Basic Principles of Fishing Gear Design and Construction

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Fishing gears have generally evolved on a trial and error basis and until recently, only empirical approaches have been used to determine design parameters rather than analytical procedures. Design and development efforts based fish behaviour, engineering studies, system analysis and model studies taking into consideration resource conservation, ecological and economic issues have been taking place in the recent decades. With the development and wider availability of synthetic gear materials, recent advances in vessel technology, navigational electronics, gear handling machinery, fish detection methods and fish behaviour studies, large-scale changes have taken place in the design, fabrication, operation and catching capacity of modern fishing gears such as trawls, purse seines and long lines. Widely used traditional fishing gears such as entangling nets, hook and lines and traps have also benefited by way of design upgradation and efficiency improvement in the recent years. New innovative fishing systems such as electrical fishing, light-assisted fishing, FAD-assisted fishing and fish pumps have also been developed and accepted in different parts of the world. Design process for fishing gear has been greatly influenced in the recent years by the resource management and conservation, environmental safety and energy efficiency imperatives.

Design process

Design process involves a divergent phase when analysis of the situation, statement of needs, specifications, standards of operation and constraints are spelt out; a transformational phase which includes generation of design ideas; and a convergence phase during which an evaluation in terms of objectives of design, utility and economic viability, prototype development, testing and evaluation takes place. A preliminary design thus generated is further refined based on additional information through an iterative cycle until final design is adopted.

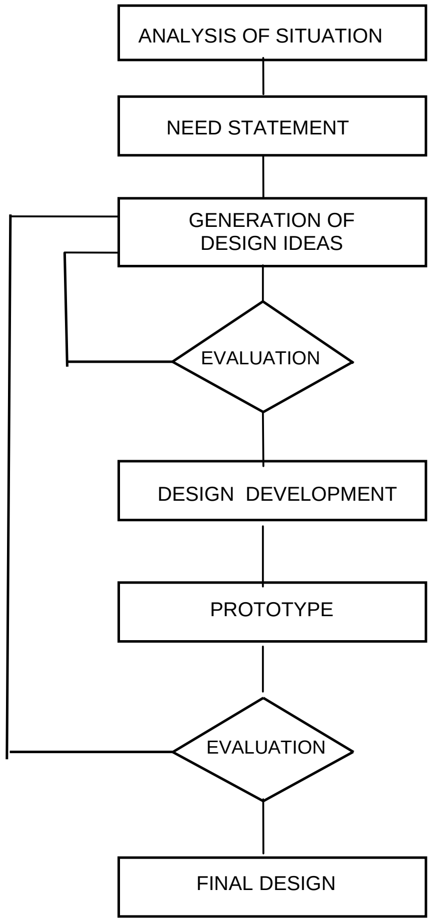


Fig. 1 Design process

Choice of fishing gear and its design primarily depends on biological, behavioural and distribution characteristics of the target species. There is no universal fishing suitable for all fishing conditions and resources. Fishing gear has to be selected or designed based on the presence of maximum number of attributes suitable for the particular fishing condition and resource and trade-offs may be necessary. Principal mechanisms used in fish capture are (i) filtering e.g. trawls, seines, traps; (ii) Tangling e.g. gill nets, entangling nets, trammel nets; (iii) Hooking, e.g. hand line, long line, jigging; (iv) Trapping, e.g. pots, pound nets; (v) Pumping, e.g. fish pumps. Main behaviour controls used in the fish capture process are (i) attraction, e.g. bait, light, shelter; (ii) repulsion or avoidance reaction, e.g. herding or guiding by netting panels as in set nets and trawls or sweeps and wires as in boat seines and trawls.

Model testing is increasingly used for design evaluation of the existing commercial fishing gear designs with a view to optimise their design parameters and for development of newer designs. In model testing, a scaled down model of the fishing gear is tested in a flume tank in order to study its behaviour and estimate working parameters. Principles of similarity are then used to assess the dimensions, specifications and characteristics of the full-scale version based on model studies. The fishing gears are further evaluated using full-scale version through statistically designed comparative field trials with a gear of known fishing efficiency and operational parameters are verified through gear monitoring instrumentation and underwater observations.

Factors affecting fishing gear design

Important factors which influence the design of fishing gears are discussed below:

Biology, behaviour and distribution of target species

Choice and design of fishing gear is greatly influenced by biological characteristics such as body size and shape, feeding habits and swimming speed; behaviour in the vicinity of fishing gear and during capture process; spatial distribution and aggregation behaviour of the target species.

