. (1984). The ratios of lead line diameters to maximum diameter 3.7 m in accordance with the ratios of pursing time (P_r) to total pursing time 15 s ($P_r=1\fallingdotseq 0.2H_r$ where H_r is ratio of total hauling time) was shown in Fig. 5. Their relationship can be expressed as a linear equation with a ratio of major axis (R_{xp}) in F~H of lead line and a ratio of minor axis (R_{zp}) in G~I of lead line in case of an ellipse as follows;

$$R_{xp}=1.033-0.834P_r \quad (n=30,\ r=0.992)$$
$$R_{zp}=0.984-1.143P_r \quad (n=30,\ r=0.981) \qquad (2)$$

If the shape of lead line in X~Z axises is similar to as a water drop, it could be formulated as a form of next equation (3).

The projected lateral view of lead line as Y~Z axis (F, G, H, I and J in Fig. 1) with pursing was shown in Fig. 6 and inner part of lead line was so called a gate which is mainly considered fish escaped. The relationship between ratios of Z-axis (R_{zp}) to $D_m=3.7$ m and ratio of depth (R_{yp}) to maximum net depth (Y_m) 2.3 m in Fig. 6 can be

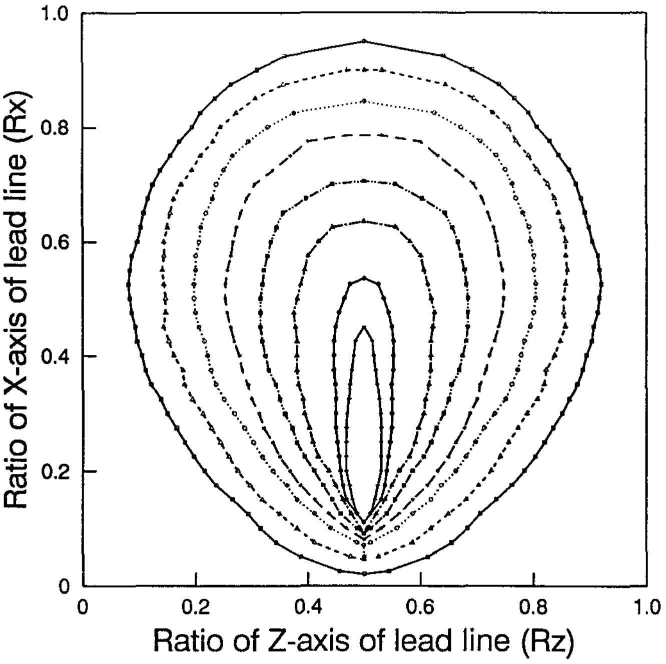

Fig. 4. The projected horizontal geometry of lead line as X-axis (R_x) and Z-axis (R_z) and varied from as an outer circle just after shooting to as an inner shape of water drop in accordance with ratio of pursing (P_r) as 0.09, 0.18, 0.27, 0.36, 0.46, 0.55, 0.64 and 0.73 respectively.

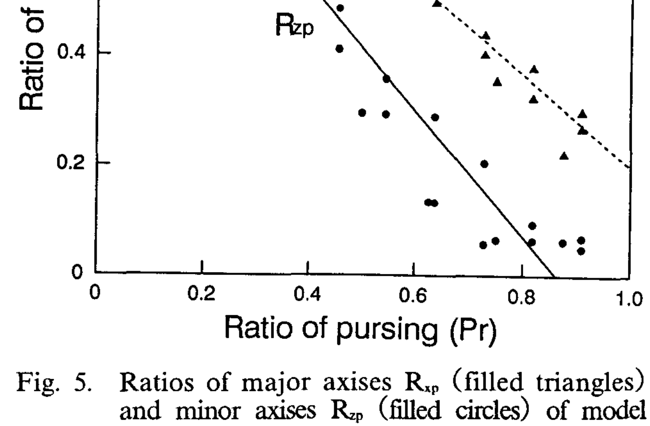

Fig. 5. Ratios of major axises R_{xp} (filled triangles) and minor axises R_{zp} (filled circles) of model lead line as a horizontal ellipse during pursing in accordance with ratios of pursing P_r.

