BRITISH STANDARD

BS 6349-6:
1989

Code of practice for

Maritime structures —

Part 6: Design of inshore moorings and floating structures

UDC [624.034.3/.4 + 69.034.3/.4]

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Civil Engineering and Building Structures Standards Policy Committee (CSB/-) to Technical Committee CSB/17, upon which the following bodies were represented:

Association of Consulting Engineers
British Ports Association and the National Association of Ports Employers
British Steel Industry
Concrete Society
Department of the Environment (Property Services Agency)
Department of Transport (Marine Directorate)
Federation of Civil Engineering Contractors
Health and Safety Executive
Institution of Civil Engineers
Institution of Structural Engineers
Oil Companies International Marine Forum

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Contents

Foreword

This Part of BS 6349 has been prepared under the direction of the Civil Engineering and Building Structures Standards Policy Committee.

This code of practice contains material which is both for the information and guidance of engineers and material which forms recommendations on good practice. As such conformity with its recommendations is not obligatory and variations from its recommendations may well be justified in special circumstances and engineering judgement should be applied to determine when the recommendations of the code should be followed and when they should not.

A code of practice is intended for the use of engineers having some knowledge of the subject. It embodies the experience of engineers successfully engaged on the design and construction of a particular class of works so that other reasonably qualified engineers may use it as a basis for the design of similar works.

It is not intended that it should be used by engineers who have no knowledge of the subject nor that it should be used by non-engineers.

A code of practice represents good practice at the time it is written and, inevitably, technical developments may render parts of it obsolescent in time. It is the responsibility of engineers concerned with the design and construction of works to remain conversant with developments in good practice, which have taken place since the publication of the code.

Following suggestions from the Maritime and Waterways Board of the Institution of Civil Engineers, the Standards Committee for Civil Engineering Codes of Practice set up an ad hoc panel to make further studies. The panel's report, presented in 1975, concluded that existing British codes were inadequate for the special aspects of maritime structures and that there was a need for such a code.

A format was proposed that divided the work into two distinct stages.

The standard will be issued in seven Parts as follows:

— *Part 1: General criteria;*

— *Part 2: Design of quay walls, jetties and dolphins;*

— *Part 3: Design of dry docks, locks, slipways and shipbuilding berths, shiplifts and dock and lock gates*[1]*;*

— *Part 4: Design of fendering and mooring systems;*

— *Part 5: Recommendations for the dredging of waterways and for land reclamation*[1]*;*

— *Part 6: Design of inshore moorings and floating structures;*

— *Part 7: Design of breakwaters and training walls*[1][2].

The full list of the organizations which have taken part in the work of the Technical Committee is given on the inside front cover. The Chairman of the Committee is Mr J T Williams OBE, C Eng, FICE, F I Struct E and the following were members of the Technical Committee.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to vi, pages 1 to 52, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

1.1 Scope

This Part of BS 6349 gives guidance and recommendations on the design of moorings and floating structures at inshore locations. The mooring of ships alongside fixed structures is included in BS 6349-4.

Information on wave, wind and current loads which is specific to moored floating structures is contained in section 2. It should be used in conjunction with the general information for all maritime structures, contained in BS 6349-1.

The selection, design and analysis of moorings is covered in section 3 which also includes information on anchors, mooring equipment and maintenance and inspection of moorings. Detailed information on the design of deepwater mooring structures for the offshore industry is beyond the scope of the code, and is not included.

Design criteria which are specific to floating structures are covered in section 4. Loads, codes and classification society rules are considered together with fundamental information and criteria on stability, motion response and longitudinal strength.

General information on pontoons, floating docks and floating breakwaters is provided in section 5. Information on the detailed design of such structures is not included since specific codes and rules already exist (see **4.3** for guidance).

NOTE The titles of the publications referred to in this standard are listed on the inside back cover. The numbers in square brackets used throughout the text relate to the bibliographic references given in Appendix A.

1.2 Definitions

For the purposes of this Part of BS 6349, the definitions given in BS 6349-1 apply together with the following.

1.2.1
intact stability

the stability that covers the non-damaged condition of a vessel

1.2.2
damage stability

the stability with one or more watertight compartments flooded as a result of damage (collision)

1.2.3
displacement (of a vessel)

the mass of water displaced by a vessel

NOTE Displacement is sometimes expressed as the volume of water displaced.

1.2.4
centre of buoyancy

the centroid of the underwater volume of the vessel; it is the point through which the total buoyancy force acts

1.2.5
metacentre

the point at the intersection of vertical lines through the centres of buoyancy in the initial and slightly inclined positions

1.2.6
metacentric height

the distance between the centre of gravity and the metacentre

1.2.7
free surface effect

the reduction in the value of the metacentric height resulting from the presence of liquid in any tanks in the vessel

1.3 Symbols

The following symbols are used in this Part of BS 6349. Several meanings are given to some of the symbols and the specific meaning is given in each case in the text where the symbols are used.

A	Waterplane area
A_n	Area normal to flow
A_x	Effective wind area normal to x axis
A_x	Effective current area normal to x axis
A_y	Effective wind area normal to y axis
A_y	Effective current area normal to y axis
B	Breadth
B	Beam of vessel or structure
(BM)	Distance between centre of buoyancy and metacentre
b	Dimension normal to wind
C	Damping force
C_D	Drag force coefficient
C_f	Wind force coefficient
C_x	Wind force coefficient for x axis
C_x	Current force coefficient for x axis
C_y	Wind force coefficient for y axis
C_y	Current force coefficient for y axis
D	Draught of vessel or structure
d	Distance

d	Still water depth
d	Dimension measured in direction of wind
F	Chain tension at fairlead
F	Trochoidal wave profile factor
f	Wave frequency
f_c	Frequency of cyclic loading
F_D	Drag force
F_{max}	Maximum wave force per unit length of structure
f_N	Natural frequency of structure or member
F_{RW}	Resultant wind force
F_{WD}	Mean wave drift force
F_x	Wind force acting along x axis
F_x	Current force acting along x axis
F_y	Wind force acting along y axis
F_y	Current force acting along y axis
f_y	Characteristic strength of reinforcement
g	Acceleration due to gravity (9.81 m/s^2)
(GM)	Metacentric height
(GZ)	Righting lever
H	Wave height
H	Horizontal component of chain tension
H_{inc}	Incident wave height
H_s	Significant wave height
h	Horizontal distance from fairlead to chain touch down point on seabed
I	Second moment of area
k	Radius of gyration
K	Stiffness of mooring system
(KB)	Vertical distance of centre of buoyancy above keel
(KG)	Vertical distance of centre of gravity above keel
(KM)	Vertical distance of metacentre above keel
L	Length of vessel or structure
L	Wavelength
L	Length of chain from fairlead to touch down point
l	Greater horizontal dimension
M	Mass of water displaced
m_D	Displacement of vessel
P	Amplitude of the harmonic force (maximum wave force)
P_y	Maximum hydrodynamic pressure at elevation y
q	Wind pressure
q	Proportion of critical damping
q	Submerged unit mass of chain
$R^2(f)$	Drift force coefficient at wave frequency f
$S_\eta(f)$	One-dimensional spectral density function of surface elevation, at wave frequency f
t	Time variable
V	Displaced volume of water
V	Incident current velocity
V	Basic wind speed
V_w	Design wind speed
w	Mass
w	Lesser horizontal dimension
x	Horizontal displacement
y	Vertical displacement
α	Maximum wave slope
α	Angle of wind or current to the axis
β	Phase angle
γ_{fL}	Load factor
η	Instantaneous height of water surface above still water level
θ	Angle of heel
θ	Angle of chain to horizontal, at fairlead
ξ	Wave particle horizontal amplitude
π	Ratio of circumference to diameter of circle
ρ	Mass density of water
ρ_1	Mass density of a liquid
ϕ	Angular displacement
ϕ_0	Amplitude of natural angular displacement

Section 2. Environmental loads

2.1 General

The various environmental phenomena which should be considered for investigation at a coastal site and methods of data collection are included in section 2 of BS 6349-1:1984. Information on sea states is contained in section 4 of BS 6349-1:1984 and general information on loads, movements and vibrations is contained in section 5 of BS 6349-1:1984.

The purpose of this section is to provide information on wave, wind and current loads which is specific to vessels and floating structures. For ships moored alongside a quay or jetty the information contained in clauses **30**, **31** and **42** of BS 6349-1:1984 should be used.

2.2 Return period and limiting conditions

A floating structure should normally be designed for extreme environmental conditions having a return period of not less than 50 years.

The moorings for a vessel or floating structure may be designed for conditions having an average return period of less than 50 years provided that there are contingencies which allow the vessel or structure to be safely removed before the design limits of the mooring are reached. For example, procedures may be laid down for a vessel to leave a mooring under its own power, and/or with tug assistance. In such instances the procedures should reflect the operational limits of tugs and/or line boats.

2.3 Combined loading

The environmental conditions assumed to occur simultaneously should be not less severe than the following:

a) the still water levels over a range equal to the range of the highest annual spring tide plus positive and negative storm surges;

b) the 1 min mean wind speed for the return period being considered[4)];

c) the 10 min mean current for the return period being considered;

d) the wave condition corresponding to the return period being considered.

Combinations of wind, current and waves should be considered for all directions.

2.4 Wave loading

2.4.1 Wave climate

The wave climate and design wave properties should be estimated in accordance with section 4 of BS 6349-1:1984. The range of conditions considered should reflect the characteristics of the vessel or structure, and the moorings. It should be noted that the response of moored vessels and structures to waves is highly dependent on wave period and wave length. For example, maximum response may occur when a wave period coincides with the natural frequency of motion of a structure, or when a wave length coincides with the structure length.

2.4.2 Description of wave loading

The primary wave-induced forces on a vessel or structure are oscillatory and have, in general, the same frequency characteristics as the waves themselves. They are usually defined as "first order" forces, which are proportional to wave amplitude. In addition to the oscillatory forces there are slowly varying drift forces which act on the vessel or structure and are primarily due to non-linear second order terms in the pressure field associated with the waves. These drift forces are proportional to the square of the wave amplitude and have a much smaller frequency than the first order forces. The magnitude of the forces is small compared to first order forces. There is a resulting mean value, commonly called the mean drift force. This mean drift force is similar to the wave "set-up" observed when a wave reflects off a fixed wall or shoreline.

Most floating structures are of sufficient size to cause disturbance of the waves incident on the structure. Physical models, and computational models based on diffraction theory can be used to simulate wave disturbances and hence the forces and resulting motions of a structure. Simple estimates of wave loading can be made for the two limiting cases of:

a) no disturbance of the waves;

b) complete reflection of the waves.

2.4.3 Basic design principles

2.4.3.1 *First order forces and resultant motions.* Vertical motions (pitch, roll and heave) cannot normally be suppressed by a mooring or restraining system and should be allowed to exist unimpeded.

[4)] Loads due to gusts of less than 1 min will usually be damped out in water. However, the effect of gusts should be checked for taut line mooring systems, small structures and small vessels.

Horizontal motions (surge, sway and yaw) can be suppressed by stiff restraining systems such as dolphins. However, significant wave action (of the order of 2 m height or over) will cause large first order forces. These forces can be avoided by providing a soft system, e.g. a chain or wire mooring, such that the structure moves freely.

In the case of a stiff restraining system, e.g. sets of dolphins, the stiffness of the system can be used in theory to predict the response of the vessel or floating structure to waves. However, in practice the softness or slackness of guide systems and fendering will allow motion which will generally be erratic and unpredictable. As a consequence, a stiff restraining system should be designed with an allowance for impact load added to the force required to hold the structure rigid.

For sheltered locations it may be sufficient to make simple estimates of forces and motions, as outlined in **2.4.4**. The use of physical or mathematical models should be considered for exposed locations.

2.4.3.2 *Drift forces and slowly varying motions.* The mean drift force acting on a vessel or structure should be considered as a steady force which acts in combination with steady forces due to wind and current. For locations where the significant wave height is less than 2 m, it is sufficient to make a simple estimate of mean drift force as outlined in **2.4.4**. Slowly varying drift forces and resultant motions may be neglected provided that the mean drift force is shown to be small.

For exposed locations, or locations where long waves are known to exist, mean and slowly varying drift forces should be estimated by taking account of the wave climate, the motions of the structure and the stiffness of the moorings. Physical or computational models which input irregular waves can be used to obtain estimates.

2.4.4 Simple estimates of forces and motions

2.4.4.1 *First order forces.* When a vessel or structure is small or slender it will have little effect on wave form, and forces may be estimated by the use of Morison's equation as described in **39.4.4** of BS 6349-1:1984.

When a vessel or structure is of a shape such that waves impingeing on it are reflected, forces can be estimated as for a standing wave. The maximum pressure on the structure elevation γ, relative to still water level P_γ (in kN/m²), is then given by the equation:

$$P_\gamma = \rho g \gamma + \rho g H_{inc} \cosh[2\pi(\gamma + d)/L]/\cosh(2\pi d/L) \quad (1)$$

where

- ρ is the mass density of water (in t/m³);
- g is the acceleration due to gravity (9.81 m/s²);
- γ is the elevation relative to still water level, measured positively upward (in m);
- H_{inc} is the incident wave height (in m);
- d is the still water depth (in m);
- L is the wavelength (in m).

Equation (1) neglects the set-up of the wave due to the presence of the vessel or structure.

For a structure extending to the seabed the maximum wave force for unit length of the structure (in a horizontal direction), F_{max} (in kN/m), is given by the equation:

$$F_{max} = \rho g H_{inc} L \tanh(2\pi d/L)/2\pi \quad (2)$$

For deep water equation (2) reduces to:

$$F_{max} = \rho g H_{inc} L/2\pi \quad (3)$$

For shallow water the equivalent equation is:

$$F_{max} = \rho g H_{inc} d \quad (4)$$

2.4.4.2 *Response to first order forces.* The response of a vessel or floating structure to regular waves can be described in terms of response amplitude operators (RAOs) which give the ratio

$$\frac{\text{amplitude of motion of vessel or structure}}{\text{amplitude of wave motion}}$$

for a defined wave frequency or period, or length. Simple estimates of RAOs can either be made from known estimates for similar vessels or structures, or recourse can be made to physical or mathematical modelling.

In deep water the horizontal amplitude of motion of a wave particle at the surface is equal to the vertical amplitude. As the water depth decreases, horizontal particle motions increase, as indicated in Figure 1. This increase should be allowed for when assessing horizontal motions.

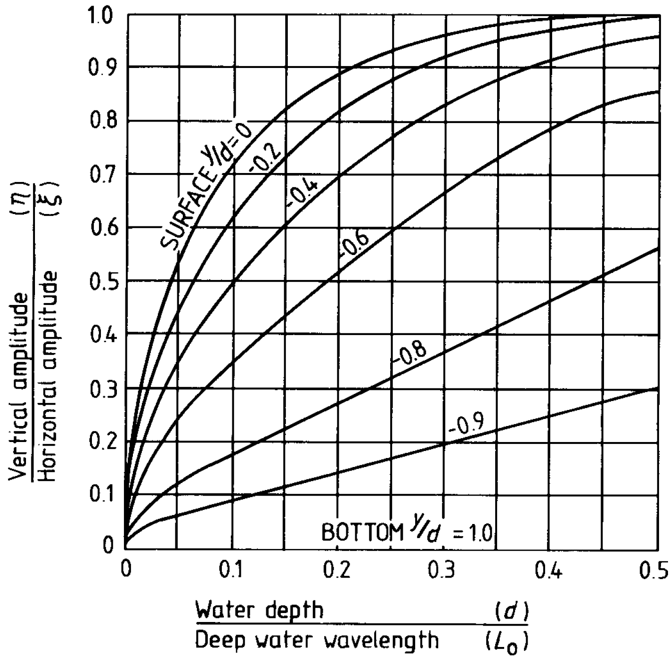


Figure 1 — Wave particle amplitude of motion versus water depth

2.4.4.3 *Mean wave drift.* The mean wave drift force, F_{WD} (in kN), in an irregular sea is given by the equation:

$$F_{WD} = 2gL\rho \int_0^\infty S\eta(f)R^2(f).df \qquad (5)$$

where

ρ	is the mass density of water (in t/m^3);
g	is the acceleration due to gravity (9.81 m/s^2);
L	is the length of the vessel or structure normal to the wave;
$S_\eta(f)$	is the one-dimensional spectral density function of surface elevation, at wave frequency f;
$R^2(f)$	is the drift force coefficient at wave frequency f.