Body size and shape determine the mesh size required to enmesh and hold the fish in gill nets and the mesh size to retain the target size groups of the species with out gilling in the trawls, seines and traps. Body size is also related to the tensile strength requirements for the netting twine in gill nets and hook size and lines in hook and line. Body size is again directly proportional to the swimming speed which is a significant attribute to be considered in the fishing success of dragged gear. Feeding habit of the target species is more important in passive fishing methods like hook and line and traps where the fish is attracted by the bait, and in the active fishing methods like troll line used for catching predatory fishes.

Consideration of the swimming speed of the target species is important particularly in the active fishing methods like trawling, seining and trolling. Fishes are known to sustain a cruising speed of 3-4 body lengths per second for long periods without fatigue and burst speeds of 10 body lengths per second for short duration. During burst speeds reserve energy supplies in the fish muscle is used up. Fish in front of the trawl mouth will be eventually caught if the trawling speed is greater than the cruising speed of the fish. Behaviour of different species might vary when they turn back into the trawl. It is reported that flat fish and cod turn back in the horizontal plane close to the bottom; whiting turn back at a level higher than this and haddock rise and turn at a still higher level. Such differential behaviour makes it possible to separate the different species using separator panels inside the trawl. Selective capture of the slow moving crustaceans providing opportunity for the fast swimming non-target finfishes to escape, could be possible by controlling the towing speed and minimising the longitudinal length of the trawl net.

Table 1 Choice of fishing gear based on biological, behavioural and distribution characteristics of the target species

	Biological, behavioural and distribution characteristics	Choice of fishing gear
1	Demersal, large feeding fish with sparse, scattered distribution	Bottom set long line, bottom vertical long lines, bottom gill nets, hand lines, traps, bottom trawls
2	Demersal small sized fishes	Gill nets, traps, bottom trawls
3	Pelagic, large sized with sparse and scattered distribution	Drift long lines, vertical long lines, gill nets, midwater trawls
4	Pelagic, small and medium sized schooling fishes	Purse seines, midwater trawls, hand lines
5	Pelagic predatory fishes	Troll lines, long lines
6	Light-attracted fishes and cephalopods	Light-assisted dip nets and purse seines, jigging
7	Fish concentrated by FADs	Purse seines, hand lines, gill nets

Table 2 Choice of fishing gear based on sea bottom, current and weather conditions

	Fishing conditions	Choice of fishing gear
1	Rough sea bottom, demersal fishes	Hand line, vertical long line, bottom vertical long line, traps
2	Strong currents	Long lines, gill nets
3	Bad weather	Hand lines, vertical long line, long line, gill nets

Table 3 Choice of fishing gear based on the energy use

	Energy use	Choice of fishing gear
1	Low energy fishing	Gill nets and entangling nets, hand line, long lines, traps, surrounding nets
2	Energy-intensive fishing	Bottom trawls, midwater trawls, dredges, troll lines, light fishing

Behavioural differences between fish and crustaceans and size differences between them, could be used in the design of selective trawl designs. In such designs rigid grids are placed at an angle, before codend. Small sized prawns move through the grid into the codend while fish and other non-target species are deflected by the grid and are released through an escape chute. Such devices are sometimes called Trawl Efficiency Devices as they reduce the sorting time and thus increases the efficiency of operations. Protected species like turtles are allowed to escape in a similar way using Turtle Excluder Devices (TEDs).

Large mesh trawls and rope trawls, in which front trawl sections are replaced with very large meshes or ropes in order to reduce drag, make use of the principle of repulsion or herding to guide the finfish into trawl codend. In the conventional trawling systems, herding effect by the otterboards, wires and sweeps and sand-mud cloud created by the boards on finfishes in between the boards, is made use of to improve the catch rate by increasing the effective sweep area. Long leader nets placed in the path of migratory fishes guide them into large set nets operated in Japan. Tendency of some fishes to aggregate towards light is used in squid jigging, light-assisted purse seining and dip net operations. Behaviour of fishes like tuna to aggregate around the floating objects, is utilised successfully in FAD-assisted purse seining.

Catching efficiency is maximised when the vertical opening of the trawl mouth, vertical dimension in gill nets, and the catenary of the main line of the long line with branch lines and hooks, coincide with the vertical range of the layer of maximum fish abundance. Hence knowledge of the vertical distribution of the target species could be used to optimise the horizontal and vertical dimensions of the netting panels in gill nets, main line catenary in long line and mouth configuration in trawls. Some species of fish are sparsely distributed either singly or in small groups and thus exhibit a pronounced patchiness, while some others form dense schools. Sparsely distributed scattered fish are more efficiently caught by passive fishing methods such as gill netting and long lining, where as schooling fishes are effectively caught by purse seining and aimed midwater trawling.