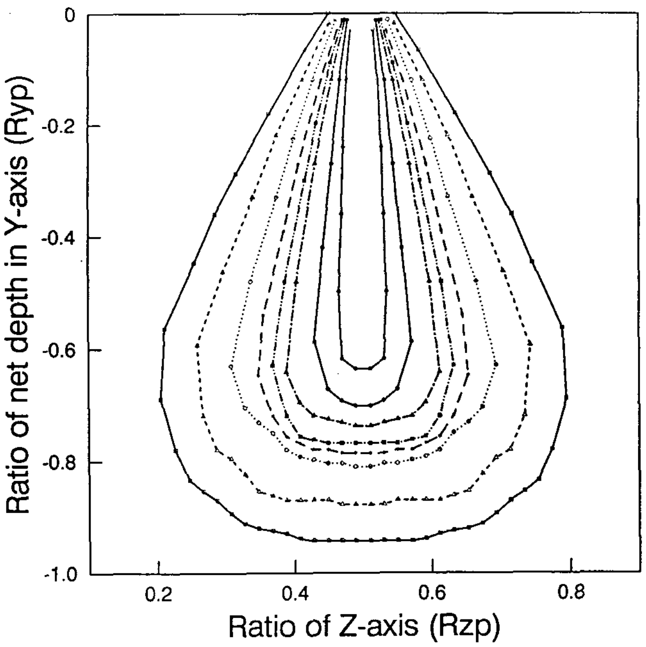

Fig. 6. The lateral view of lead line as a relationship between ratio of Z-axis (R_{zp}) and ratio of net depth (R_{yp}) with pursing as a shape of a water drop decreased with pursing ratios P_r from bottom curve 0.2 to top curve 0.9 by interval of 0.1 respectively.

expressed as shapes of water drop as follows;

$$R_{zp}=(-0.75-0.4P_r)R_{yp}\sqrt{1+R_{yp}-0.25P_r} \quad (R_{zp}>0,\ R_{yp}<0) \qquad (3)$$

where P_r is a ratio of pursing. The resultant 3-D geometry of the lead line can be obtained by combination of equations (2) and (3) with same R_{zp} and P_r.

The tension (T, kg) of a purse line when pursing both ends in the model purse seine with a ratio of pursing (P_r) was represented as following exponential equation;

$$T=0.0682\ e^{3.59P_r} \quad (n=72,\ r=0.99) \qquad (4)$$

Kim (1999) reported tension of purse line from model experiments considering pursing time and the ratio of diameter of netting twine to length of mesh bar. However factors for tension of purse line seem to be more complicated such as by the weight of lead line in water and curved net shape etc.

3. The lateral shape of purse seine net

The maximum net depth (Y_m) when end of shooting was as observed about 2.3 m nearly equal to 69% of the stretched net depth. The net depth with X-axis was gradually decreased with pursing and hauling net operation. The cross sectional shape of purse seine net as X~Y axises (A, F, H and C in Fig. 1) at center of Z-axis as ratio of R_z= 0.5 was observed as a rectangular before pursing and then sagging curves with pursing and hauling operation as an example of Fig. 7. The lateral shape as X~Y axises was non-symmetry due to pursing right direction as already demonstrated by Ben-Yami (1994). The relationship between ratio of net depth (R_{yn}) to Y_m=2.3 m and ratio of horizontal X-axis (R_x) to D_m=3.7 m can be represented as polynomial equation from 2nd to 4th order as follows;

$$R_{yn}=b_0+b_1R_x+b_2R_x^2+b_3R_x^3+b_4R_x^4 \qquad (5)$$

In Fig. 7, number of data n were 36~69 except 5~7 for H_r=0.1−0.2 and correlation coefficients were more than 0.98. The coefficients $b_{(0-4)}$ have no significant relationship with ratios of hauling operation (H_r).