The mean wave drift force in a regular sea is given by the equation:

$$F_{WD} = \rho g L R^2(f)\,(H/2)^2 \qquad (6)$$

where H is the height of the regular wave (in m).

Physical and mathematical models have been used to determine values of drift force coefficient $R^2(f)$ for tankers, semi-submersible vessels and barges [1, 2, 3, 4]. Various definitions of drift force coefficient exist, and care should be taken when interpreting results.

For a motionless structure the value of $R^2(f)$ tends to a maximum of 0.5 for waves of large frequency (small period). This value indicates full reflection of waves off the structure.

A simple conservative estimate of mean drift force can be made, without recourse to the modelling of a structure, by assuming that all waves are fully reflected off the structure, i.e. the value of $R^2(f)$ is 0.5. The mean drift force in an irregular sea is then given by the equation:

$$F_{WD} = \frac{\rho g L {H_s}^2}{16} \qquad (7)$$

where H_s is the significant wave height (in m).

Similarly the mean drift force for a regular sea is given by the equation:

$$F_{WD} = \frac{\rho g L H^2}{8} \qquad (8)$$

where H is the regular wave height (in m).

The equations for an irregular sea will generally apply. However, in certain instances, such as when a steady swell of almost invariant height exists, it may be more appropriate to consider the more conservative regular sea equation.

2.4.5 Physical models

Guidance on the use of physical models is contained in **31.3.2** of BS 6349-1:1984 and [5]. Tests are performed either in a narrow wave tank or a wave basin of large plan area. Tests in wave tanks normally allow accurate modelling of the vessel or structure and moorings. However, the wave climate is simplified in that it is essentially two-dimensional. The tests are often performed in order to calibrate mathematical models. Tests in wave basins often allow modelling of changes in wave climate due to topography, coastline and harbour features. However, care should be taken that the inclusion of these details does not lead to problems of scale when modelling a vessel or structure and moorings.

Model tests should be conducted by experienced personnel. The accuracy of tests will depend on the ability to satisfy scaling laws, the ability to model vessel or structure properties, the method of wave generation and the accuracy to which waves, vessel motions and mooring forces can be measured. The degree of accuracy of tests should be stated in test reports. Particular care should be taken when applying results to conditions which are different from those modelled, such as for instance when results are "scaled up" to represent more severe sea states.

The load factors and factors of safety normally applied in design should not be reduced as a consequence of model tests.

2.4.6 Computational models

Computational models are described briefly in **31.3.4** of BS 6349-1:1984. Most models use a three-dimensional source technique to account for the incident waves, diffraction of the waves by a vessel or structure, and the radiation of the waves due to the motions. The basic theory is usually referred to as "diffraction theory" [6].

In order to model vessels or structures they have to be divided into a number of small elements. Waves can be treated as either regular or irregular. However, irregular waves have to be modelled in order to calculate slowly varying drift forces.

Computational models are complex and should be run by personnel experienced in their calibration and operation. Where possible, results should be checked against those obtained from physical model tests or other calculations. Particular care should be taken to ensure that the most severe load cases are considered when evaluating factors of safety for moorings.

2.5 Wind loading

2.5.1 General

This clause covers factors considered to be of particular relevance to vessels and floating structures in coastal waters. It is intended to supplement CP 3:Chapter V-2. It should generally be used in conjunction with CP 3:Chapter V-2. However, sufficient information is included in this clause to allow loads on simple structures in "open" locations to be calculated without reference to CP 3:Chapter V-2. The information contained herein is also intended to supplement other codes applying to locations outside the British Isles.

2.5.2 Basic wind speed (3 s gust)

In CP 3:Chapter V-2 the basic wind speed is defined as the 3 s gust speed estimated to be exceeded, on the average, once in 50 years. A map of basic wind speeds at 10 m above ground in an open situation is provided in CP 3:Chapter V-2. A wind map for offshore locations is contained in Appendix B and has been derived by extending the wind map in CP 3:Chapter V-2 from the coast. These maps are compatible, and either may be used for coastal sites in the British Isles. However, the accuracy of the data and the availability of further data should be checked where necessary using expert advice such as that provided by the Meteorological Office.

Where local data is used to calculate basic wind speeds, care should be taken in converting wind speed to differing duration and height above sea level to the basic speed. If data from offshore locations such as weather ships or light vessels are to be used, the use of expert advice should be considered. The following information is a guide for data at the standard height of 10 m above sea or ground level:

a) *for data from offshore sites:*

3 s gust speed = 1.30 × 10 min mean speed;

3 s gust speed = 1.37 × hourly mean speed;

b) *for data from coastal or land station:*

3 s gust speed = 1.5 × hourly mean speed.

This information is based on the fact that gust speeds over the open sea are similar to those over open land. However, mean speeds over the open sea are higher than over land.

2.5.3 Design wind speeds

2.5.3.1 *General.* The design wind speed should be calculated by taking account of the type of structure, the height above sea level and the return period being used.

2.5.3.2 *Type of structure and height above sea level.* The height above sea level and type of structure can be accounted for by applying the factors given in Table 1 to basic wind speeds of 3 s duration.

Categories A, B and C (see Table 1) should be used for the design of individual members or substructures. Category D (see Table 1), which is based on a 1 min mean speed, should be used to derive the total loads on a vessel or floating structure. These recommendations are based on the fact that very short gust loads (less than 1 min) have little effect on the moorings of most floating vessels or structures unless they are small and are on taut lines.

Wind speed factors for "open" country (contained in CP 3:Chapter V-2) are similar to those contained in Table 1, except for heights of less than 10 m. The factors in CP 3:Chapter V-2 can be used but are not generally applicable to floating structures at heights of less than 10 m due to the fact that the wind is influenced less by the sea than by the ground. CP 3:Chapter V-2 does not contain information on 1 min mean speeds. A study of land based data for open sites provides an approximate relationship between the 1 min mean speed 10 m above ground level and the 3 s gust speed, as follows:

1 min mean speed = 0.82 × 3 s gust speed.

This information should be used with caution. The use of Table 1 to calculate 1 min mean speeds will lead to more generous estimates. For example, for the open sea at 10 m above sea level:

1 min mean speed = 0.85 × 3 s gust speed.

Table 1 — Wind speed factors for use over the open sea

Height	**Category**[a]			
	A	**B**	**C**	**D**
	3 s gust speeds	**5 s gust speeds**	**15 s mean speeds**	**1 min mean speeds**
	Individual members, etc.	**Small structures**	**Large structures**	**For use with maximum wave**
m				
5	0.95	0.93	0.88	0.78
10	1.00	0.98	0.93	0.85
20	1.05	1.03	0.99	0.93
30	1.09	1.07	1.02	0.97
40	1.11	1.09	1.05	1.00
50	1.13	1.11	1.08	1.03
60	1.14	1.13	1.09	1.05
80	1.17	1.16	1.12	1.09
100	1.19	1.18	1.14	1.12
120	1.21	1.20	1.16	1.15
150	1.23	1.22	1.19	1.17

[a] The four categories are as follows:

a) Category A refers to individual members, and equipment secured to them on open decks for which the 3 s gust speed applies with a factor for increase of speed with height according to a power-law equation having an exponent of 0.075.

b) Category B refers to parts or the whole of the superstructure above the lowest still water level whose greatest dimension horizontally or vertically, does not exceed 50 m, for which a 5 s gust applies using a power-law exponent of 0.08.

c) Category C refers to parts or the whole of the superstructure above the lowest still water level whose greatest dimension, horizontally or vertically exceeds 50 m, for which a 15 s mean speed applies using a power-law exponent of 0.09.

d) Category D refers to the exposed superstructure, regardless of dimension, to be used when determining the wind forces associated with maximum wave or current force which predominates, for which a 1 min mean speed applies using a power-law exponent of 0.12.

2.5.3.3 *Return period.* A factor S_3 (defined in **5.6** of CP 3:Chapter V-2:1972) based on statistical concepts can be applied to take account of the degree of security required and the period of time, in years, during which there will be exposure to waves. A factor of 1 should normally be applied, equivalent to a period of 50 years. For periods of exposure other than 50 years the factors presented in Figure 2 of CP 3:Chapter V-2:1972 and described in Appendix C of CP 3:Chapter V-2:1972 should be applied.

2.5.4 Force coefficient

Information on coefficients for ships is contained in clause **42** of BS 6349-1:1984. Coefficients are provided for longitudinal, transverse and rotational forces for winds in any direction.

Information on coefficients for individual structural members is contained in CP 3:Chapter V-2. Coefficients for the forces along the major axis of the members are provided for intervals of wind direction of 45°.

Information on coefficients for "box like" structures is provided in Table 2. The coefficients have been derived from Table 10 of CP 3:Chapter V-2:1972 and apply to winds acting normal to surfaces. For winds acting at an angle to the surface, forces may be evaluated as described in **2.5.6**.

2.5.5 Trim and heel

Trim or heel of a vessel or structure is usually only significant in open seas. Increases in wind loading due to trim or heel of a moored structure can usually be ignored.

2.5.6 Simplified method of evaluating wind loading

A detailed evaluation of wind loading cannot always be justified. A simplified approach may be sufficient for the following:

a) temporary moorings;

b) mooring of vessels, where contingencies exist for leaving the mooring;

c) mooring where large factors of safety apply;

d) locations where limited wind data exist;

e) feasibility studies.

A simple method for evaluating wind loads is provided below. The following assumptions are made:

1) the site is "open";

2) the height of the vessel or structure is small (< 20 m);

3) the structure is predominantly solid.

The design wind speed V_w may be taken as the 1 min mean speed, and can be related to the basic wind speed (3 s gust) V by

$V_w = 0.85\ V.$

The wind pressure q (in kN/m^2) may be taken as:

$$q = 0.613 \times 10^{-3} \times V_w^{\ 2} \qquad (9)$$

where V_w is the design wind speed (in m/s).

The wind forces on the structure are as follows:

$$F_x = qA_x\ (C_x \cos \alpha) \qquad (10)$$

$$F_y = qA_y\ (C_y \sin \alpha) \qquad (11)$$

$$F_{RW} = \sqrt{(F_x^{\ 2} + F_y^{\ 2})} \qquad (12)$$

where

x and y are the major axes of the structures;

F_x is the wind force acting along the x axis (in kN);

F_y is the wind force acting along the y axis (in kN);

q is the wind pressure (in kN/m^2);

A_x is the effective wind area normal to the x axis (in m^2);

A_y is the effective wind area normal to the y axis (in m^2);

C_x is the wind force coefficient for the x axis;

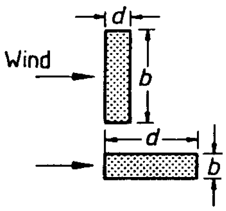
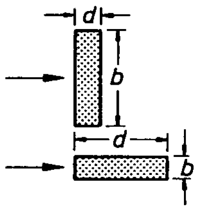
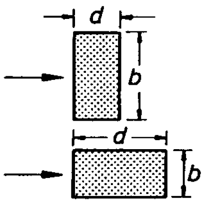
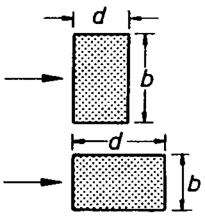
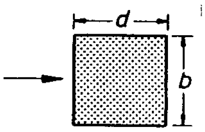
C_y is the wind force coefficient for the y axis;

α is the angle of the wind to the x axis;

F_{RW} is the resultant wind force (in kN).

The use of this method for loads on ships gives reasonable agreement with the method described in clause **42** of BS 6349-1:1984. The application of force coefficients of 1.0 to barge and pontoon hulls is standard practice, i.e. $C_x = C_y = 1.0$. The simplified approach outlined above should be used to check more detailed calculations.

Table 2 — Wind force coefficient C_f for rectangular bodies

Plan shape	l / w (see note)	b / d (see note)	Height/breadth ratio: Up to ½	1	2	4	6	10	20
			Wind force coefficient C_f						
	⩾ 4	⩾ 4	1.2	1.3	1.4	1.5	1.6	—	—
		⩽ ¼	0.7	0.7	0.75	0.75	0.75	—	—
	3	3	1.1	1.2	1.25	1.35	1.4	—	—
		1/3	0.7	0.75	0.75	0.75	0.8		
	2	2	1.0	1.05	1.1	1.15	1.2	—	—
		½	0.75	0.75	0.8	0.85	0.9	—	—
	1½	1½	0.95	1.0	1.05	1.1	1.15	—	—
		2/3	0.8	0.85	0.9	0.95	1.0	—	—
	1	1	0.9	0.95	1.0	1.05	1.1	1.2	1.4

NOTE
b is the dimension normal to the wind;
d is the dimension measured in the direction of the wind;
l is the greater horizontal dimension;
w is the lesser horizontal dimension.

2.6 Current loading

2.6.1 General

This clause complements clause **42** of BS 6349-1:1984.

2.6.2 Design speed

The design speed should be assessed taking account of the most unfavourable combinations of tide, surge and wind-induced currents for the return period being considered. It is normal to correlate current measurements with tide records. The assessment of maximum currents should reflect the accuracy and detail of the data on tide elevations and current speeds available. A simple assessment from chart data or Admiralty Sailing Directions (Pilots) should allow for the fact that values quoted are often typical rather than proven maxima.

The calculation of wind induced currents should be based on a wind of 12 h duration. The surface current speed is generally found to be 2 % to 3 % of the wind speed, and a linear decay of the wind induced current with depth is usually assumed.

It is recommended that a 10 min mean current speed is used in design.

2.6.3 Force coefficients

The nature of the forces on floating bodies is considerably complex and not fully understood. In theory, the forces depend on factors such as speed of flow, area normal to the flow, total wetted area, roughness, detailed form or shape, and the proximity of the seabed or other boundaries and bodies. In practice, simplifications are made when describing forces. For bodies where areas normal to the flow are small compared to their length parallel to the flow, such as the longitudinal forces on ships, the forces are usually described by a coefficient which relates the force to the current speed and the wetted area (usually defined in terms of length and draught). Coefficients for ships are given in clause **42** of BS 6349-1:1984.

For bodies presenting significant cross-sectional area to the flow (compared with length parallel to the flow), the force is usually described by a coefficient which relates the force to the current speed and the cross-sectional area of the body. Such an example is transverse loading on a ship. Coefficients for transverse loading are given in clause **42** of BS 6349-1:1984.

For a body where width normal to the flow is similar to the length parallel to the flow, the governing factor is usually assumed to be width not length. For forces on structural members such as cylinders or piles the following equation is used:

$$F_D = ½ (C_D \rho V^2 A_n) \qquad (13)$$

where

F_D is the steady drag force (in kN);

C_D is the drag force coefficient;

ρ is the mass density of water (in t/m^3);

V is the incident current velocity (in m/s);

A_n is the area normal to the flow (in m^2).

Drag coefficients for common pile shapes are contained in **38.2** of BS 6349-1:1984.

There is very little data on forces or coefficients for floating structures such as barges and pontoons. However, towing tests on barges have been performed, and graphs of typical drag coefficients are reproduced in Figure 2 to Figure 5 [7]. Towing tests on wall-sided boxes have also been performed and results are reproduced in Table 3 [4].

The coefficients in Figure 2 and Figure 3 and Table 3 apply when the water is deep (depth/draught $\geqslant$ 5). The coefficients in Figure 4 and Figure 5 apply in shallow water. The correction factor for ships in shallow water, given in Figures 29 and 30 of BS 6349-1:1984 may be used in place of the data in Figure 4 and Figure 5.

The following equations should be used when applying the coefficients given in Figure 2 to Figure 5.

$$F_x = ½ (C_x \rho V^2 A_x) \qquad (14)$$

$$F_y = ½ (C_y \rho V^2 A_y) \qquad (15)$$

where

F_x is the current force along the longitudinal (x) axis (in kN);

F_y is the current force along the transverse (y) axis (in kN);

C_x is the longitudinal current force drag coefficient;

C_y is the transverse current force drag coefficient;

ρ is the mass density (in t/m^3);

A_x is the effective current area normal to the longitudinal (x) axis (in m);

A_y is the effective current area normal to the transverse (y) axis (in m);

V is the incident current velocity (in m/s).

Table 3 — Typical current drag coefficients for wall-sided boxes

Shape of model	Breadth/draught ratio *B*/*D*	Drag force coefficient C_D
Square	8.1 3.4 1.6	0.72 0.70 0.86
Octagon (face leading)	8.1 3.4 1.6	0.57 0.52 0.60
Octagon (corner leading)	1.8	0.58
Cylinder	8.1 3.4 1.6	0.47 0.39 0.45
NOTE 1 A drag coefficient of 1.0 should be used unless more reliable values can be obtained. NOTE 2 The data source for this table is reference [4].		