Fishing depth, current and visibility

Hydro-acoustic pressure increases approximately at the rate of one unit atmospheric pressure (1 bar) for every 10 m depth. Buoyancy elements used in the deep sea fishing gears such as deep sea trawls, gillnets and bottom vertical lines have to be strong enough to withstand the high pressure at the fishing depth. Compressible buoyancy elements that are simple light and cheap can only be used in surface operated gears such as seines and surface gillnets as they absorb water and loose their buoyancy in deeper waters.

Prevailing strong currents in the fishing ground may restrict the choice of fishing gears to longlines and gillnets which are less affected by currents. Light levels at the fishing depth could influence the fishing success, as vision of fish is affected by light levels. In passive fishing gears such as gillnets, visibility of netting panel adversely affects fishing efficiency. Visibility is again negatively indicated in hook and line operation while in light-assisted jigging controlled lighting plays an important part. Visibility is also important in effective herding during the capture process in trawls and in large pound nets and trapping enclosures where leader nets are used.

Sea bottom conditions

Rough sea bottom conditions limits the operation of most of the fishing gears close to the ground except handlines, vertical longlines , bottom vertical longlines and traps. Trawling on rough bottom requires special rigging such as bobbin rig or rock hopper rig, improvements in trawl design to minimise gear damage or loss and selection of appropriate otter boards.

Other factors

Choice of fishing gear and their design features will also be influenced by the scale of operations, size and engine power of fishing vessel, energy conservation objectives, selectivity and resource conservation objectives, catch volume requirements, operational and handling requirements of the gear, prevailing weather conditions, skill required for fabrication, maintenance and operation, material availability, local traditions and economic considerations.

Fishing gear construction

Fishing gear materials are either of textile origin such as netting, twine and ropes or of non-textile origin such as floats and sinkers, hooks and jigs and sheer devices. Most of the widely used fishing gears such as trawls, encircling nets, gillnets and entangling nets, lift nets, falling gears and many of the trap nets extensively use netting panels as a restrictive barrier in their design and construction. Notable exceptions are longlines, handlines, squid jigs, troll lines and some of the pots and creels. Most commonly used netting materials have a quadratic or diamond shape when hung.

Shaping of netting

Each netting panel used in the construction of fishing gear can be derived from one or more sections of particular geometric shapes such as rectangle, trapezium or triangle each with a uniform mesh size and twine specifications (Fig. 2 & 3). The shape of these component pieces constituting the netting panels is achieved by increasing, decreasing or maintaining the number of meshes in the N-direction or T-direction. This is done by shape cutting the pieces from machine made webbing.