The cross sectional shape of purse seine net as

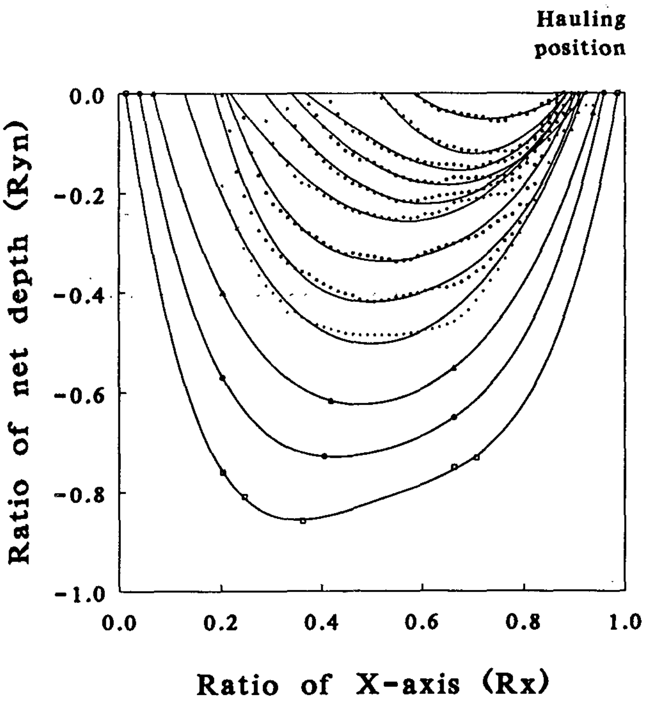

Fig. 7. The relationship between ratio of net depth (R_{yn}) and ratio of X-axis (R_x) in accordance with ratios of hauling operation (H_r) from bottom curve to upper curve as 0.10, 0.15, 0.20, 0.40, 0.42, 0.44, 0.47, 0.49, 0.52, 0.59, 0.70 and 0.77 respectively.

Y~Z axises observed at right half side net from $R_x=0.5$ when pursing and hauling operation was shown as an extended example of Fig. 8. The lateral shape as Y~Z axises was rectangular before pursing and symmetry when hauling at center of Z-axis direction due to bidirectional pursing even though right side hauling net. The relationship between a ratio of net depth (R_{yp}) and a ratio of horizontal Z-axis (R_z) to $D_m=3.7$ m can be represented as a sine function as follows;

$$R_{yz}=q_0+q_1\sin(0.5\,\pi R_z) \tag{6}$$

In Fig. 8, numbers of data n for each curves were 13~41 and correlation coefficients were larger than 0.99. The coefficient q_0 and q_1 were varied with ratios of hauling operation H_r as following polynomial equations;

$$\begin{aligned} q_0&=-0.229+3.057H_r-9.646H_r^2+9.985H_r^3 \\ &\quad (n=19,\ r=0.995) \\ q_1&=-0.920+0.059H_r+4.354H_r^2-6.225H_r^3 \\ &\quad (n=19,\ r=0.961) \end{aligned} \tag{7}$$

The maximum ratio of net depth at the end of pursing in this experiment 0.6 was larger than about 0.4 from Girenko (1957). This reason seems to be coming from the big difference of a ratio of maximum net depth to a maximum shooting diameter such as between 0.62 in this experiment and 0.24 in herring purse seine net from Girenko (1957). The lateral shape of net could be changed by pursing and hauling net speed pointed by Ben-Yami (1994).