2.6.4 Evaluation of model tests and theoretical formulae

Considerable care is required when interpreting model tests and theoretical equations due to difficulties in defining and scaling the various components contributing to the force or resistance of a body.

The drag force coefficient C_D is usually referred to as a "total" drag coefficient, since in theory it is composed of several components such as "pressure drag", "skin friction drag" and "wave making resistance". The total drag coefficient may not have been "corrected" to allow for depth or width limitations in the model tests. The use of "corrected" values of coefficients implies that no boundaries exist near the body. If boundaries such as the seabed do exist near the body, the coefficients may be factored to allow for the boundary.

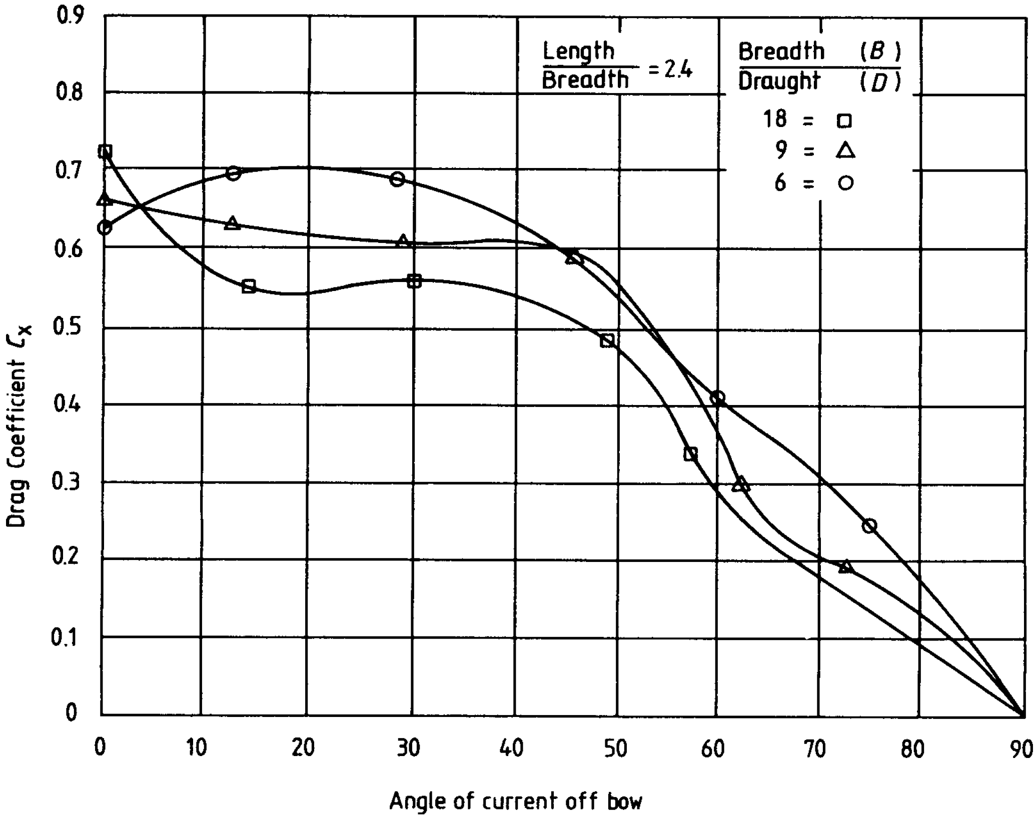


Figure 2 — Longitudinal drag coefficient for rectangular pontoon in deep water

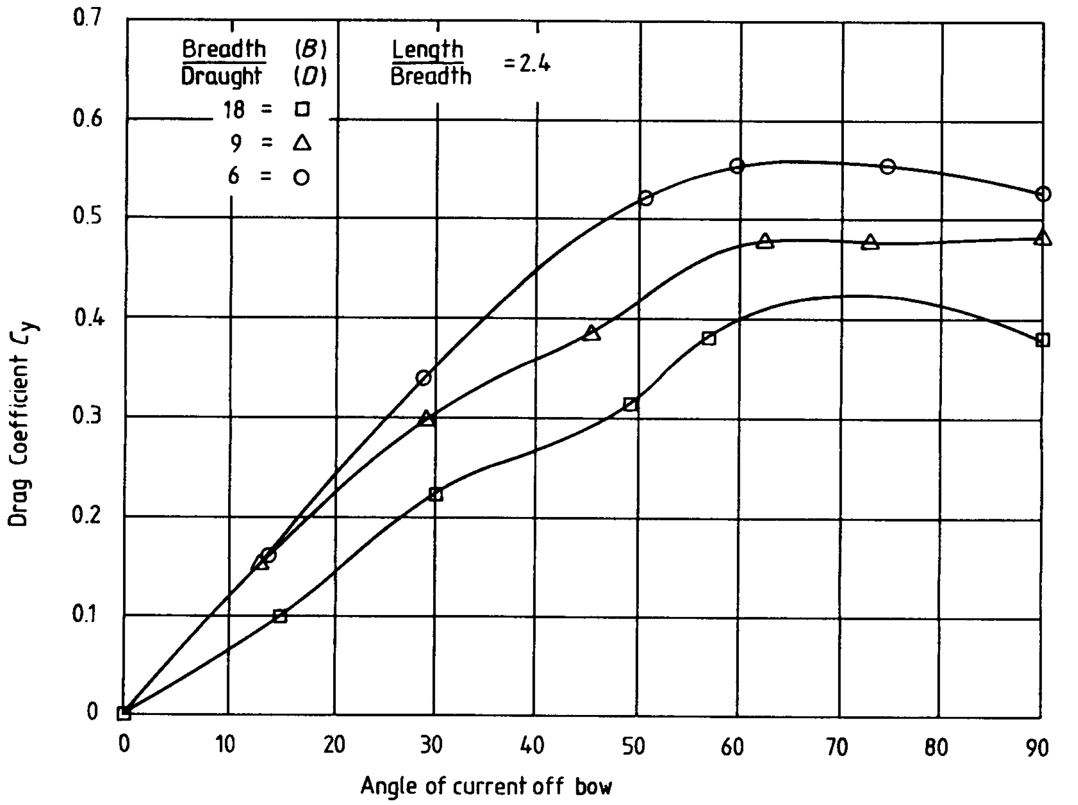


Figure 3 — Transverse drag coefficient for rectangular pontoon in deep water

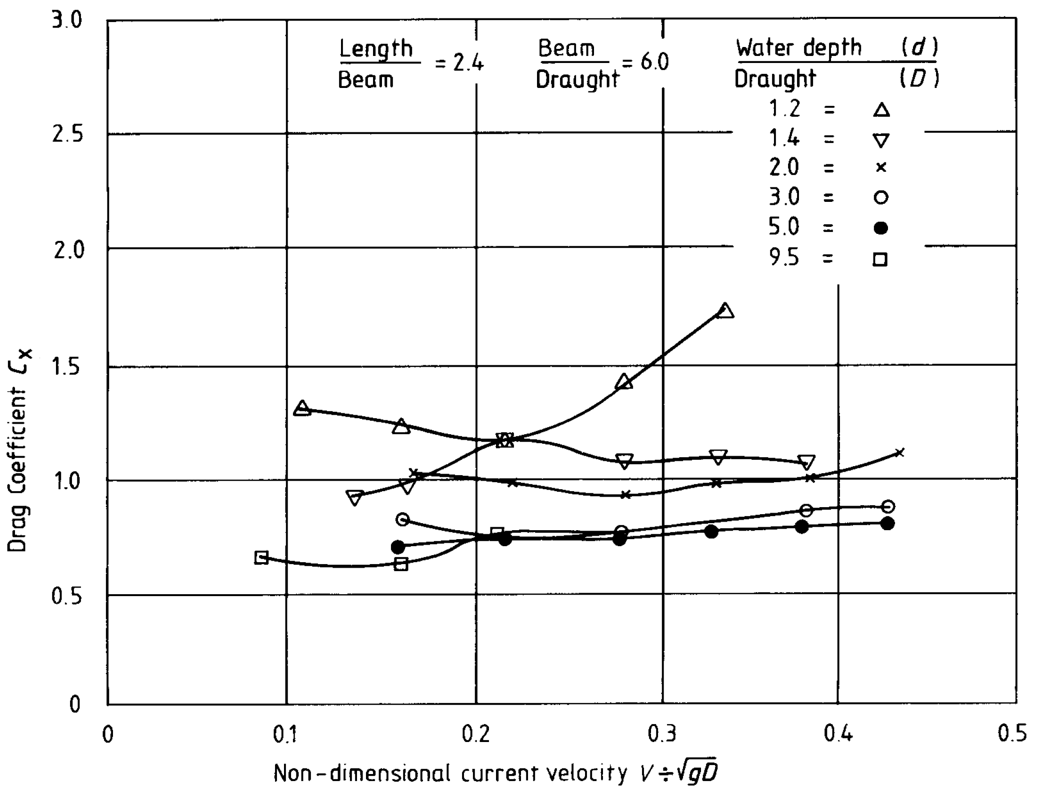


Figure 4 — Longitudinal drag coefficient at various water depths for rectangular pontoon with current head on

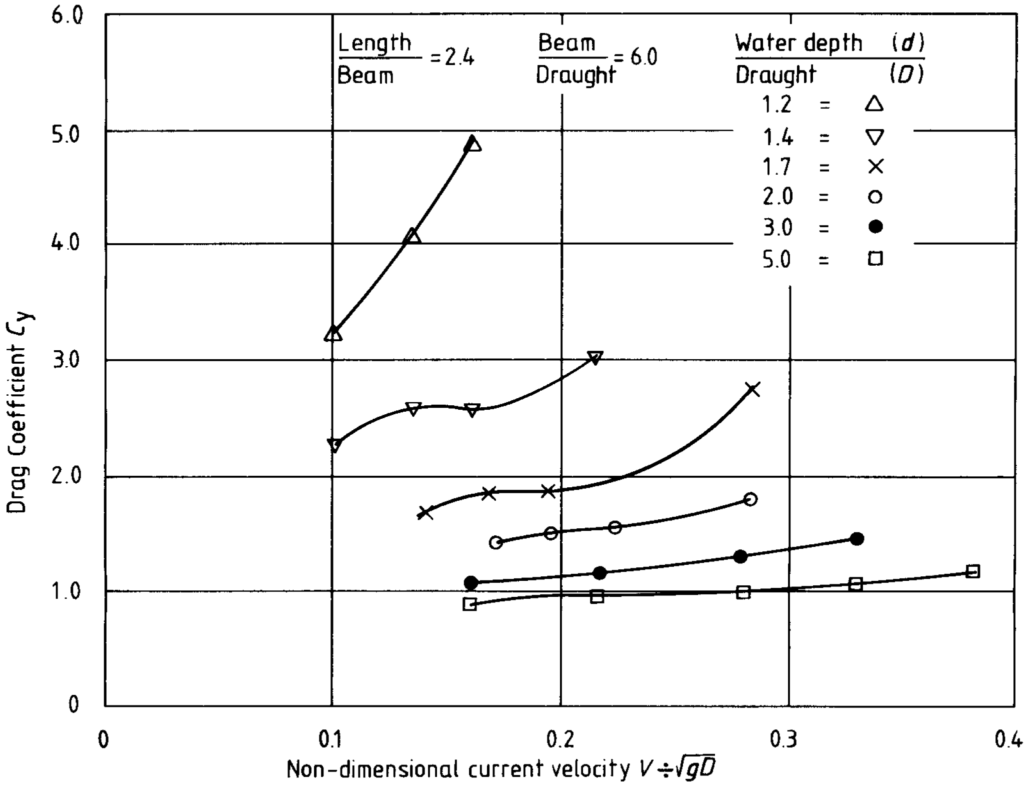


Figure 5 — Transverse drag coefficient at various water depths for rectangular pontoon with current beam on

The use of uncorrected values of coefficients assumes that the proximity of the real boundaries is similar to those in the model.

The assumptions on which the scaling of a model are based should be checked to ensure that the results are suitable for application to "full size".

2.6.5 Simplifications in design

In instances where wind and wave loads are dominant, a simplified approach to evaluating current loads may be justified. The application of a drag coefficient of 1.0 to a projected area normal to the flow will generally provide an adequate estimate of forces for deep water. A correction factor for depth should be applied for depth/draught ratios of less than 5.

Section 3. Moorings

3.1 General

The selection and design of moorings is considered in **3.2** to **3.5**. Information on anchors and mooring equipment is contained in **3.6** and **3.7**. Inspection of moorings is considered in **3.8**.

3.2 Types of moorings

3.2.1 General

Moorings can be composed of chain or wire lines spanning from the surface to seabed anchors, structures such as dolphins which are fixed to the seabed, or structures such as lattice booms which span between a fixed shorepoint and the moored structure. Moorings which employ chain or wire lines are referred to as "anchor leg moorings". They are described in **3.2.2**. Dolphins and mooring booms are described in **3.2.3**.

3.2.2 Anchor leg moorings

3.2.2.1 *Admiralty type mooring buoy.* This system involves a buoy connected by chain to a ground ring which lies on the seabed and connects ground anchors together (see Figure 6).

3.2.2.2 *Single anchor leg mooring (SALM).* This consists of a seabed anchor connected to the moored object by chain or wire or a combination of both (see Figure 7). The anchor for inshore moorings may be of the clump weight or gravity type. In certain instances piles may anchor a template to the seabed to resist the uplift forces. The single anchor leg mooring can be designed to maintain constant tension on the line by deballasting the buoy. This has the advantage of restricting the excursions and is known as a tension leg mooring.

3.2.2.3 *Catenary anchor leg mooring (CALM).* This is the common term frequently given to a multi-line mooring system connected to a buoy where the mooring lines are pre-tensioned against each other and remain in catenary at all times (see Figure 8). This system is frequently used for mooring buoys connected to submarine pipelines where the buoy is also used as a support for the oil product flowline which is in turn connected to the tanker which can "weathervane" around the buoy (see Figure 8). The system can be used without oil product flowlines and is frequently used with smaller mooring buoys in a spread buoy mooring system.