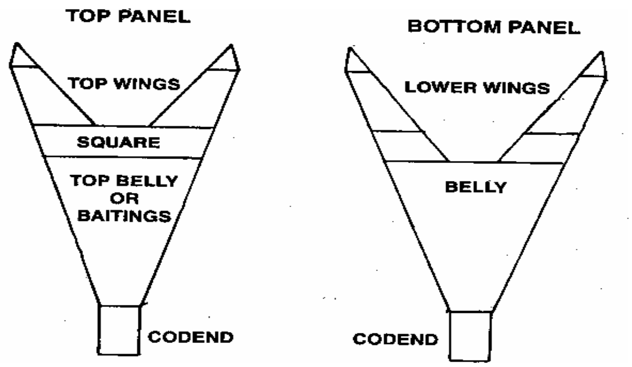


Fig 2 Basic trawl design illustrating constituents of netting panels

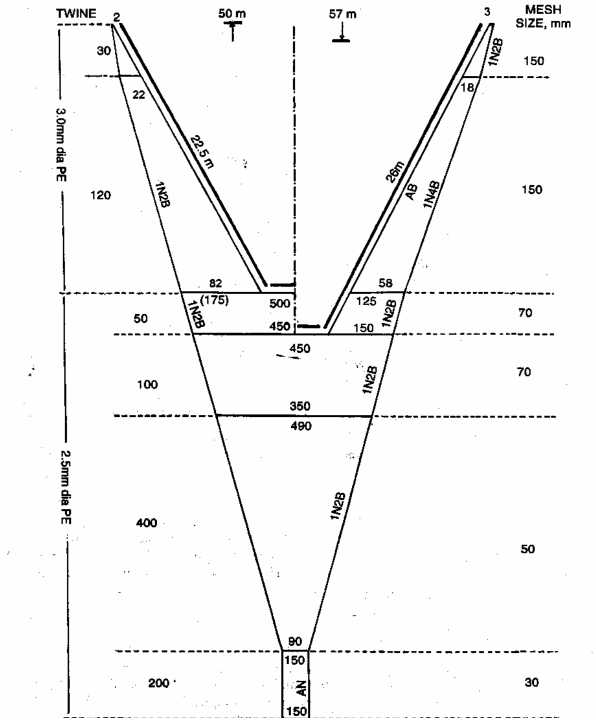


Fig 3 Design of a 50 m demersal trawl

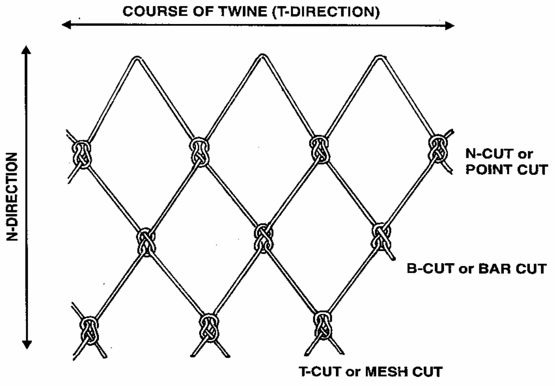


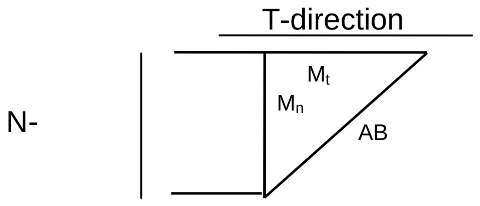
Fig. 4 Types of cuts used to shape netting

N-cut, T-cut and B-cut

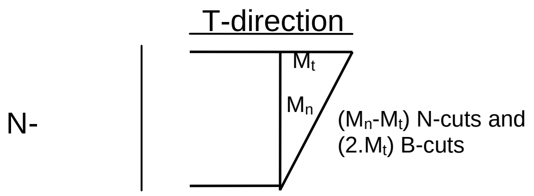
Three types of cuts viz., N-cut, T-cut and B-cut are used to shape the netting
(Fig. 4)

(i) N-cut through both the twines at one side of the knot advances by one mesh in the N-direction. If the knot in N-cut is undone , the mesh is opened. Hence it has to be stabilised in a seam or mend. This is also called point-cut or P-cut.
(ii) T-cut through both the twines at the top or bottom of the knot, advances by one mesh in the T-direction. The knot in T-cut when undone gives a clean mesh. This is also called Mesh cut or M-cut.
(iii) B-cut through one twine at a knot advances by half a mesh in both N and T directions. The knot in B-cut when undone forms a fly mesh or dog-ear. This is also called Bar cut. B-cuts in the same direction forms an oblique taper in which the number of meshes in the N-direction is equal to that in the T-direction.

(i) **Taper ratio, R = unity i.e., $M_t = M_n$**
Cutting rate = All B-cuts



(ii) **Taper ratio, R < 1 i.e., $M_t < M_n$**
Cutting rate = $(M_n-M_t)/(2.M_t)$
Cutting cycles of (M_n-M_t) N-cuts and
$(2.M_t)$ B-cuts provide the desired taper



(iii) **Taper ratio, R > 1 i.e., $M_t > M_n$**
Cutting rate = $(M_t-M_n)/(2.M_n)$
Cutting cycles of (M_t-M_n) N-cuts and
$(2.M_n)$ B-cuts provide the desired taper

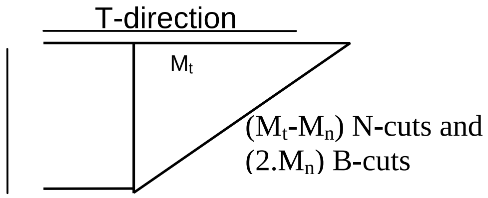


Fig. 5 Calculation of cutting rates

Taper ratio

Netting sections required to make up the gear panel are cut according to pre-calculated taper ratio from the machine made netting.

Taper ratio R : M_t / M_n,
where M_t is the number of meshes in the T-direction and M_n is the number of meshes in the N-direction.

Cutting rate

Cutting rate is regular repeated cycle of N-cuts; T-cuts; B-cuts; N-cuts and B-cuts; or T-cuts and B-cuts made in the correct proportion to obtain the required taper ratio. Based on taper ratio cutting rate is calculated as given in Fig. 5.

In order to keep the taper cut even, the number of B-cuts and N-cuts/T-cuts in each cutting cycle should be reduced to the smallest possible integers. The N-cut and B-cut or T-cut and B-cut as the case may be should be mixed uniformly, maintaining the correct taper ratio to obtain the smoothest taper possible (Fig 6). Representative cutting rates are given in Fig. 7. Approximate angles given by different cutting rates at a particular hanging coefficient (E=0.5) is given in Fig 8. Netting usage can be economised by careful planning of the cuts of the complementary pieces used in gear construction. Table 4 gives cutting rates for various common taper ratios.

Hanging

Actual shape of a mesh or netting panel is determined by the process of hanging it on to a rope frame.