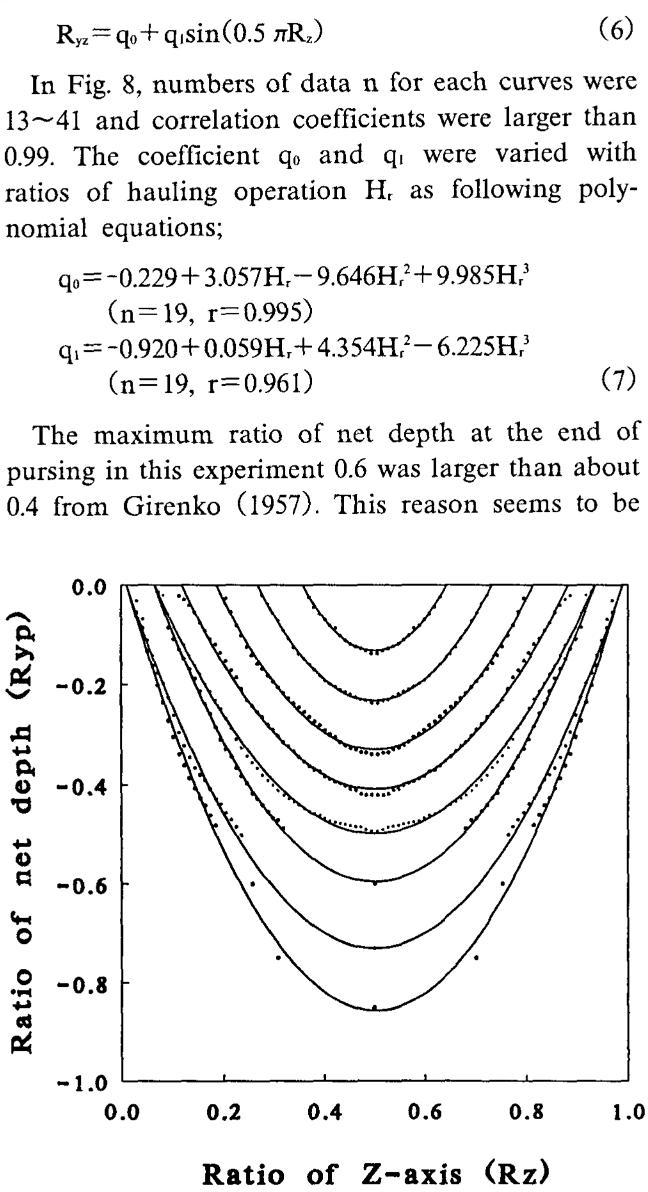

Fig. 8. The relationship between ratios of net depth (R_{yp}) and ratios of Z-axis (R_z) when ratios of hauling operation (H_r) from bottom curve to upper curve as 0.10, 0.13, 0.33, 0.38, 0.55, 0.63, 0.72 and 0.80 respectively.

The overall 3-D performance of the net curvatures could be approximated by using the equations (1), (5), (6) and (7). Two horizontal points in X-axis such as R_{x1} and R_{x2} when net depth ratio R_y, can be obtained from equations (1) and (5). Similarly, two horizontal points in Z-axis such as R_{z1} and R_{z2} can be obtained from equations (6) and (7). The horizontal geometry in X~Z axises at constant net depth R_y can be formulated using a major axis ratio $0.5(R_{z1}-R_{z2})$ and a minor axis ratio $0.5(R_{x1}-R_{x2})$ as an ellipse. Then, geometry of purse seine net with ratios $R_{(xyz)}$ as X, Y, Z-axises can be approximated as a following equation of an ellipse;

$$R_{x(y)}^2/(R_{x1}-R_{x2})^2+R_{z(y)}^2/(R_{z1}-R_{z2})^2=0.25 \tag{8}$$

The horizontal shape of float and lead line were varied as an ellipse or water drop in this observation as well as by Girenko (1957) and Ben-Yami (1994) more realistic rather than as a simple circle by Kim (1999). In above equations, main variables for 3-dimensional geometry for a purse seine were ratio of shooting diameter or maximum depth in relation to dimension of net such as $R_{(xyz)}$ and ratio of hauling operation such as P_r or H_r.

Therefore, let estimates an enclosed volume of a purse seine assuming an ellipse as horizontal shape using relevant equations. From equation (5), let a ratio of X-axis radius $R_{dx}=|R_x-R_{xm}|$ with R_{yn} where R_{xm} is R_x when maximum R_{yn}. Then real radius of X-axis X_r is $R_{dx}D_m$ where D_m is a maximum diameter of shooting net. Similarly from equations (6) and (7), let a ratio of Z-axis radius $R_{dz}=|R_z-0.5|$ with R_{yp} and then real radius of Z-axis Z_r is $R_{dz}D_m$. Then enclosed volume $V(H_r)$ of purse seine from as an area of ellipse can be expressed with a ratio of hauling time (H_r) as follow;

$$\begin{aligned} V(H_r)&=\int_0^{Y_m}\pi X_r Z_r\,dy \\ &=\pi\, D_m^2\int_0^{Y_m}(|R_x-R_{xm}|)(|R_z-0.5|)\,dy \end{aligned} \tag{9}$$

If $|R_{x1}-R_{yn}|$ and $|R_{x2}-R_{yn}|$ as R_{dx} is different in equation (5) in case of asymmetry, R_{dx} must be substituted 2 values of major and minor axises to equation (9) for each half ellipse.

More realistic performance of the purse seine from fishing ground is very complicated and difficult to measure due to natural underwater conditions and movements of seiner etc. (Ben-Yami, 1994). The movement of hauling positions in this experiment was not mimicked perfectly to field operation using full scale net and seiner due to restricted model test. In addition, measurements of net curvature as a whole was partially limited by means of video observations and viewing angle of video camera. Further study on 3-dimensional geometry for full scale net of purse seine is necessary in relation to fishing conditions and its modelling and simulation (Delmer and Stephens, 1981).

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References

Azvolinskii, A.I., N.N. Andreev and A.A., Yakovlev. 1975. Selection of hanging coefficient for purse seine. Ryb. Khoz., 51(8), 60~63 (in Russian).

Bag, J.S. 1986. Studies on the mackerel purse seine operating in the sea area of Cheju Island-1. Model experiment on the changes of net shape in stagnant water. Bull. Korean Fish. Tech. Soc. 22(2), 7~15 (in Korean).