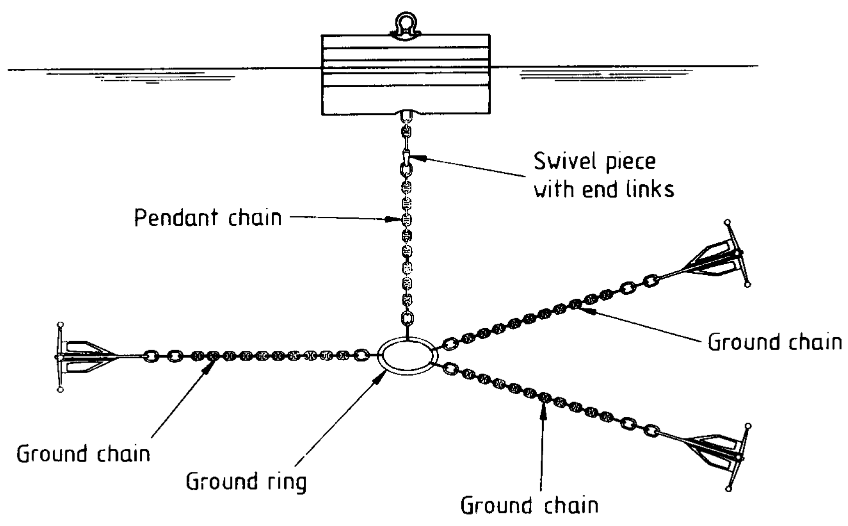


Figure 6 — Admiralty type mooring buoy

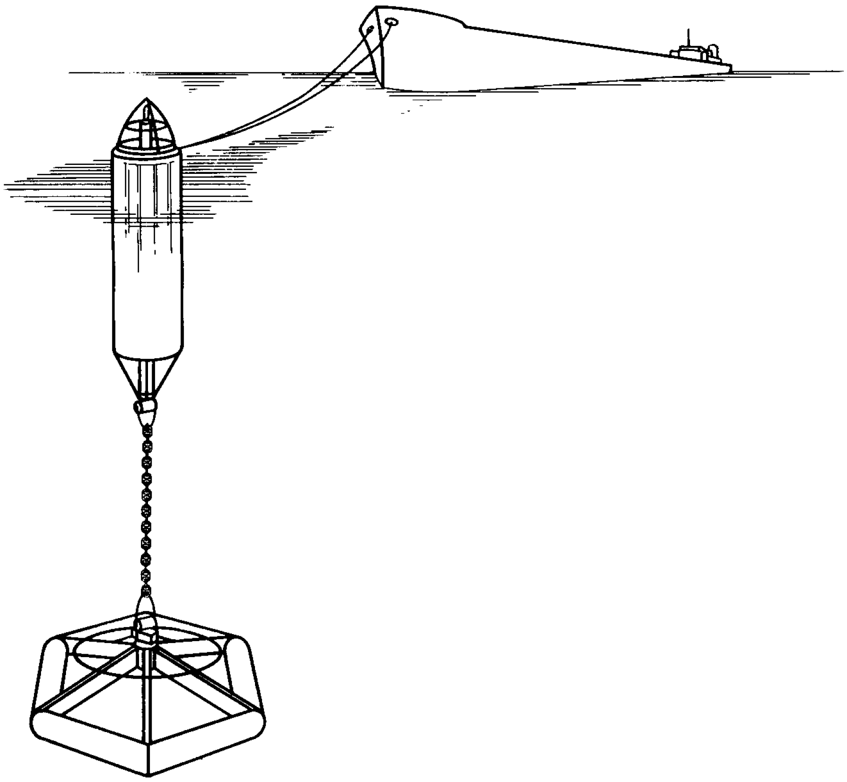


Figure 7 — Single anchor leg mooring

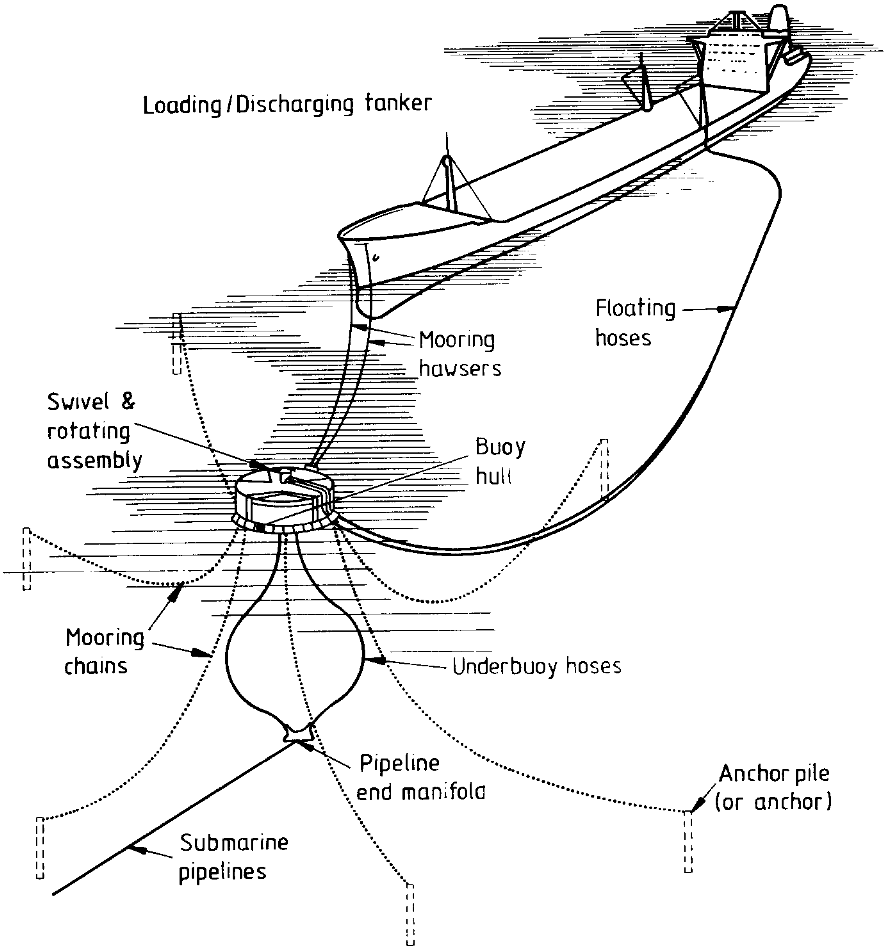


Figure 8 — Catenary anchor leg mooring or single point mooring (SPM) for tankers

3.2.2.4 *Spread buoy moorings.* These consist of several buoys which are positioned around the moored vessel or structure (see Figure 9). The buoys can be free of each other or they can be linked.

3.2.3 Mooring dolphins and booms

3.2.3.1 *Dolphins.* A typical arrangement of mooring dolphins used to hold a pontoon in position is shown in Figure 10.

The dolphins generally consist of a pile cap, vertical piles and in some cases raking piles for resisting horizontal loads. Pontoons often bear against vertical frames attached to the dolphins. In some cases mooring booms or mooring chains can be used to prevent the pontoon drifting away from the vertical frames of the dolphin. Alternatively, steel frames attached to the pontoon can be fixed around guide piles.

The frames have to be adequately fendered, using flat faced buffers or rollers, which allow vertical movement (throughout the tide range) without causing excessive horizontal movement. Small pontoons or jetties are often restrained using single piles rather than multi-pile dolphins.

3.2.3.2 *Mooring booms.* Mooring booms (see Figure 11) provide a simple control of a structure's position over the rise and fall of a tide. They are also suitable for controlling structures whose draught is likely to vary significantly, such as floating docks. They cannot accommodate horizontal forces due to environmental or impact loads, unless energy absorption anchorages are provided. Booms are hinged at each end.

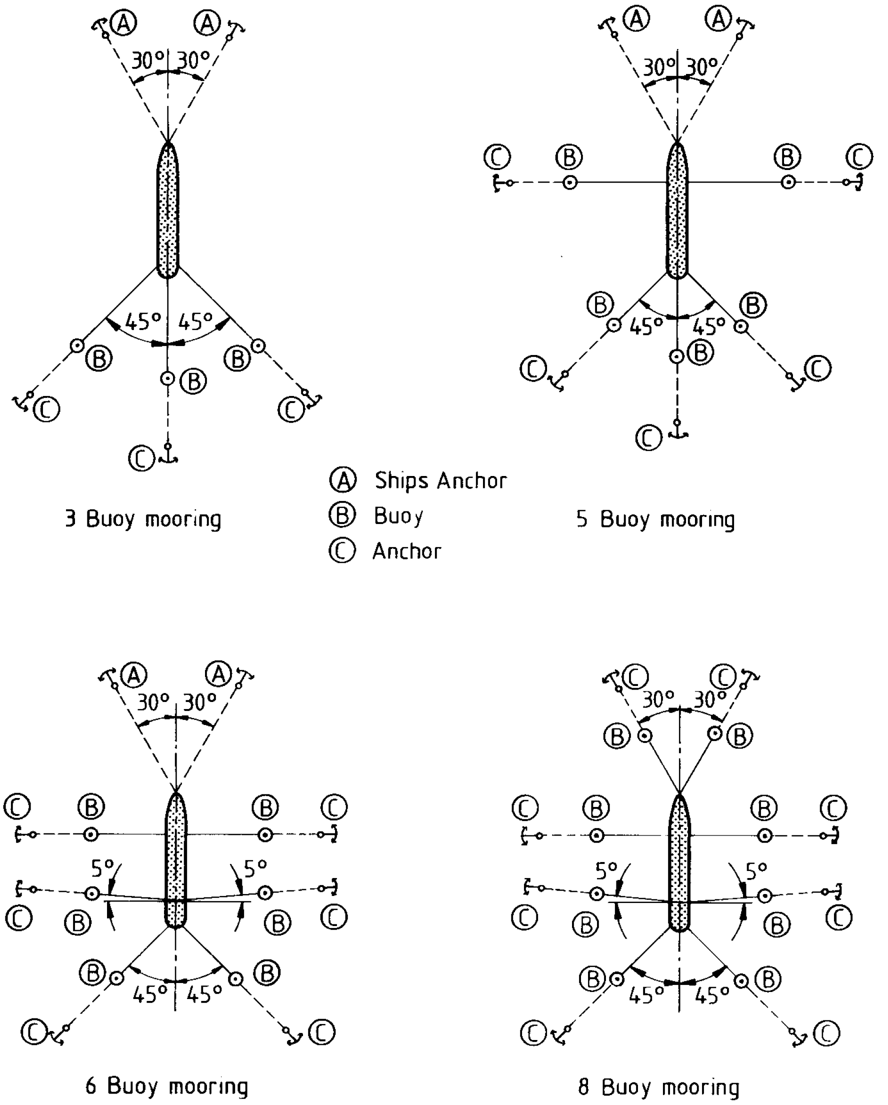


Figure 9 — Various arrangements of spread buoy moorings

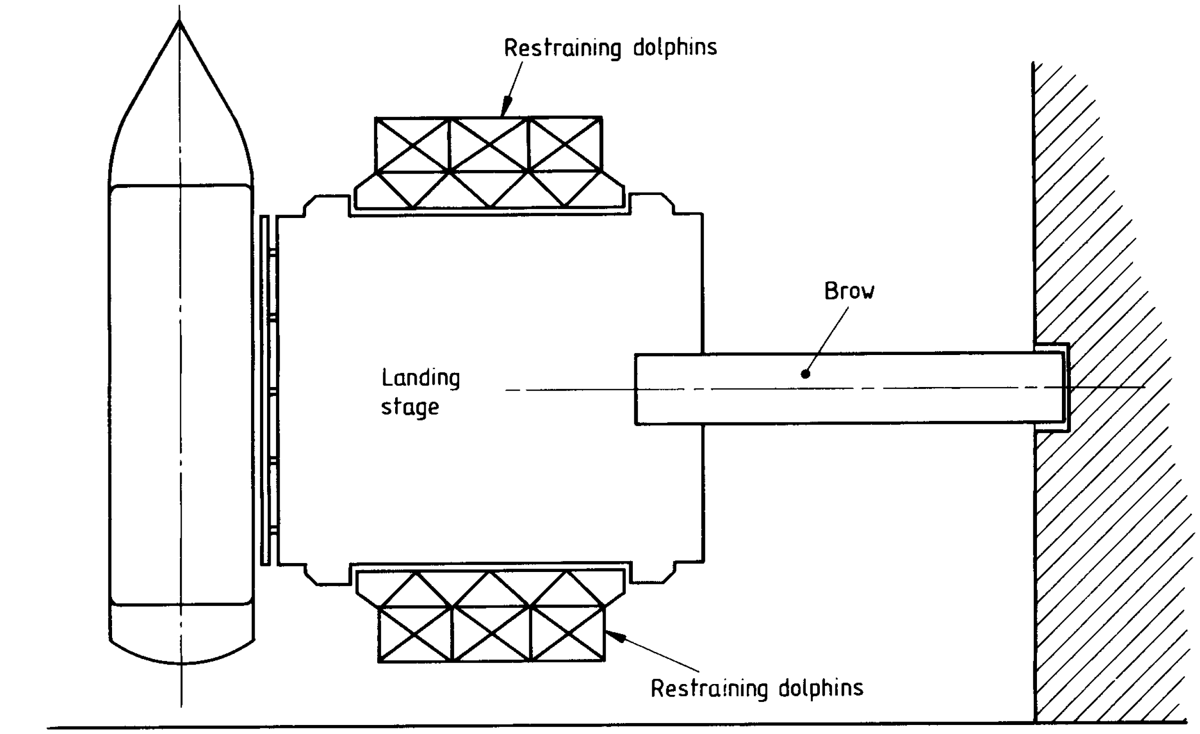


Figure 10 — Dolphins used to restrain a landing stage

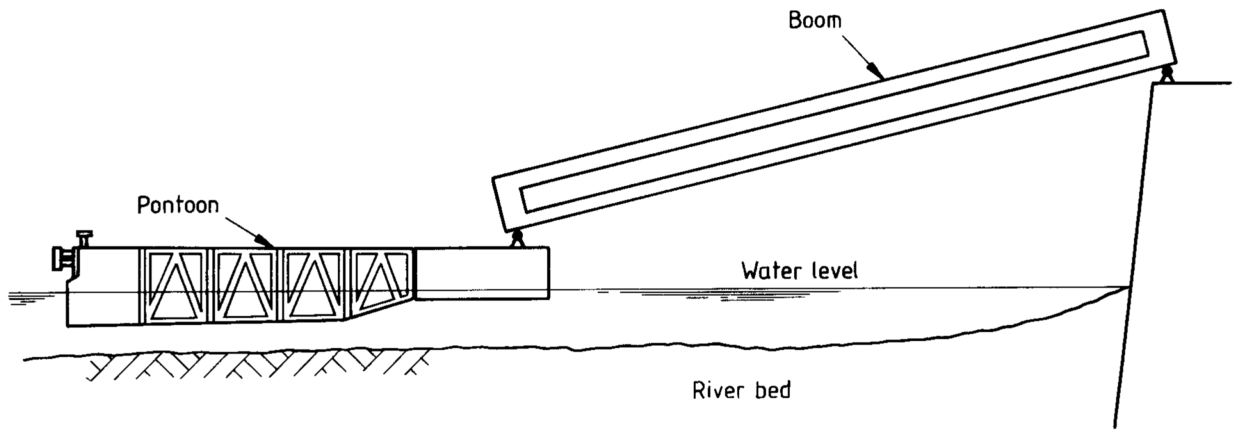


Figure 11 — Mooring boom

3.3 Selection of mooring system

3.3.1 Operational and environmental considerations

Selection of the mooring system should be based on full knowledge of the operational requirements of the moored structure or vessel, and the environmental conditions.
The following factors should be considered:

a) the prevailing direction of wind, wave and current, and the influence of water depth;

b) the tidal range;

c) restrictions on operations due to motions (roll, pitch etc.);

d) limitations, if any, on mooring excursions, e.g the need to be close to a pipeline terminal or overhead conveyor;

e) the type of access required;

f) the ability to attend to and adjust the mooring system;

g) the available searoom around the vessel or structure and the required underkeel clearance;

h) the mooring of other vessels alongside, for all or part of the time;

i) seabed conditions for piling or anchoring;

j) limitations on mooring layout due to sea-walls, breakwaters, etc.;

k) limitations on mooring layout due to other vessels operating in the vicinity;

l) the ease of manoeuvring into the mooring.

3.3.2 Commonly adopted mooring systems

3.3.2.1 Small craft moored in sheltered waters can be connected bow and stern to pre-installed buoys or single piles.

3.3.2.2 Small craft moored in exposed locations can be allowed to "weathervane" around the mooring buoy to minimize the mooring loads and prevent the craft from being swamped by beam seas.

3.3.2.3 Ships can be moored to a buoy or dolphin and allowed to "weathervane" but care has to be taken to prevent overrunning the mooring, and adequate searoom has to be available. Alternatively, depending on the degree of exposure of the location and operational requirements, they can be connected to a spread buoy mooring arrangement on a fixed heading.

3.3.2.4 Tankers which load or unload their cargo through submarine pipelines usually need to be moored on a fixed heading with a spread buoy mooring if loading is via floating hoses and a side manifold. If the tanker is large and the location exposed, a single point mooring system is generally adopted.

3.3.2.5 Bulk carriers which are loaded via a conveyor are usually required to moor on a fixed heading, using a spread buoy mooring system.

3.3.2.6 Ships laid up or undergoing repairs or which are used for permanent storage are moored using a spread buoy mooring system or single point mooring. They can be moored on a fixed heading using anchor buoys to supplement their own onboard system if searoom is restricted.

3.3.2.7 Landing stages and pontoons are frequently moored alongside piles or dolphins which restrict movement under operating and environmental loads. Mooring booms are used in areas of high tidal range. Anchor leg moorings are often used to hold the pontoons against the piles or dolphins.

3.3.2.8 Dry docks can be moored alongside quays or piles and dolphins, or they can be moored in open water locations using a conventional catenary anchor leg mooring system. Pre-installed spread buoy systems are also used.

3.3.2.9 Floating breakwaters and offshore pontoons would in most instances be moored using a conventional catenary anchor leg mooring system with drag embedment anchors or piles.

3.4 Design of anchor leg mooring

3.4.1 Check list of design activities

The following activities should be performed in designing a mooring system.

a) Obtain environmental data for the mooring location (wind, wave and current), hydrographic data from charts and surveys and geotechnical data for the probable anchoring area.

b) Obtain general arrangement and detailed drawings of the object to be moored and establish its operational and maintenance requirements.

c) Define design environmental criteria and calculate the environmental forces (consider direction and the summation of wind, wave and current).

d) Select the preferred mooring layout (number and position of mooring legs) and resolve the environmental forces along the mooring legs.

e) Determine the design safety factors for the components under consideration and select the anchor leg components (chain, wire, anchors, shackles, etc.).

f) Analyse the mooring line tensions and excursions of the moored object (by desk calculation or computer, as appropriate).

g) Modify the mooring system following the detailed analysis, e.g. by adding sinkers, extending the length of the leg, or increasing the number of legs, as appropriate.

h) Prepare detailed plans and elevations ensuring that all components can be connected to each other, and check the strength of the mooring point on the moored object.

i) Investigate and prepare detailed mooring procedures which will include any pre-laying of moorings and anchors, pre-tensioning of the system and post-tensioning after the moored object has been connected.