Hanging coefficient, E_h =
Hung length of the netting / Fully stretched length of the netting
Resultant vertical hanging coefficient, $E_v = \sqrt{1-E_h^2}$
Hung depth of a panel of netting in meters is given by

$\sqrt{(1-E_h^2)}.n.m.0.001$

where $\sqrt{(1-E_h^2)}$is the resultant vertical hanging coefficient;

n is the number of meshes in depth and m is the mesh size in mm

Effect of different hanging coefficients on the shape of netting and mesh opening is illustrated in Fig. 9. Hanging or mounting of netting is illustrated in Fig. 10.

Assembly of netting

The various constituent pieces of netting panels prepared by shape cutting, are assembled by either joining or seaming. Joining requires braiding an extra row connecting the two panels. When the edges to be joined has the same number of meshes and same mesh size, joining is made mesh to mesh. When the two pieces to be joined has the same stretched width but different mesh size, additional or 'take up' meshes in the panel of small mesh size are interspersed uniformly among the meshes of other panel.

In seaming one or several meshes on the edge of each panel re joined together by lacing. In trawl fabrication, seams are used for assembling the corresponding pieces of the two panels to e joined longitudinally. It is generally done by taking up 3-6 meshes on each edge of the trawl panels, using double twine, seizing by half hitches approximately every 50 cm, after 4 or 5 passages through meshes. Fig. 12 shows pictorial view of a fully assembled two panel demersal trawl.

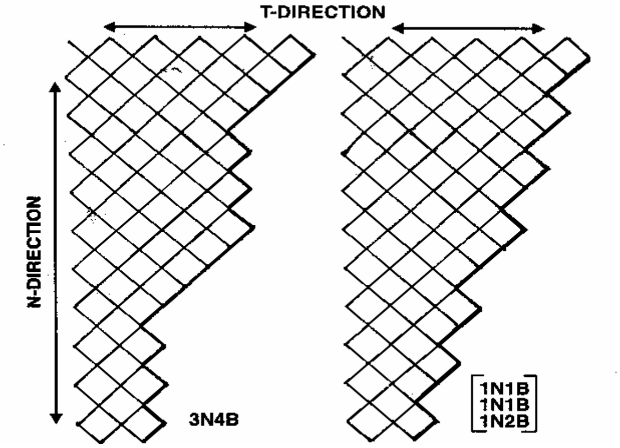
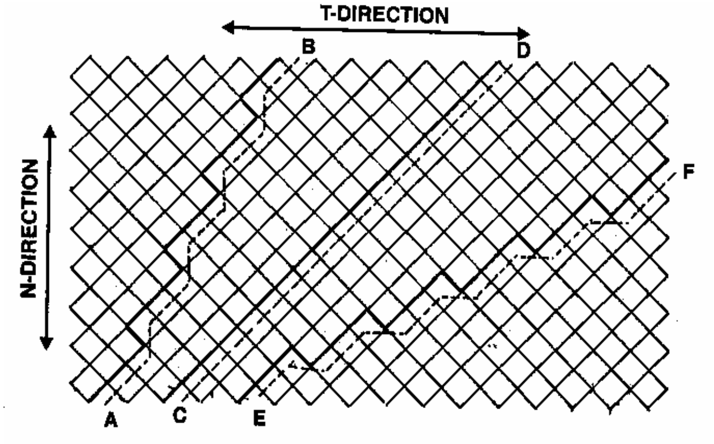