Bag, J.S., T. Aoyama, M. Suzuki. 1986. Studies on the mackerel purse seine operating in the sea area of Cheju Island-2. Model experiment on the deformation of net in two layer current. Bull. Korean Fish. Tech. Soc., 22(4), 32~40 (in Korean).

Ben-Yami, M. 1994. Purse seining manual. Fishing News Books. p. 6~170.

Delmer, T.N. and T.C. Stephens. 1981. Development of a numerical simulation of purse seine fishing. Southwest Fisheries Center Admin. Rep. (USA) LJ-81 (13C), 125 pp. NOAA/NMFOS, La Jolla.

Girenko, V.N. 1957. Improvement of herring purse seines. Ryb. Khoz., 32(8), 33~40 (In Russian).

Hasegawa, E. and H. Soeda. 1984. The calculation of the three-dimensional coordinations of objects in water by the stereo method with two cameras. Bull. Japanese Soc. Sci. Fish. 50(10), 1685~1691 (in Japanese).

Iitaka, Y. 1956. Model experiments on the sardine purse seine operating in Hyuganada-IV. Bull. Japanese Soc. Sci. Fish. 22(7), 389~392 (in Japanese).

Iitaka, Y. 1958. Model experiments on the sardine purse seine operating in Hyuganada-V. Bull. Japanese Soc. Sci. Fish. 23(9), 511~513 (in Japanese).

Inoue, M. 1954. Model experiments on a sardine ringnet. Bull. Japanese Soc. Sci. Fish. 15(9), 942~946 (in Japanese).

Kim, S.J. 1999. Studies on the improvement of the fishing efficiency of purse seine in the sea area of Cheju Island.- the changes of seine volume and tension in the purseline during pursing- Bull. Korean Soc. Fish. Tech. 35(2), 94~101 (in Korean).

Kim, Y-H. 1996. Developing a model of fish behaviour to towed fishing gear. PhD thesis in the University of Aberdeen. p. 93~158.

Kim, Y-H. and T. Huh. 1987. Sinking movements and catch of the tuna purse seine off Southeast Guam. Bull. Tongyeong Fish. Jr. Coll., 22, 1~6 (in Korean).

Konagaya, T. (1971). Studies on the design of the purse seine. J. Fac. Fish. Mie Univ. 8(3), 209~296 (in Japanese).

Liu, D.C., O. Sato, K. Nashimoto and K. Yamamoto. 1984. Configuration of lead line of purse seine during pursing. Bull. Fac. Fish. Hokkaido Univ. 35(4) 234~242 (in Japanese).

Misund, O.A. 1992. Predictable swimming behaviour of schools in purse seine capture situations. Fish. Res. 14, 319~328.

Misund, O.A. 1993. Avoidance behaviour of herring (*Clupea harengus*) and mackerel (*Scomber scombrus*) in purse seine capture situations. Fish. Res. 16, 179~194.

Misund, O.A., W. Dickson and A.K. Beltestad. 1992. Optimization of purse seines by large-meshed sections and low lead weight. Theoretical considerations, sinking speed measurements and fishing trials. Fish. Res. 14, 305~317.

National Fisheries Research & Development Agency. 1989. Modern fishing gear of Korea. p. 443~469 (in Korean).

Park, J.S. 1991. Studies on the mackerel purse seine operating in the sea area of Cheju Island-4. The characteristics of catch and ability in purse seine. Bull. Korean Fish. Tech. Soc. 27(4), 247~254 (in Korean).

Park, J.S., S.J. Kim and S.K. Kim. 1997. A study on the behaviour of fish schools in the process of catch of the purse seine fishing method. Bull. Korean Soc. Fish. Tech. 33(3), 173~182 (in Korean).

Park, J.S., H. Kikukawa and S.J. Kim. 1999. A study on the tension of a purse line in the process of catch of the purse seine fishing methods-1. Model experiment on the tension of a purseline by net shape. Bull. Korean Fish. Tech. Soc., 35(1), 1~10 (in Korean).

Shimozaki, Y., Y. Osawa, H. Niwa and K. Honda. 1988. On the tension on a pursing line in purse seining. Bull. of Japanese Fish. Eng. Inst. 8, 303~310 (in Japanese).

Tauti, M. 1934. A relation between experiments on model and on full scale of fishing net. Bull. Jap. Soc. Sci. Fish. 3(4), 171~177.