3.4.2 Environmental and geotechnical data

3.4.2.1 *General.* Information on environmental conditions, sea state and geotechnical considerations is given in section 2, section 4 and section 6 respectively of BS 6349-1:1984.

3.4.2.2 *Wind, wave and current.* Section 2 gives information on the effects of wind, wave and current on moored structures.

3.4.2.3 *Hydrographic data.* Hydrographic charts showing water depths at the location of the moored object and over the whole mooring area are essential. They should include submarine pipelines, obstructions, wrecks, and other moorings which may foul the proposed mooring. Special attention should be paid to the possibility of mooring lines crossing each other or of lines passing over pipelines or other seabed obstructions.

3.4.2.4 *Geotechnical data.* The extent of geotechnical investigations required for anchor selection will depend on the degree of sophistication of the mooring design, but the minimum requirement is to determine the nature and depth of the upper layer of sediment at the proposed anchor location.

Where there is a risk of rock outcrops fouling the mooring lines then seabed investigations should include the planned route of each mooring line.

3.4.3 Selection of number of mooring legs

In general, the least number of mooring legs possible should be selected. This is because the distribution of forces under these circumstances is more easily predicted and the costs thus reduced. Selection of the number of legs will depend on obtaining the correct balance between the reasonable size of components, the degree of redundancy required, the maximum allowable movement of the moored object, the site conditions and ease of handling. In this context, the degree of redundancy can be defined as the provision of additional mooring legs to cover possible failure in one line. For example, a 4-leg mooring has more redundancy than a 3-leg, and a 5-leg more than a 4-leg, etc.

3.4.4 Length of mooring line

The length of the mooring line should be such that maximum line tension does not give uplift forces on a drag embedment anchor. The length can be calculated using Table 5. If vertical forces at the anchor cannot be avoided then alternative forms of anchor (piled, deadweight, etc.) should be used.

3.4.5 Selection of mooring components

Reference should be made to the relevant clauses in this Part of BS 6349 for detailed descriptions of the various components used in a mooring system as follows:

a) anchors: **3.7**;

b) chains: **3.8.1**;

c) chain fittings: **3.8.2**;

d) wire ropes: **3.8.3**;

e) man-made fibre ropes: **3.8.4**.

The following summarizes the salient points in selecting the major components of a mooring system.

1) Chains are preferred for catenary moorings because of their greater weight, durability and robustness. They are proof tested to 70 % breaking load.

2) Wires are frequently used for lines above water due to their high strength to mass ratio, a typical application being the connection of vessels to floating buoys. They have a much shorter operational life than chains. They can be used for underwater moorings when frequent inspection is carried out.

3) Man-made fibre ropes are used in horizontal short term moorings where their elasticity and light weight is of advantage. They are susceptible to fatigue failure, abrasions, etc. and have to be replaced at frequent intervals.

4) Drag embedment anchors are the most common form of anchor. They can be separated into two main types, i.e. stock and stockless anchors of the traditional type and the modern, more effective, high holding power anchors. The former have a holding power to mass ratio of between 5 and 10 whilst the latter have a ratio of between 10 and 30 according to the anchor type and seabed characteristics.

5) Sections of chain are joined by Kenter type shackles which are of the same size as a common link and can pass over a windlass.

6) Chain and wires are connected to each other and to anchors and other fittings with either bow, Dee or anchor shackles. Shackles are proof tested to twice their safe working load (SWL) and have a breaking load of the order of six times SWL.

3.4.6 Capacity of mooring components

Chains and wires are normally designed using factors of safety (FOS) against breaking (see **3.5.5**). Shackles are generally designed according to safe working load. Mooring points are usually designed for ultimate capacity (see **4.2.1.3**). Anchors are usually designed by considering the holding power prior to dragging. Suggested criteria for selecting the capacity of each of the above mentioned components are given in Table 4.

Table 4 — Suggested criteria for selecting the capacity of mooring components

Component	Normal operating conditions	Extreme conditions
Chain (see **3.5.5**)	FOS = 3.0	FOS = 2.0
Ropes (see note 1) (see **3.5.5**)	FOS = 3.0	FOS = 2.0
Shackles	Maximum load = SWL	Maximum load < proof load
Mooring point on structure (see **4.2.1.3**)	—	Ultimate capacity = 1.2 × chain or wire breaking load
Drag embedment anchors (see note 2)	—	The holding power should be greater than the maximum load expected, but generally less than the breakload of the chain or wire
Piled anchors		Ultimate capacity at least minimum breaking load of chain or wire

NOTE 1 Adequate inspection and/or renewal is assumed. Higher factors of safety should be considered if the location is exposed such that heavy cyclic loading occurs.
NOTE 2 The consequences of anchor drag should be considered when selecting holding power.

3.5 Analysis of moorings

3.5.1 General

This clause refers to the analysis of anchor leg moorings in order to find line tensions and excursions of a moored vessel or structure.

3.5.2 Methods of analysis

3.5.2.1 *General.* Mooring line tensions should be calculated taking into account both steady forces on the moored vessel or floating structure, and motions of the vessel or floating structure. The three principal methods of evaluating line tensions are "quasi-static analysis", "frequency domain analysis" and "time domain analysis", see **3.5.2.2**, **3.5.2.3** and **3.5.2.4** respectively. Essentially, they differ only in the method by which the motions of the vessel or floating structure are allowed for in the analysis.

3.5.2.2 *Quasi-static analysis.* Quasi-static analysis is the most common form of analysis, and is invariably sufficient for the design of most moorings. Analysis can be performed using either a computer or desk calculations. However, in the latter case it is usually necessary to simplify the action of the moorings, such that each line gives restraint in either a longitudinal or a transverse direction, but not both.

The analysis is used for moorings where second order motions due to long waves are not significant (see **2.4.2**). The characteristics of most moorings are such that they will not affect first order motions. The maximum first order motions are assessed independently of the mooring system and then added to the movements of the structure or vessel due to steady loads from wind, current and mean wave drift. Methods of assessing first order motions and steady loads are discussed in **2.4.1**.

3.5.2.3 *Frequency domain analysis.* This method is used where the first and second order motions of the vessel or structure are significant. The response to regular or irregular waves, combined with steady forces due to wind, current and waves can be found by assuming the load and deflection characteristics of the moorings to be linear for the range of motions anticipated. The method relies on standard frequency response analysis for a multi-degree of freedom system. Wave forces are generally computed using diffraction theory (see **2.4.6**). The method should only be used if the load and deflection characteristics of the mooring system can be linearized for the range of motions expected and the steady forces being considered. The method requires the use of a medium to large capacity computer.

3.5.2.4 *Time domain analysis*. This method is used where the first and second order motions of a vessel or structure are significant and the load and deflection characteristics of the moorings are highly non-linear for the range of motions anticipated. The method of solution relies on standard integral techniques. Wave forces are generally computed using diffraction theory (see **2.4.6**). It is a time consuming method of analysis and can only be performed on medium to large capacity computers.

3.5.3 Mooring line characteristics

Mooring lines should be modelled using data on mass stiffness, proof loads and breaking loads supplied by manufacturers (see **3.8.1.5**).

Calculations should allow for tension in a line due to horizontal forces from a moored body and vertical forces due to line mass. Vertical pull due to motions of the structure can often be neglected. The possibility of a line becoming sufficiently taut to cause uplift on an anchor should be allowed for.

Calculations should be performed using standard equations for catenaries. Data applicable to non-elastic chain of uniform mass anchored to a flat (horizontal) bed is contained in Table 5.

3.5.4 Directional effects

The tension in each line should be analysed for forces from a range of directions. For simple moorings with high factors of safety it is sufficient to take a number of standard directions, such as the direction of each line, or eight points of the compass. In the latter case it is common to define a major axis of the floating structure as north. In certain cases where safety factors are low it will be necessary to evaluate tensions in each line by considering a small interval (of the order of 15°) between directions of force.

3.5.5 Factors of safety

The acceptability of factors of safety will depend largely on the function of the mooring and contingencies in the event of failure. The effects of any one line failing should be evaluated. Commonly accepted values for the factor of safety against a line breaking are as follows:

a) normal operating conditions: FOS = 3;

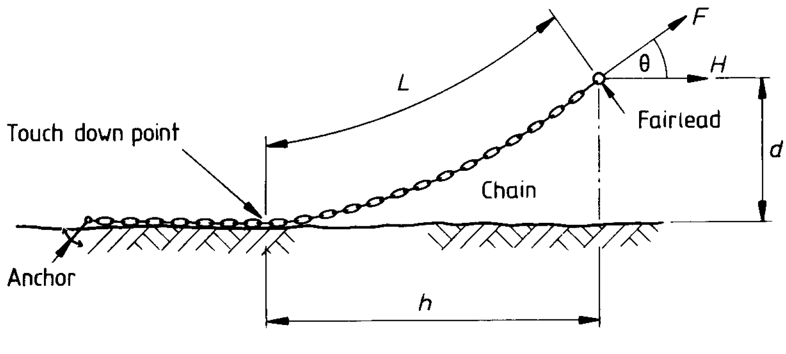
b) operating with one line broken: FOS = 2;

c) extreme conditions: FOS = 2;

where the factor of safety is defined as the minimum breaking load of the line divided by the maximum line tension. It is commonly accepted that the FOS for extreme conditions can be reduced from 2 to 1.4 in cases where it can be shown that line failure will result in a floating structure moving away from neighbouring installations.

Information on factors of safety for various components of a mooring line is contained in **3.4.6**. The factors of safety given in a) to c) are only a guide. Each mooring should be evaluated taking account of the degree of redundancy of the system, and the consequences of a vessel or structure moving outside its normal operating area, or completely breaking free.

Table 5 — Chain catenary: geometry and tension applicable at all water depths



Definition sketch of chain catenary

θ is the angle of chain to horizontal, at fairlead;
L is the length of chain from fairlead to touch down point;
d is the water depth;
h is the horizontal distance from fairlead to chain touch down point on seabed;
q is the submerged unit mass of chain;
F is the chain tension at fairlead;
H is the horizontal component of chain tension.

$\theta°$	$\frac{L}{d}$	$\frac{h}{d}$	$\frac{L-h}{d}$	$\frac{F}{qd}$	$\frac{H}{qd}$
90	1.00	0	1.0000	1.00	0.00
60	1.73	1.32	0.4151	2.00	1.00
55	1.92	1.55	0.3684	2.35	1.35
50	2.14	1.82	0.3258	2.80	1.80
45	2.41	2.13	0.2864	3.41	2.41
40	2.75	2.50	0.2495	4.27	3.27
35	3.17	2.96	0.2146	5.53	4.53
30	3.73	3.55	0.1813	7.46	6.46
25	4.51	4.36	0.1493	10.67	9.67
20	5.67	5.55	0.1183	16.58	15.58
15	7.60	7.51	0.0889	29.35	28.35
12.5	9.13	9.06	0.0732	42.20	41.20
10	11.43	11.37	0.0584	65.80	64.80
07.5	15.26	15.21	0.0437	117.00	116.00
05	22.90	22.87	0.0291	263.00	262.00

3.6 Design of mooring dolphins and booms

3.6.1 Dolphins

3.6.1.1 *General design.* The design of piles and dolphins should be in accordance with sections 6 and 7 respectively of BS 6349-2:1988. Additional information on flexible dolphins is contained in **4.9.3** of BS 6349-4:1985. It should be noted that the term flexible is used in relation to berthing energies absorbed and does not imply that flexible dolphins can absorb wave motions.

3.6.1.2 *Special considerations.* Dolphins should be designed to take combined wind, current and wave loads acting on the moored structure and any vessels alongside. There should be sufficient resistance to peak wave forces and an allowance for motions of the structure, within the tolerances of any fendering or guide system installed for control of the structure, should be made (see **4.5**). Berthing loads are covered in BS 6349-4. They should include an allowance for accidental berthing. Possible variations in tidal conditions and draught of the structure should be considered when evaluating stresses in a dolphin.

3.6.2 Mooring booms

Careful detailing of shore and structure connections are required to ensure that all likely motions can be accounted for.

Booms should be designed to ensure that buckling does not occur. Impact loads due to accidental collision or heavy berthing are difficult to absorb at boom anchorages. Loading of booms can be limited by providing additional restraints such as dolphins or chains.

3.6.3 Fendering and guides

3.6.3.1 *Fendering.* The design of berthing fenders is included in BS 6349-4. Guidance on materials for fendering and rubbing strips is contained in **60.3.4**, and **67.2.2** of BS 6349-1:1984. The general principles of fendering between vessels for transfer operations can be found in [8] and [9].

3.6.3.2 *Guides.* Guide systems such as piles surrounded by roller bearings or “collars” of steelwork can contain buffers which reduce impact loads and wear and tear on steelwork. Provision should be made for adjusting and replacing guide brackets. The consequences of a guide “jamming” should be considered.

3.7 Anchors

3.7.1 Types

3.7.1.1 *Deadweight anchors.* Deadweight anchors consist of solid blocks of steel or concrete which are also known as “clumps” or “sinkers”. They rely only on their weight and friction with the seabed to generate holding power. Although these anchors are of the earliest form they are still used today in various sizes which can be up to several hundred tonnes. They have a poor holding power efficiency and can be expensive to install if large in size. Their most frequent use is in mooring small craft and yachts but they have been successfully used for mooring large structures in areas of poor holding ground, and where uplift forces need to be resisted.

3.7.1.2 ***Drag embedment anchors***

3.7.1.2.1 *General.* Drag embedment anchors penetrate the seabed under load and generate their holding power by building up a wedge of material in front of the anchor fluke. Drag embedment anchors are known by their type or trade name. Some are manufactured and supplied under licence, others exclusively by the designer. Examples of the more common types presently available are illustrated in Appendix C and described in **3.7.1.2.2** to **3.7.1.2.5**.

3.7.1.2.2 *Hook anchors.* Hook anchors, which are the earliest form of ship’s anchor, are of a “V” form and made from cast iron and wood. These anchors are reliable on all types of sea floor, but their holding efficiency is very low when compared with modern design.

3.7.1.2.3 *Stockless anchor.* This drag embedment type of anchor replaced the hook anchor at the turn of the century and is widely used today in the shipping industry. It is robust and well suited for varying seabed conditions but it does not have the most efficient holding capacity by modern standards because it is stockless and therefore has a relatively small fluke area.

3.7.1.2.4 *Articulated stock anchor.* Stocks were added to anchors to give greater stability and roll resistance when penetrating the seabed. Articulation between the fluke and the shank allowed for adjustment to suit different soil conditions and better stowage. Typical stock anchors are Danforth, LWT, AC 14, Stato, Boss and Moorfast. This type of anchor has been widely used on barges and semi-submersible platforms since 1942.

3.7.1.2.5 *High holding power anchors.* High holding power anchors have been developed since about 1970 due to the offshore petroleum industry's requirements to moor large structures in exposed locations offshore thus requiring holding power in the range of 200 t to 500 t. The most efficient type of high holding power anchors are the Bruce anchors, the Stevin range (Stevmud, Stevfix, etc.) and the Flipper delta. These anchors are a further development of the stock anchor and are all of the drag embedment type.

Stock anchors, although generally being less efficient, may however fall into the category of high holding power because their efficiency (see **3.7.2**) is significantly greater than the early stockless anchors. Such anchors include those listed in **3.7.1.2.4** [10, 11].

3.7.1.3 *Piled anchors.* Piled anchors consist of tubular steel (or concrete) piles driven or drilled into the seabed with "padeyes" or other fittings which allow connection to mooring chains and wires. These anchors are used generally only for long-term moorings because, once installed, they usually cannot be removed. Piles can be used singly or in clusters to secure anchor frames to the seabed. Such anchors are better suited for resisting uplift forces than all types of drag embedment anchor which will become unstable and pull out of the seabed if any vertical uplift force is applied.