Fig. 6 Illustration of obtaining smoother taper



A–B = 1N2B, C – D = All Bars, E – F = 1T2B

Fig. 7 Representative cutting rates

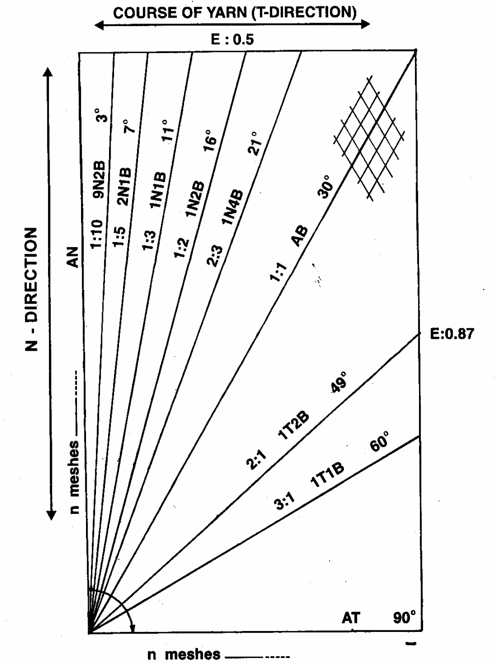


Fig. 8 Calculation of cutting rates

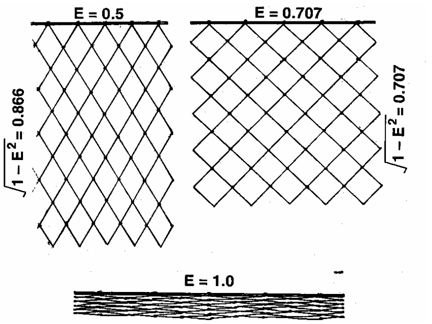


Fig. 9 Effect of different hanging coefficients on shape of netting

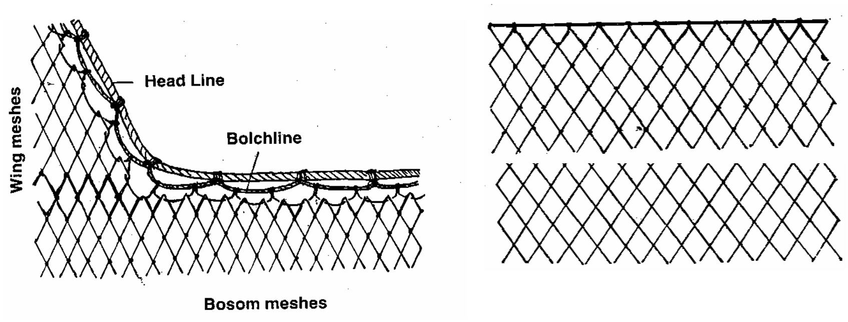
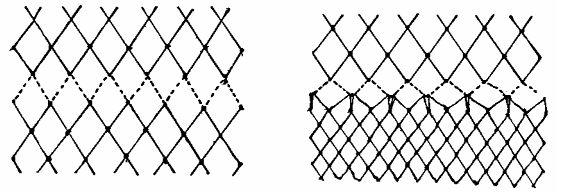
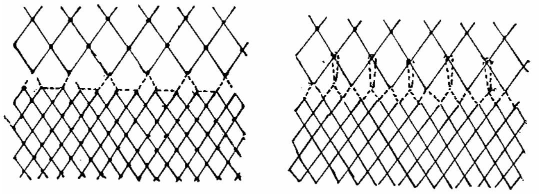


Fig. 10 Illustration of mounting



a Normal joins (Mesh size & stretched length same)

b1 Join of two panels in 1/2 take-up ratio (Stretched length same mesh size different)