3.7.1.4 *Special anchors.* A variety of novel anchoring methods has been developed in recent years. These are not suited for most types of mooring systems because their proven experience is limited. In certain circumstances they may be used where unusual mooring requirements exist. Examples are:

a) *vibro-driven anchors,* which are formed of an anchor plate which is vibrated into the seabed and rotates such that it mobilizes the passive pressure of the soil;

b) *penetrant anchors,* which are pushed into the seabed and open up to provide resistance to upward forces;

c) *suction anchors,* which provide resistance by creating a vacuum in a drum on the seabed;

d) *fluidization anchors,* which penetrate the seabed by a water injection system which fluidizes the soil and allows the anchor to sink under its own weight.

3.7.2 Anchor holding power

Anchor holding power is a function of the mass of the anchor and its ability to mobilize the passive resistance of the soil by penetrating the seabed.

Holding power is typically defined as the anchor efficiency which is equal to the holding power divided by the anchor mass.

Anchors of the gravity or deadweight type have the lowest efficiency, and the modern high holding power anchors have, as their name suggests, the highest efficiency because they are designed for maximum penetration. The deeper the anchor penetrates the greater the volume of soil that is mobilized.

The holding power of the drag embedment types of anchor (i.e. stock, stockless, high holding power) is a function of:

a) fluke area;

b) fluke to shank angle (see Figure 12);

c) shear strength of the soil.

The fluke to shank angle can be pre-set on most forms of modern anchor and should be 32° for cohesive and 50° for non-cohesive soils.

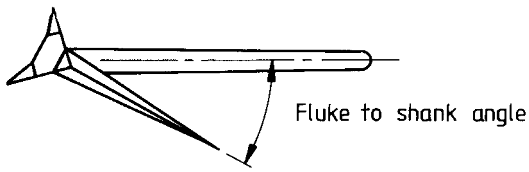


Figure 12 — Fluke to shank angle

Table 6 gives the approximate range of anchor efficiencies for the different anchor types.

Further information on anchor holding power can be obtained from anchor manufacturers and standard texts [10, 12].

Table 6 — Approximate anchor efficiency

Anchor type	Range of efficiency	
	Poor soils	Good soils
	Silts and soft clay	Sand and firm clay
Deadweight anchors	0.3 to	0.5
Stockless anchors	2 to	5
Stock anchors	5 to	10
High holding power anchors	10 to	30

NOTE Anchor efficiency = $\frac{\text{anchor holding power}}{\text{anchor mass (in air).}}$

3.7.3 Summary of features

3.7.3.1 *Deadweight (clump) anchors* (see **3.7.1.1**). The salient features of deadweight (clump) anchors are as follows.

a) They are robust and have a holding power generally independent of the seabed conditions.

b) They are suitable for lower mooring line tensions especially where the force may be omnidirectional.

c) In larger sizes they require heavy lifting equipment for installation and recovery.

d) They can be built to any size, providing marine lifting equipment is adequate but limited generally by cost effectiveness of installation method.

e) They can be made self-buoyant in large sizes and ballasted on to the seabed with gravel or concrete or similar high density material.

3.7.3.2 *Traditional stock and stockless anchors* (see **3.7.1.2.2** to **3.7.1.2.4**). The salient features of traditional stock and stockless anchors are as follows.

a) The anchor's own mass represents a higher percentage of ultimate holding capacity than in the case of high holding power anchors.

b) They are robust and require a less scientific approach in their design and selection.

c) They do not require great depths of soft sediment for adequate penetration.

d) They are made from cast iron or steel which, although making them robust, does restrict their size to a maximum of about 30 t.

e) They have holding power within the normal capacity of inshore moorings.

f) They can accept some uplift forces without significantly reducing their holding power.

g) They are more suited to ships moorings and single point moorings where the mooring load is applied over a wide horizontal angle.

3.7.3.3 *High holding power drag embedment anchors* (see **3.7.1.2.5**). The salient features of high holding power drag embedment anchors are as follows.

a) They require a seabed which can be penetrated, i.e. one where the upper layer consists of soft to firm clay, silts or sand.

b) They rely on a large fluke area to mobilize the passive resistance of the soil.

c) They require a depth of sediment which allows at least full penetration of the anchor and therefore has to be at least 0.5 m for anchors of up to 1 t in mass and 3 m to 5 m for anchors of over 1 t and up to 20 t.

d) They will move horizontally (defined as anchor drag) as well as vertically downwards (anchor penetration) in developing their holding power.

e) They require the fluke to "trip" open during the initial load application to commence penetration.

f) They can be designed to provide holding capacities of over 1 000 t equal to the strongest chains available and are frequently used for holding loads in the range 200 t to 500 t.

g) They are of welded steel construction which (theoretically) gives no limit on the size of anchor that can be manufactured (current largest size is 65 t).

h) They cannot accept any vertical uplift forces without reducing efficiency.

3.7.3.4 *Piled anchors* (see **3.7.1.3**). The salient features of piled anchors are as follows.

a) They are ideal where anchor drag during load application is not permitted.

b) They cannot be recovered and therefore are only suited to long-term mooring applications.

c) They only become cost effective when installed in quantity or as part of another piling operation, because of cost of mobilizing piling rig.

d) They are suitable when the mooring line needs to be removed for maintenance at regular intervals, except in shallow water or in locations where easy diver access to the connecting shackles is possible.

3.7.3.5 *Special anchors* (see **3.7.1.4**). The salient features of special anchors are as follows.

a) They are less predictable during installation, e.g. they can be deflected off course by boulders.

b) They give less predictable holding capacity.

c) They usually require a more complicated mechanical method of installation.

d) They may be suitable for unusual mooring requirements, e.g. low loads in deep water where other anchors may require heavy marine equipment.

e) They are not frequently used in the marine and offshore industries.

3.7.4 Manufacture and certification

The manufacture of anchors is in most cases approved by one of the leading classification societies (Lloyd's Register, DNV, ABS, etc.).

This approval involves an independent check of the structural components and overall structural design of the anchor together with material analysis, physical tests and a proof test on completion of manufacture. Certificates are issued for each anchor showing that it has been approved. These should correspond with stamp marks on the anchor. The proof test involves jacking the fluke away from the shank to a specified force and measuring the permanent set, if any, on release of the proof load. It should be noted that the point of application of the force on the fluke is one-third of the fluke length from the tip of the fluke.

3.8 Mooring equipment

3.8.1 Chains

3.8.1.1 *Grades*

3.8.1.1.1 *General.* Mooring chain is manufactured from four different internationally accepted qualities of steel, designated grade 2, grade 3, oil rig quality (ORQ) and grade 4, in bar sizes which range from about 20 mm to 180 mm diameter. Chain of grades 2, 3 and 4 is manufactured to Classification Societies Specification (Lloyds Register etc.) and ORQ chain is based on the American Petroleum Industry's (API) Specification. Grade 1 chain is no longer manufactured.

3.8.1.1.2 *Grade 2.* Grade 2 chain is the lowest quality chain manufactured. It has been used successfully in moorings but, as stated in **3.8.1.1.3**, grade 3 chain is recommended.

3.8.1.1.3 *Grade 3.* For most inshore mooring configurations grade 3 chain is the most suitable. It is the most common grade used and its cost per unit mass is only marginally greater than that of grade 2 which is significantly heavier for a comparable breaking load.

3.8.1.1.4 *Oil rig quality.* ORQ chain, although having the same mass to strength ratio as grade 3, has special properties which make it more suited to deepwater offshore moorings. It is more brittle than grade 3 and therefore more affected by handling blemishes, e.g. notches, scours.

3.8.1.1.5 *Grade 4.* Grade 4 chain is only used where a high strength to mass ratio is required. It is very brittle and is not suited for the moorings covered in this Part of BS 6349.

3.8.1.2 *Sizes.* The most commonly used chain sizes for mooring are in the range 50 mm to 75 mm which have breaking loads varying from about 1.37 MN to 6 MN, depending on the material and diameter (see Figure 13).

3.8.1.3 *Shots.* Chain is normally manufactured in lengths of 27.5 m which are known as shots. Chain can be ordered in continuous lengths, thus avoiding the need for expensive joining shackles. For most inshore moorings the convenience of having chain supplied in shots outweighs the additional costs involved.

3.8.1.4 *Studs.* Chain can be ordered with or without inserted studs. In order to maintain the same strength, chains without studs (i.e. open links) need to be formed of metal of 20 % greater diameter than chain with studs. For the moorings covered within this Part of BS 6349, inserted stud link chain only should be used. The studs should not be welded as this can lead to a greater risk of manufacturing defects.

3.8.1.5 *Proof load.* The exact size of chain and theoretical breaking load will vary slightly with each manufacturer, and reference should be made to printed literature from the supplier to obtain quoted breaking loads and proof loads. All chain is proof load tested to about 70 % of the estimated breaking load and a 3-link sample is tested to breaking load.

3.8.1.6 *Break test.* Up to one break test is taken per shot or heat treatment batch.

3.8.1.7 *Identification.* Chain is usually identified at the end links with hard stamping, and the length supplied with a certificate of proof load and break tests and of proper manufacture issued by one of the classification societies (e.g. Lloyd's Register of Shipping).

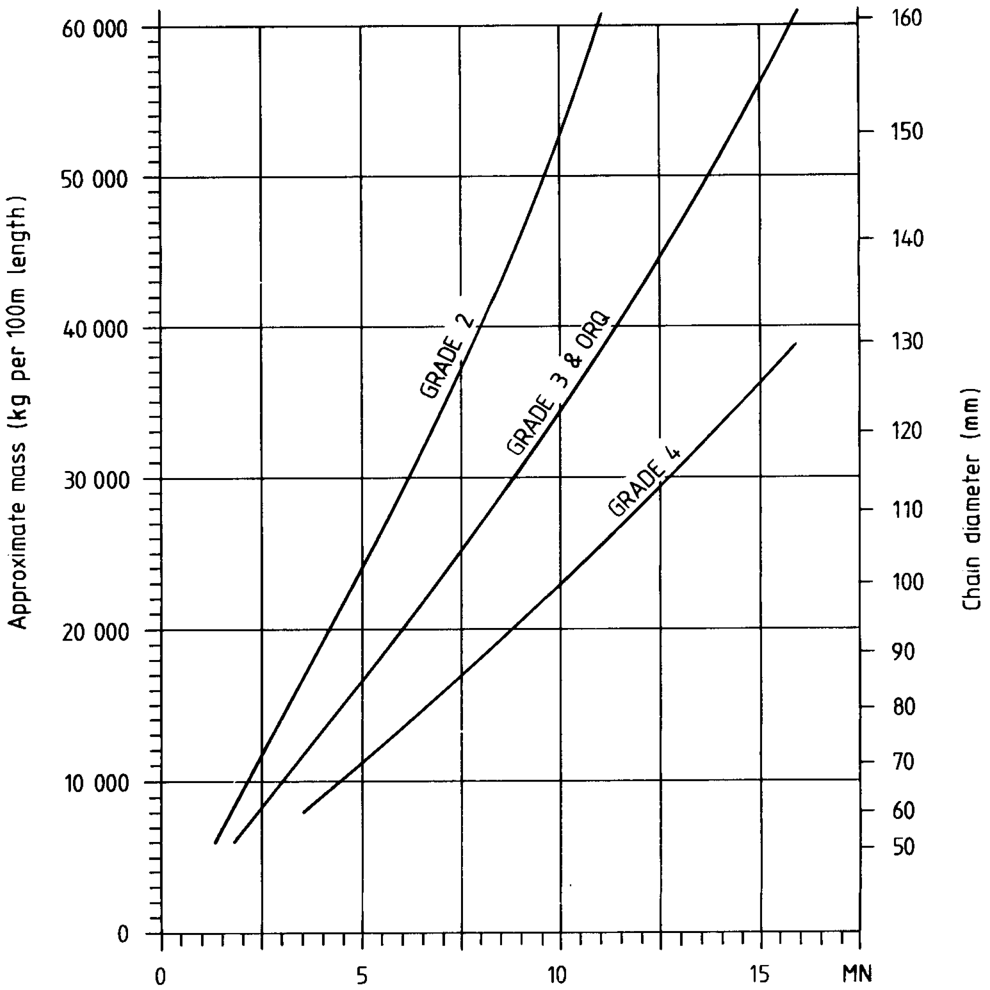


Figure 13 — Comparison of chain strengths

3.8.2 Chain fittings

3.8.2.1 *Types.* Individual lengths of chain, and connections between the chain and the anchor or chain locker, are normally made with a shackle. Figure 14 shows the different types of individual connections, and their application for coupling to the anchor and between lengths as follows.

a) *Common link.* See Figure 14 (a) which shows an inserted stud link.

b) *Enlarged link* [see Figure 14 (b)]. This is commonly used in connection with an anchor swivel.

c) *End link* [see Figure 14 (c)]. This is often used as the connection between a swivel and anchor shackle or between the end of a chain and the chain locker connection.

d) *Joining shackle, type Dee* [see Figure 14 (d)]. The pin is removable, and the shackle is used to secure the end of the chain in the locker or to join lengths, but not in ships.

e) *Joining shackle, type Kenter* [see Figure 14 (e)]. This is a carefully machined shackle which splits in two halves, both halves being secured with an angled taper pin and lead sealing plug. It is of compatible size with common links and is thus used to join lengths which have to pass over a windlass. This type of shackle is also known as a lugless shackle.

f) *Anchor shackle, type Dee* [see Figure 14 (f)]. This is used to connect the anchor to the end link.

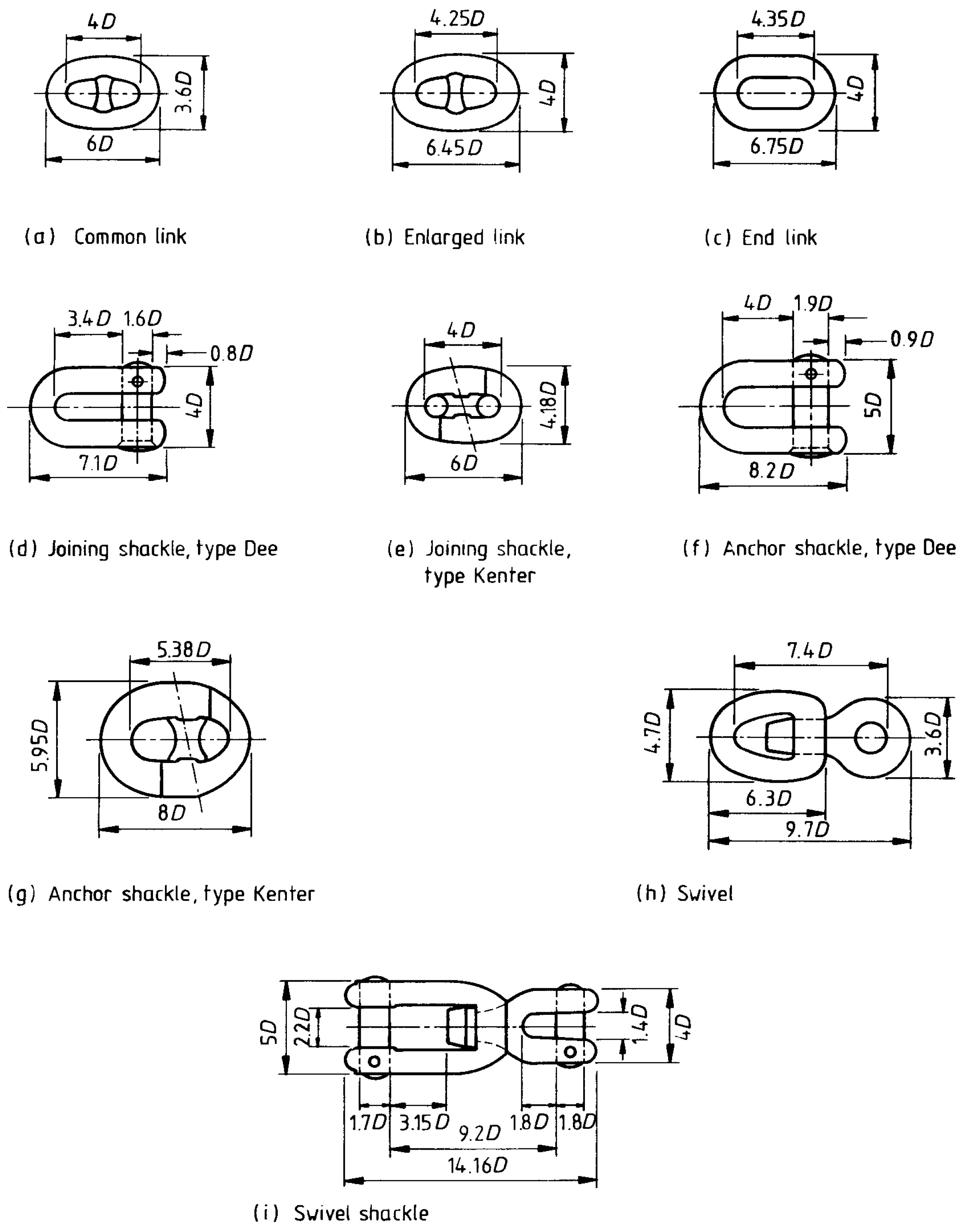
g) *Anchor shackle, type Kenter* [see Figure 14 (g)]. This is an alternative to f).

h) *Swivel* [see Figure 14 (h)]. This is used to release rotational forces in the chain.

i) *Swivel shackle* [see Figure 14 (i)]. As the name suggests this is a combination of two components.

3.8.2.2 *Identification.* Chain fittings are normally manufactured at works approved to supply steel castings or steel forgings, as appropriate. All fittings should be subjected to a proof load test.

On completion, fittings are identified by hard stamping, and supplied with a certificate of material, proof load and break test (if appropriate), by a recognized classification society. Typically, shackles are proof tested to twice their safe working load (SWL), and the ultimate capacity of a shackle is six times SWL.



NOTE *D* is the bar diameter.

Figure 14 — Chain fittings

3.8.3 Wire ropes

3.8.3.1 *Method of construction.* A wire rope consists of several strands, usually six, laid helically around a central core. Each strand is made up of several wires laid helically in one or more layers. A spiral strand rope is just one single strand.

3.8.3.2 *Behaviour.* The behaviour characteristics of wire rope and its durability under a given set of operating conditions are largely determined by certain basic features of the design including:

a) number of strands in the rope;

b) number and arrangement of the wires in the strands;

c) tensile strength of the wire;

d) type of core in the rope;

e) special processing applied, such as pre-forming;

f) coating and lubrication.

3.8.3.3 *Lay of rope.* Wire ropes are made either in ordinary lay or in Lang's lay. In ordinary lay ropes, the strands and the rope are laid in opposite directions, while with Lang's lay ropes, both strand and rope are laid in the same direction. (For further information see BS 302.)

Ordinary lay ropes should be used for mooring wires to minimize torque build-up during tensioning, and eliminate spooling problems.

3.8.3.4 *Core.* Wire ropes have cores made of fibre or steel wire. The latter are known as independent wire rope core (IWRC) and should be used in moorings in preference to fibre core ropes.

3.8.3.5 *Protection.* Wire ropes for marine use should be of wire hot dip galvanized in accordance with BS 729. They are protected by a lubricant which fills the spaces between the wires and the strands.

3.8.3.6 *Elongation.* Wire ropes stretch during use, the amount depending on the scale and frequency of loading. Lightly loaded ropes with a factor of safety greater than eight will stretch up to 0.25 % of their total length. If the factor of safety is less than five, extensions of between 1 % and 2 % can be expected.

3.8.3.7 *Bending.* Bends and joints can reduce the capacity of a wire rope. Reductions of up to 50 % in breaking load due to a wire rope being bent around a sheave or pin of twice its diameter should be allowed for.

The reduction in breaking load is 15 % for a ratio of sheave to rope diameter of 10 and 5 % for a ratio of 30 or more. A minimum sheave to rope diameter ratio of 20 is recommended for mooring wires. End attachments such as spliced thimbles, sockets, etc. reduce the breaking load by 10 % to 20 % according to the type of attachment used.

3.8.3.8 *Selection.* Factors to consider when selecting a wire rope are:

a) tensile strength based on maximum applied load with an appropriate safety factor;

b) ability to withstand fatigue and bending;

c) ability to withstand abrasion due to metal being worn away;

d) ability to withstand crushing and distortion due to bending which reduces its strength;

e) ability to resist corrosion;

f) reduction in capacity due to bending.

Wire ropes in moorings have a very limited life and should not be used in preference to chains unless their characteristics of low mass and elongation are of benefit.

3.8.4 Fibre ropes

3.8.4.1 *General.* Man-made fibre ropes are stronger and lighter than natural fibre ropes and should be used in preference to natural fibre ropes. The lightest ropes are those made from polypropylene. It has a specific gravity of less than unity, and the ropes will float on water.

The strongest fibre ropes are made of nylon. Reference should be made to BS 4128 and manufacturers' data for detailed information on sizes, strength, degradation, cyclic loading, wet and dry properties, elongation and general construction. General information is provided in **3.8.4.2** to **3.8.4.6**.

3.8.4.2 *Degradation.* Man-made fibre ropes are generally unaffected by rot, mildew and fungus. The effect of chemical contamination depends to a great extent on the type of fibre from which the rope is made. Nylon will be attacked by a moderate concentration of acids, whilst it will be virtually immune to damage by alkalis. Polyester ropes, on the other hand, are highly resistant to acids but subject to damage by alkalis. Polypropylene ropes are unaffected by either acids or alkalis. Although synthetic fibres do not degrade by oxidation, as does steel, they are affected by the ultraviolet radiation of sunlight, as are all textile fibres.

3.8.4.3 *Cyclic loading.* Man-made fibre ropes vary considerably in their ability to withstand cyclic loading. The number of cycles to failure for a nylon rope at one-third of its wet breaking load is approximately 10^4. Polyester has a much better performance, the number of cycles to failure at one-third of its wet breaking load being approximately 2×10^5. The performance under cyclic load should be taken into account for exposed locations.

3.8.4.4 *Wetting and drying.* There is hardly any deterioration in the strength of man-made fibres by alternate wetting and drying. Natural fibres are ultimately weakened by such effects. The initial strength of ropes should be based on their wet strength.

Nylon ropes have a wet strength of approximately 85 % of their dry strength. Polyester ropes suffer no reduction in strength on immersion in water.

3.8.4.5 *Elongation.* The elongation of fibre ropes varies according to their age. The “worked in” load/elongation properties will generally be more applicable than load/elongation data for new ropes.

3.8.4.6 *Construction.* Man-made fibre ropes used in moorings are generally of 8-strand plaited construction or braided. These types of rope do not kink, can be coiled both ways and are relatively pliable even when wet.

3.8.5 Winches, windlasses and capstans

3.8.5.1 *Types.* Two types of winch are relevant to moorings. These are:

a) anchor handling windlasses and capstans;

b) mooring winches and capstans.

3.8.5.2 *Operation.* The basic function of the winches is to control loads associated with chain cable or wire rope and whilst each type of equipment has its own operational requirements, certain aspects of design and operation are common. Most winch machinery is idle during much of its life and, due to this intermittent duty requirement, gears and drives are normally designed to a limited rating of 0.5 h to 1 h. Despite long periods of idleness, often in severe weather conditions, the machinery has to operate immediately when required.

3.8.5.3 *Brakes.* Mooring winches should be fitted with drum brakes, the strength of which is sufficient to prevent unreeling of the mooring line when the rope tension is equal to 80 % of the breaking strength of the rope as fitted on the first layer on the winch drum.

3.8.5.4 *Warping speed.* Full load duties of warping capstans and mooring winches vary from 3 t to 30 t at from 0.3 m/s to 0.6 m/s, and twice full load speed is normally provided for recovering slack lines.

3.8.5.5 *Double barrel winches.* The size of wire rope used on mooring winch barrels is governed by the size of wire manageable by the crew; currently it is accepted that a rope of 140 mm circumference is the largest that can be handled manually. The basic problems associated with the use of wire ropes are as follows:

a) they are difficult to handle;

b) they do not float; and

c) when used in multi-layers, due to inadequate spooling, the top, tensioned layer cuts down into the underlying layers causing damage.

To counteract c) a divided barrel can be used such that the wire may be stored on one portion and a single layer of wire transferred to the second portion when tensioned.

3.8.5.6 *Constant tension winches.* Mooring winches provide the facility for tensioning the wire up to the stalling capacity of the winch, usually 1.5 times full load; thereafter the load is held by the prime mover brake or barrel brake when the power is shut off. The winch cannot pay out wire unless the brake is overhauled, or recover wire unless manually operated, thus wires may become slack.

Automatic mooring winches provide this manual control but, in addition, incorporate control features such that, in the “automatic” setting, the winch may be overhauled and the wire paid off the barrel at a predetermined maximum tension; also wire is recovered at a lower tension should it tend to become slack.

3.8.6 Permanent mooring buoys

3.8.6.1 *General description.* Buoys are generally of two types, i.e. steel or glass reinforced plastics (GRP). The basic design parameters are:

a) reserve buoyancy, which is simply a function of the mass and volume;

b) tension capacity, which is usually provided by a tension bar running vertically through the centre of the buoy.

Other factors affecting design are:

1) the method of connecting and releasing lines;

2) impact resistance;

3) durability;

4) maintenance.

Reference should be made to manufacturers’ data for detailed information. General information is provided in **3.8.6.2**.

3.8.6.2 ***Factors in selection***

3.8.6.2.1 *Reserve buoyancy.* A buoy should generally have sufficient reserve buoyancy to take the maximum expected downward pull, without submerging. In certain cases it may be acceptable to allow submergence of a buoy under extreme load. However, the buoy should not be submerged below the maximum depth of submergence for which it has been designed.

3.8.6.2.2 *Tension capacity.* The tension capacity of a buoy should be not less than 1.2 times the mooring line breaking load. Buoy connections such as shackles should be such that the maximum line load is less than the proof load.

3.8.6.2.3 *Line connection and release.* The ability to release lines quickly in an emergency should be considered. Buoys with quick release hooks are frequently employed for vessel moorings.

3.8.6.2.4 *Impact resistance or softness.* Impact resistance and the consequences of flooding should be considered. Steel buoys are sometimes provided with several compartments in order to minimize the risk of capsizing. Glass reinforced plastics buoys are generally filled with foam that will not absorb water. "Soft" buoys such as GRP buoys are unlikely to cause severe damage to vessels. Steel buoys should be fendered so as to minimize damage to themselves and to vessels.

3.8.6.2.5 *Durability and maintenance.* Steel buoys should be designed for corrosion resistance. In some cases buoys can be reversed so as to minimize wear. Fittings for steel and GRP buoys should generally be hot dip galvanized in accordance with BS 729. Large steel buoys should be provided with access manholes and facilities for dewatering.

3.8.7 Miscellaneous fittings

3.8.7.1 *Mooring points and fairleads.* Means should be provided to enable mooring lines to be adequately secured onboard the moored object. The strength of the mooring points should be capable of holding not less than 1.5 times the sum of the maximum breaking strength of the mooring lines used.

3.8.7.2 *Chain stoppers.* Chain stoppers are used to secure the end of a chain at the mooring point on the moored object. They can be either fixed or adjustable.

3.9 Maintenance and inspection of moorings

3.9.1 General

The procedures for mooring inspection will vary according to the type of mooring, its location and its usage. Information on types of moorings is contained in **3.3.2**. Information and recommendations on maintenance and inspection are provided in **3.9.2** to **3.9.10**.

3.9.2 Admiralty type and general inshore moorings

These types of mooring are constantly being picked up and placed back on the seabed by the action of the vessel moored above. The areas which suffer wear are those which move and especially the linkage connections directly under the buoy.

An interim inspection and partial raising should be carried out at regular intervals according to the type of buoy and its use. The interim inspection is performed by diver, without removal, and the partial raising, as its name suggests, involves disconnecting some legs and removing the buoy from the water for detailed inspection underneath.

Typical inspection schedules are given in Table 7.

Table 7 — Typical inspection schedules

Class of buoy	Interim inspection	Partial raising
	Years	Years
Admiralty type	1½ to 2	2 to 7 depending on buoy type
Telephone buoys	1	1
Navigation buoys	1	2

Diving inspections should be performed to examine the anchors, chain and fittings for wear, to confirm that parts are not fouled and to check that pins have not loosened on shackles.

3.9.3 Floating docks and pontoons

It is normal practice for floating dock and pontoon moorings to be checked annually on the basis of one leg per year. The annual inspection should be by diver and should include anchor chains and fittings. Partial raising of each anchor leg should take place on a 2 year cycle. Full inspection of the moorings may be carried out when the dock itself is dry docked for survey and overhaul.

3.9.4 Light vessel and similar moorings in exposed locations

The procedure and frequency of inspection to be adopted depends on the exposure of the unit. Reference should be made to those authorities (e.g. Trinity House Authority) responsible for operating vessels for guidance on frequency and method of inspection. The following is a typical example.

An exposed light vessel in the UK (off Lands End) has mooring legs which consist of about 550 m of 44 mm grade 2 chain. Because of its exposure, the moorings are inspected annually by a tender vessel which fully removes the chain on to her deck for visual inspection. Every 3 years the chain is totally replaced with a new chain and the old chain is used in more sheltered locations.

3.9.5 Single point moorings (SPMs)

3.9.5.1 *General.* There are a wide variety of SPMs in service in many different locations. They are used for the loading and unloading of oil tankers from submarine pipelines. The method of inspection and frequency vary considerably and that described in **3.9.5.2** to **3.9.5.5** is considered typical.

3.9.5.2 *Visual inspection.* Visual inspection should be carried out on a weekly basis when the mooring is first installed to ensure the integrity of the mooring geometry after usage by vessels.

3.9.5.3 *Re-tensioning.* Re-tensioning of the mooring chains should be made if wear is detected caused by the chains becoming slack or, alternatively, if too much tension develops in the chains. Checks on pre-tensioning should be carried out initially every 3 months, and then at intervals of between 2 years and 6 years, depending upon the buoy location.

3.9.5.4 *Disconnection.* After 6 months, one anchor leg should be disconnected at the chain stopper and as great a length as is possible brought to the surface for a thorough examination. The results of the inspection will decide how frequently the inspections are to be carried out.

3.9.5.5 *Anchors.* Every 6 months inspection of the positions of the anchors should be carried out, and the chains examined for wear in the critical areas, i.e. "thrash" and "top linkage".

3.9.6 Inspection of wire rope during service

3.9.6.1 *Elongation.* The length of the rope will increase by an amount dependent upon the construction and elasticity of the material. A new rope will permanently elongate by a certain amount. An abnormal increase in length indicates that the wire has been overloaded.

3.9.6.2 *Lubrication.* Inspection of the rope should be made for corrosion and general dryness. Ropes will last longer if kept well greased. Crushing or breaking of strands and distortion of the lay will cause loss of strength.

3.9.6.3 *Terminations.* Particular attention should always be paid to the terminations where a residual strength of the rope of up to 75 % of the breaking load may occur, depending upon the type of termination.

3.9.7 Inspection of fibre rope during service

3.9.7.1 *Factors affecting service life.* Factors which affect the service life of a fibre rope and which should be considered are:

a) heat due to raising of temperature by high cyclic loadings and friction;

b) degradation due to sunlight and weather;

c) abrasion and fracture of filaments;

d) wetting and drying of the rope (natural fibre only);

e) rot and mildew (natural fibre only);

f) marine growth and organisms;

g) vermin and insects (insects thrive on cellulose).

Of these items, which can cause deterioration of the fibre ropes without being visually obvious, the most serious are degradation by sunlight and melting of the internal core of the ropes by heat.

3.9.7.2 *Degradation by sunlight.* Tests have shown that man-made fibre ropes have their strength reduced by 50 % by the action of sunlight over a 2 year period when they are in hot climates. This compares with a 10 % reduction in the UK. For this reason, ropes should be replaced at regular intervals, irrespective of apparent good visual condition.

3.9.7.3 *Degradation by friction.* Heat generation by internal friction due to ropes stretching is a common phenomenon in moorings. Internal melting of the rope will cause rapid failure. It is common practice on SPM tanker moorings for such ropes to be inspected at intervals of no more than 3 months and changed accordingly depending on their frequency of use.

3.9.8 Inspection of chain during service

3.9.8.1 *Corrosion, cracks and deformation.* Chain should be checked at regular intervals, i.e. annually, biennially, etc. depending on the type of mooring with which it is used (see **3.9.2** to **3.9.5**), for defects such as deformation, fatigue cracks, excessive corrosion and abrasion. The careful measurement of the size of links can be used to determine the remaining chain strength. Cracks in the chain indicate that the chain is approaching catastrophic failure and should be replaced. Deformation indicates that the chain has been overloaded and its replacement should be considered.

3.9.8.2 *Handling of chain.* It should be noted that, if the chain is lying quietly on the seabed, the operation of recovering the chain and inspecting it may put a greater strain on the chain than that which it experiences in service. For this reason care should be taken in its handling.