b2 Join with braiding through the small meshes

b3 Join with extra loops on the large meshes

Fig. 11 Joining of netting panels

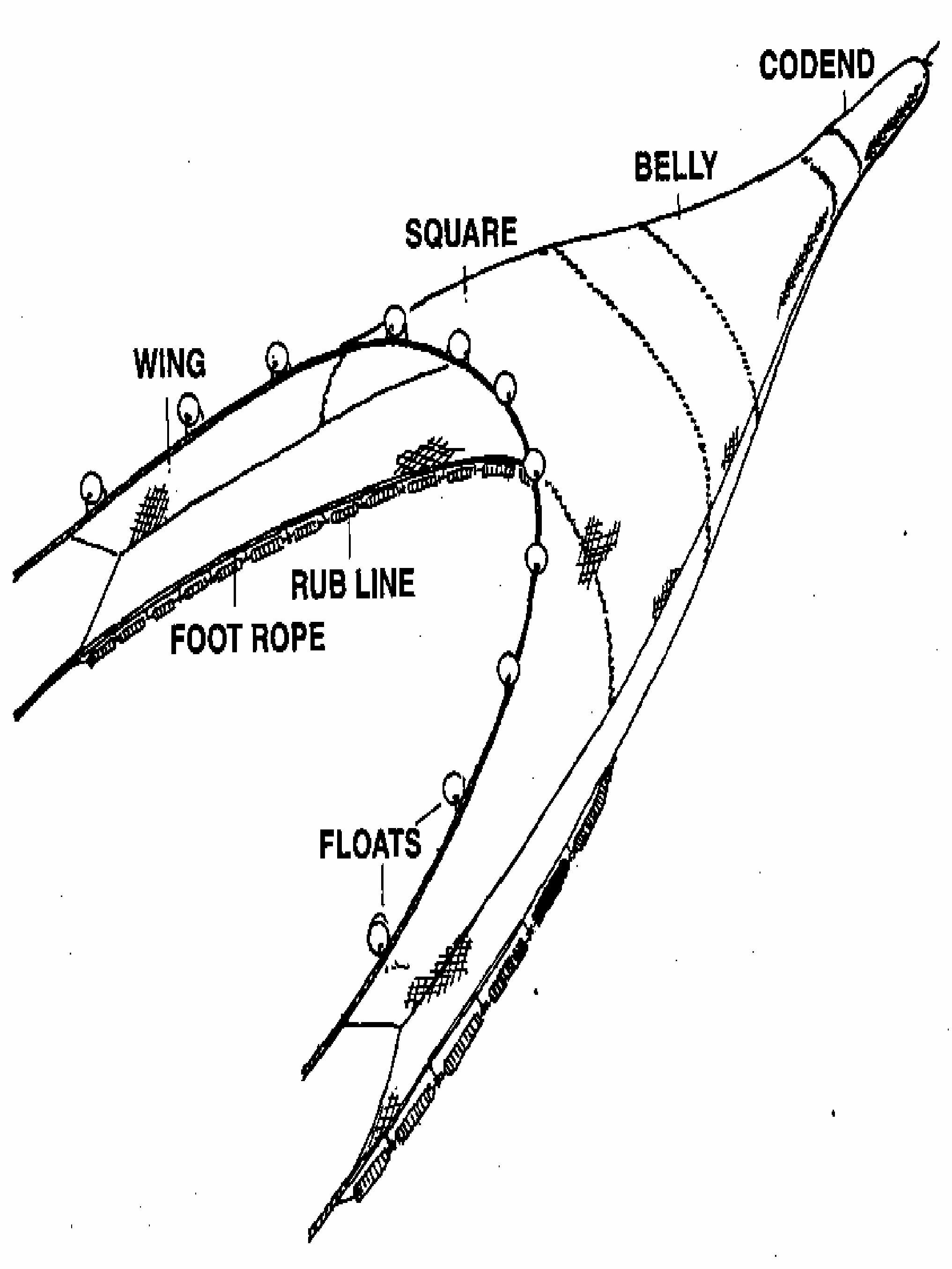


Fig. 11 Pictorial view of a 50 m two-seam Demersal trawl

Table 4 Cutting rates

Number of meshes lost or gained

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	**AB**	1T2B	1T1B	3T2B	2T1B	5T2B	3T1B	7T2B	4T1B	9T2B	5T1B	11T2B
2	1N2B	**AB**	1T4B	1T2B	3T4B	1T1B	5T4B	3T2B	7T4B	2T1B	9T4B	3T1B
3	1N1B	1N4B	**AB**	1T6B	1T3B	1T2B	2T3B	5T6B	1T1B	7T6B	4T3B	3T2B
4	3N2B	1N2B	1N6B	**AB**	1T8B	1T4B	3T8B	1T2B	5T8B	3T4B	7T8B	1T1B
5	2N1B	3N4B	1N3B	1N8B	**AB**	1T10B	1T5B	3T10B	2T5B	1T2B	3T5B	7T10B
6	5N2B	1N1B	1N2B	1N4B	1N10B	**AB**	1T12B	1T6B	1T4B	1T3B	5T12B	1T2B
7	3N1B	5N4B	2N3B	3N8B	1N5B	1N12B	AB	1T14B	1T7B	3T14B	2T7B	5T14B
8	7N2B	3N2B	5N6B	1N2B	3N10B	1N6B	1N14B	**AB**	1T16B	1T8B	3T16B	1T4B
9	4N1B	7N4B	1N1B	5N8B	2N5B	1N4B	1N7B	1N16B	**AB**	1T18B	1T9B	1T6B
10	9N2B	2N1B	7N6B	3N4B	1N2B	1N3B	3N14B	1N8B	1N18B	**AB**	1T20B	1T10B
11	5N1B	9N4B	4N3B	7N8B	3N5B	5N12B	2N7B	3N16B	1N9B	1N20B	**AB**	1T22B
12	11N2B	5N2B	3N2B	1N1B	7N10B	1N2B	5N14B	1N4B	1N6B	1N10B	1N22B	**AB**
13	6N1B	11N4B	5N3B	9N8B	4N5B	7N12B	3N7B	5N16B	2N9B	3N20B	1N12B	1N24B
14	13N2B	3N1B	11N6B	5N4B	9N10B	2N3B	1N2B	3N8B	5N18B	1N5B	3N22B	1N14B
15	7N1B	13N4B	2N1B	11N8B	1N1B	3N4B	4N7B	7N16B	1N3B	1N4B	2N12B	1N8B
16	15N2B	7N2B	13N6B	3N2B	11N10	5N6B	9N14B	1N2B	7N18B	3N10B	5N22B	1N7B
17	8N1B	15N4B	7N3B	13N8B	6N5B	11N12	5N7B	9N16B	4N9B	7N20B	1N4B	5N24B
18	17N2B	4N1B	5N2B	7N4B	13N10	1N1B	11N14	5N8B	1N2B	2N5B	7N22B	3N14B
19	9N1B	17N4B	8N3B	15N8B	7N5B	13N12	6N7B	11N16	5N9B	9N20B	1N3B	7N24B
20	19N2B	9N2B	17N6B	8N4B	3N2B	7N6B	13N14	3N4B	11N18	1N2B	9N22B	4N14B
21	10N1B	19N4B	3N1B	16N8B	8N5B	5N4B	1N1B	13N16	2N3B	11N20	5N12B	9N24B
22	21N2B	5N1B	19N6B	9N4B	17N10	4N3B	15N14	7N8B	13N18	3N5B	1N2B	5N14B
23	11N1B	21N4B	11N3B	17N8B	9N5B	17N12	8N7B	15N16	7N9B	13N20	1N2B	11N24B
24	23N2B	11N2B	7N2B	10N4B	19N10	3N1B	17N14	1N1B	5N6B	7N10B	13N22B	1N2B
25	12N1B	23N4B	13N3B	18N8B	2N1B	19N12	9N7B	17N16	1N1B	3N4B	7N12B	13N24B

Design drawings and specifications of fishing gears

Design drawing of the fishing gear should provide all information relating to the size, shape, material and construction using recognised nomenclature and symbols, in order to permit the construction of identical fishing gears from the same drawing. In the design drawing net panels are drawn to scale according to theoretical hung length and hung depth.

Hung length of the panel in m = $M_t.m.E_h.0.001$
Hung depth of the panel in m = $M_n.m.\sqrt{(1-E_h^2)} . 0.001$
where M_t = number of meshes in T-direction
M_n = number of meshes in N-direction
m = mesh size in mm
E_h = horizontal hanging coefficient
$\sqrt{(1-E_h^2)}$ = vertical hanging coefficient

Netting panels not drawn to scale are marked accordingly. Ropes, floats and other rig items are generally not drawn to scale. All measurements are given in SI units. Larger dimensions are expressed in m to the nearest 0.01m and smaller dimensions in mm to the nearest 1 mm without specifying units.

According to ISO (1975) recommendations, dimensions in length of netting panels in trawl and seine net designs, are represented as fully stretched length ($E_v = 1.0$) and in width as half stretched length ($E_h = 0.5$). In gill net and entangling net designs, length is drawn according to the length of float line. Depth is drawn according to the length of gavel lines, if they are present or according to the fully stretched netting in depth ($E_v = 1.0$). in surrounding net designs such as purse seines and lampara net, length is drawn according to the length of float line and depth according to the fully stretch netting in depth. For designs of traps, pots, dredges and lines and for rigging and auxiliary components of the design of all gear designs perspective drawings and projections are used to represent the design details.

Specifications and details given in the design drawing for nets may include:

i. Twine : material; size in R-tex; construction;
ii. Rope : material; size in R-tex or dia
iii. Netting panel: number of meshes in T-direction on upper and lower edges; number of meshes in N-direction on either side; cutting rates for all tapered edges; mesh size in mm; hanging coefficient; special features such as colour and double selvedge
iv. Joining methods
v. Float line length in m
vi. Lead line length in m
vii. Side line length in m
viii. Ground rope construction
ix. Otter board: type; dimensions; weight

x. Rigging: connecting ropes; hardware components; floats; sinkers
xi. Scale of drawing
xii. Title indicating the class of design
xiii. Vessel: Loa; hp
xiv. Target species
xv. Origin of design

Estimation of weight of netting

Information on weight of netting is required for ordering netting requirements and for determination of underwater weight of netting for rigging purposes.

The first step is to have the complete design drawing including specifications. Every net is composed of a number of sections of particular geometric shapes such as rectangle, trapezium and triangle each with a uniform mesh size, twine size and material specification. Length of the twine used in each of the netting sections are estimated as below:

$L_t = K.[((M_{t1}+M_{t2})/2).M_n].2m.10^{-3}$

where L_t = length of twine used in m

M_{t1} and M_{t2} = number of meshes in width along top and bottom edges

M_n = number of meshes in depth

m = stretched mesh size in mm

K = correction factor for length of twine used in a knot.

= length of twine used in a mesh / 2m

Correction factor K is usually within the range of 1.1 -1.5, depending on twine diameter/mesh size ratio and type of knot in knotted netting and is equal to 1.0 for knotless netting. From the length of twine thus estimated weight of the netting panel is determined as below:

Weight of the netting in kg, $W_n = L_t.\text{R-tex}.10^{-6}$

where L_t = length of twine in m

R-tex = linear density of netting twine ($g.km^{-1}$)

Alternatively, if tables of weight in grams per square meter of fictitious area (stretched length x stretched width) for particular specifications of netting are available, the weight of netting panel in grams could be estimated by multiplying it with the fictitious area of panel in sq.m. Fridman (1986) has given such tables for polyamide netting.

Weight of netting in seawater, $W_{ns} = W_n .(1-(1025/d))$

where d = the specific mass of the netting material in $kg.m^{-3}$

W_n = weight of netting in air