3.9.8.3 *Splash zone.* The most critical areas to be inspected are in the "splash" and "thrash" zones. Chain can only be satisfactorily inspected visually on its surface where, if necessary, non-destructive testing can be carried out.

3.9.9 Inspection of connections in service

3.9.9.1 *Compatibility of strength.* The configuration of a mooring necessitates connecting different lengths and sizes of chain, anchors and buoys together. It is essential that the strengths of all components are similar and therefore, where a connection is made, the connecting link in most cases has to be of a larger diameter than the chain.

3.9.9.2 *Open links and swivels.* If stud link chain is used to make the connection, a special open link needs to be positioned at the ends of the chain. Enlarged stud links are used to enable the increased diameter of the open link to fit into the chain. Swivels are also connected into the mooring where turning movement is expected, i.e. under the buoy and at other places as required, depending upon the configuration. All of these connections should be inspected at regular intervals, i.e. annually, biennially, etc. depending on the type of mooring with which it is used (see **3.9.2** to **3.9.5**).

3.9.9.3 *Kenter type shackles.* The most commonly used connecting link between chains is of the Kenter type. This consists of a patent detachable link, which comes apart. When the link is assembled the parts are held in place by a tapered pin. Where two different sizes of chain are to be connected, as in connections made to anchors, the Kenter link is made with differing sizes of apertures. It is essential that the connections fit together properly, as the wrong size of connection can be detrimental causing increased wear and introducing stresses into the system. The pin in the Kenter link needs to be secured against coming out, and frequently this is achieved by pouring hot lead into the aperture once the pin is secured. It is necessary to check that this lead is still in place.

3.9.9.4 *Bow, Dee and anchor shackles.* Other types of shackles (anchor, bow, Dee type, etc.) have shackle pins or bolts which need to be secured and will not pull out. The pin can be either a round pin or a threaded bolt type which screws into the shackle. So called "safety shackles" are fitted with a threaded pin to which a nut is attached and secured by a cotter pin. It is necessary to check that the cotter pin has not sheared and that the bolt remains in place.

3.9.9.5 *Welding of shackle pins.* Welding of shackle pins to the shackle is sometimes considered as a positive method to ensure that the pin does not work loose. This practice is not recommended because it can weaken the strength of the shackle. Shackle pins should be secured with split pins or bolts.

3.9.10 Inspection of anchors

3.9.10.1 *Pre-installation.* In general, anchors are inspected before being laid and, depending upon their construction, can be inspected or proof loaded to recognized standards classification society rules, e.g. Lloyd's Register.

3.9.10.2 *Post-installation.* After being laid it is very difficult to inspect the anchor, other than to check on its mooring geometry if the anchor is not buried.

3.9.10.3 *Anchor recovery.* Drag embedment anchors are usually recovered with the mooring chains. They can be inspected at this time for cracks and damage and either be repaired or replaced. In general though, anchors are robust and require little maintenance. Some anchors can be recovered and relaid with few problems whereas others, which rely on burial to achieve maximum holding power, can be very difficult to recover. It is generally preferable in the case of moorings to leave the anchor for as long as possible before recovering. The action of recovering for inspection will, in many cases, impose more strains on the anchor than may have occurred in service.

Piled anchors, suction anchors and similar types should not be disturbed on the seabed. Therefore they cannot be recovered for inspection and should be surveyed by divers when the mooring leg is disconnected.

3.9.10.4 *Mooring geometry.* Divers can be used to inspect the mooring for the mooring geometry, and in some cases can establish if the anchor is still free from defects. It can often be assumed that if the anchor has been free from any movement caused by the mooring and the wear on the chain is minimal in the critical zones, then the wear on the anchor will also be minimal, and little will be achieved by recovery and inspection.

Section 4. Floating structures

4.1 General

Criteria for loads on floating structures are presented in **4.2**. The detailed design of floating structures is covered in various published standards, codes and classification society rules. Guidance on the publications is contained in **4.3**. Fundamental information and criteria on stability, motion response and longitudinal strength are contained in **4.4** to **4.6**.

4.2 Loads

4.2.1 Types

4.2.1.1 *Dead load.* This is the effective mass of the structural elements of the structure. For some design analyses it may be preferable to consider the mass of the elements in air and to treat the uplift due to hydrostatic forces separately.

4.2.1.2 *Superimposed dead load.* This is the mass of all items forming loads on the structure that are not structural elements. Typical examples are mooring winches and fixed equipment for cargo handling. The self-mass of large, slow moving cranes on fixed tracks such as floating dock cranes may be included in this category.

In any analysis, the effect of removing the superimposed dead load needs to be considered since it may diminish the overall stability or diminish the relieving effect on another part of the structure.

4.2.1.3 *Imposed loads.* An allowance for impact loads should be made when assessing imposed loads. Loads from vessels berthing alongside a structure should be considered as berthing loads (see **4.2.1.4**).

Loads from anchor leg moorings should be taken as equal to the minimum breakload of the wire or chain being used. A load factor of **1.2** should be applied to the minimum breakload (see Table 8).

4.2.1.4 *Berthing or mooring loads from vessels.* Berthing and mooring loads from vessels moored alongside floating structures should, where possible, be designed in accordance with information in BS 6349-4 relating to berthing and mooring loads for fixed structures. Abnormal berthing should be included (see **4.9.1** of BS 6349-4:1985). Relative motions of moored vessel and floating structure should be considered.

4.2.1.5 *Environmental loads.* Environmental loads should be calculated as described in section 2.

4.2.1.6 *Hydrostatic loads.* When considering the effects of buoyancy it is preferable to represent the buoyancy and gravitational loads as separately applied loading systems.

If the loads are combined, local changes in pressure distribution and hydrostatic differential may be obscured in the calculations. Draught increases in the damaged condition should also be considered.

4.2.2 Load conditions

4.2.2.1 *General.* The load conditions given in this clause should not be considered as exclusive, and any other critical conditions which might possibly occur should also be analysed. Guidance on combinations of loads for particular structures is given in section 5.

The probability of two or more large loads being applied to the structure simultaneously should be assessed; some combinations of loads are mutually exclusive. Depending on the consequences of failure, it will in most cases not be economic to design for the simultaneous application of all possible extreme loads. However, where there is a very low probability that two large loads will occur simultaneously, the structure may be analysed using reduced factors of safety.

4.2.2.2 *Normal loading conditions.* Normal loading refers to any combination of loads which may reasonably be expected to occur during the design life of the structure, associated with normal operating conditions. This should include any foreseeable modifications to the structure, storage patterns and equipment on board.

The maximum normal value of each type of load described in **4.2.1** should be considered in combination.

4.2.2.3 *Extreme loading conditions.* Extreme loading refers to any combination of loads which may be expected to occur during the design life of the structure, associated with the most severe load that could be envisaged, excluding accidental loads such as that due to an uncontrolled berthing.

The likelihood of more than one extreme load occurring at any time should be assessed.

4.2.2.4 *Temporary loading during construction.* The loads which may be expected to be applied at each stage of construction should be carefully considered.

4.2.2.5 *Loading during transportation.* Loading during transportation should be evaluated taking account of the likely environmental conditions, the duration of the transportation and any relevant contingencies (such as sheltering at a port).

4.2.3 Load factors

The values of partial load factor γ_{fL} for loads for use in limit state design are given in Table 8. Where stress relief would occur in the design member as a result of lower values of any type of load being applied to the structure, a value of $\gamma_{fL} = 0.9$ should be used for that load, unless the load may be removed completely, in which case $\gamma_{fL} = 0$.

Table 8 — Partial load factor γ_{fL} for floating structures

Load	Limit state	Load case[a]		
		1	2	3
Dead: steel	ULS[b] SLS[c]	1.05 1.0	1.05 1.0	1.05
Dead: concrete	ULS SLS	1.15 1.0	1.15 1.0	1.15
Dead: superimposed	ULS SLS	1.2 1.0	1.2 1.0	1.2
Imposed	ULS SLS	1.4 1.1	1.2[d] 1.0	1.2
Berthing or mooring loads from vessels	ULS SLS	1.4 1.1	1.2[d] 1.0	—
Environmental	ULS SLS	1.4 1.0	1.2 1.0	1.2
Hydrostatic	ULS SLS	1.1 1.0	1.0 1.0	1.0

[a] Load case 1 is normal loading (see **4.2.2.2**);
load case 2 is extreme loading (see **4.2.2.3**);
load case 3 is temporary loading during construction and transportation (see **4.2.2.4** and **4.2.2.5**).

[b] ULS is the ultimate limit state.

[c] SLS is the serviceability limit state.

[d] Loads from anchor leg moorings should be taken as the minimum breaking load of a wire or chain times **1.2** (see **4.2.1.3**).

4.3 Codes and classification society rules

4.3.1 General

Owners of most forms of floating structures require them to be insured. Classification societies and marine insurance surveyors are the recognized authorities used in the marine industry to carry out independent design checks and surveys. The leading societies have published rules which are referred to where appropriate. Reference to a rule does not imply that the structure should be designed in strict accordance with the rules. The designer should verify for himself the need to conform to the classification society rules. Refer to bibliography [13, 14, 15, 16, 17, 18].

4.3.2 Steel structures

Several standards, codes of practice and classification society rules have been published for steel floating structures. They are as follows.

a) *Floating docks.* Lloyd's Register of Shipping "Rules and regulations for the construction and classification of floating docks" [13] and American Bureau of Shipping "Rules for building and classing steel floating drydocks" [14].

b) *Pontoons.* American Bureau of Shipping "Rules for building and classing steel vessels", [15] and "Rules for building and classing steel barges for offshore service" [16].

c) *Tubular members.* American Petroleum Institute RP2A "Recommended practice for the planning, design and construction of fixed offshore platforms" [17].

d) *Stiffened beam members.* BS 5400 "Steel, concrete and composite bridges".

e) *Fatigue.* Department of Energy publication "Offshore installations: Guidance on design and construction" [33] or American Petroleum Institute RP2A "Recommended practice for the planning, design and construction of fixed offshore platforms" [17].

f) *Corrosion protection.* BS 5493 "Code of practice for protective coating of iron and steel structures against corrosion" and CP 1021 "Code of practice for cathodic protection" (see clause **68** of BS 6349-1:1984).

g) *Welding inspection.* Specification for testing and inspection will vary according to the type of structure. For general guidance on structures subject to a severe environment refer to Det Norske Veritas "Rules for the design and construction of offshore structures" [18].

4.3.3 Concrete structures

Reinforced, prestressed and precast concrete should be designed in accordance with BS 8110 except where modified by BS 6349-1. Reference should also be made to other relevant publications [29, 30, 31 and 32].

4.4 Stability

4.4.1 General

The main factors in determining stability are the metacentric height (*GM*) and the range of stability (in degrees of heel).

Due to the diversity of inshore floating structures it is not possible to define minimum values of (*GM*) and the range of stability to be adopted. However, typical values are given in Table 9.

Table 9 — Typical values of metacentric height and range of stability

Vessel or structure	Metacentric height (*GM*)	Range of stability
	m	°
Ship	0.15 to 3.0	45 to 75
Dry dock	Minimum 1.0	30 to 50
Pontoon	1.0 to 15.0	25 to 50

Stability calculations should be performed in accordance with **4.4.2**. Structures should meet the criteria for intact stability given in **4.4.3**, and the criteria for stability after damage given in **4.4.4**.

The recommendation for stability after damage means that structures have to be constructed with bulkheads which form watertight compartments. The arrangement of bulkheads (and hence compartments) will determine the extent of flooding and change of stability subsequent to damage. The arrangement of bulkheads will in part be determined by structural requirements, such as overall strength and rigidity. Where structural requirements dictate closely spaced bulkheads, consideration may have to be given to simultaneous damage of more than one compartment. In certain instances it may be preferable to make some bulkheads non-watertight.

4.4.2 Stability calculations

4.4.2.1 ***Definitions and symbols***

4.4.2.1.1
intact stability
the stability that covers the non-damaged condition of a vessel

4.4.2.1.2
damage stability
the stability with one or more watertight compartments flooded as a result of damage (collision)

4.4.2.1.3
displacement (of a vessel) m_D
the mass of water displaced

NOTE It is sometimes expressed as the volume *V* of water displaced.

4.4.2.1.4
centre of buoyancy B
the centroid of the underwater volume of the vessel; it is the point through which the total buoyancy force acts

NOTE See Figure 15.

4.4.2.1.5
metacentre M
the point at the intersection of vertical lines through the centres of buoyancy in the initial and slightly inclined positions (B and B′ respectively)

NOTE See Figure 15.

4.4.2.1.6
metacentric height (*GM*)
the distance between the centre of gravity G and the metacentre M

NOTE See Figure 15.

4.4.2.1.7
(*KB*)
the vertical distance of the centre of buoyancy above the keel

4.4.2.1.8
(*KG*)
the vertical distance of the centre of gravity above the keel

4.4.2.1.9
free surface effect
the reduction in the value of (*GM*) resulting from the presence of liquid in any tanks in the vessel. The reduction is given by the expression:

$$\frac{l}{V} \times \frac{\rho_1}{\rho} \qquad (16)$$

where

- l is the transverse second moment of area of the "waterplane" in the tank;
- V is the volume of displacement of the vessel;
- ρ_1 is the mass density of the liquid in the tank;
- ρ is the mass density of the water in which the vessel floats.

4.4.2.2 *Inclining test calculation.* The actual value of (*GM*) for a vessel may be determined by a simple test called the inclining test. The vessel is heeled to a small angle by moving a known mass transversely across the deck through a known distance. The heel is measured by a pendulum.

If a mass w is moved a distance d, and results in an angle of heel θ, then the metacentric height (*GM*) is given by the equation:

$$(GM) = \frac{wd}{m_D \tan\theta} \qquad (17)$$

where m_D is the displacement.

It can be shown that

$$\tan\theta = \frac{\text{deflection of pendulum}}{\text{length of pendulum}} \qquad (18)$$

The position of the metacentre may be calculated from the equation:

$$(BM) = \frac{l}{V} \qquad (19)$$

where

V is the displacement of the vessel (in m^3);

l is the second moment of area of the vessel's "waterplane" about the vessel's centreline (e.g. for a rectangular waterplane:

$$l = \frac{(\text{length}) \times (\text{breadth})^3}{12} \text{ for} \quad (20)$$

transverse inclination.)

It should also be noted that:

$$(GM) = (KM) - (KG) = (KB) + (BM) - (KG)$$

$$= (KB) + \frac{l}{V} + -(KG) \quad (21)$$

The numerical value of (GM) is affected by "free surface" effects, as follows.

When a vessel is inclined, the buoyancy force (acting upwards at B), and the mass, acting at G, form a **righting moment.** The lever of this righting moment is known as the **righting lever** or (GZ) (see Figure 16).

4.4.2.3 *Stability calculation procedure.* The minimum calculations required to verify that the design complies with the stability guidelines given in **4.4.1** and **4.4.3** and this clause are summarized as follows:

a) determine (KG);

b) determine (KB); for a box-shaped pontoon this will be half the draught;

c) determine the displacement V;

d) determine $l = \frac{(\text{length}) \times (\text{breadth})^3}{12}$ for a rectangular pontoon;

e) determine $(GM) = (KB) + \frac{l}{V} - (KG)$ This value has to be positive;

f) determine values of (GZ), for angles of heel of 10°, 15°, 20°, etc.

$(GZ) = \sin\theta \{(GM) + ½ (BM) \tan^2\theta\}$ for a wall-sided pontoon;

g) calculate the righting moment;

h) calculate wind load and wind heeling moment;

i) check that area (A + B) ⩾ 1.4 × area (B + C) (see Figure 17).

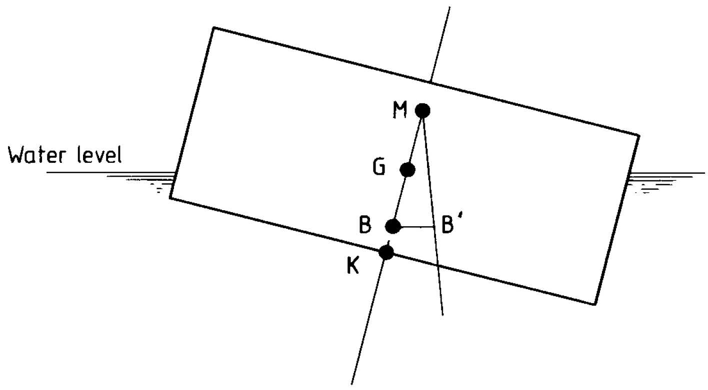


Figure 15 — Metacentre M, centre of gravity G and centre of buoyancy B

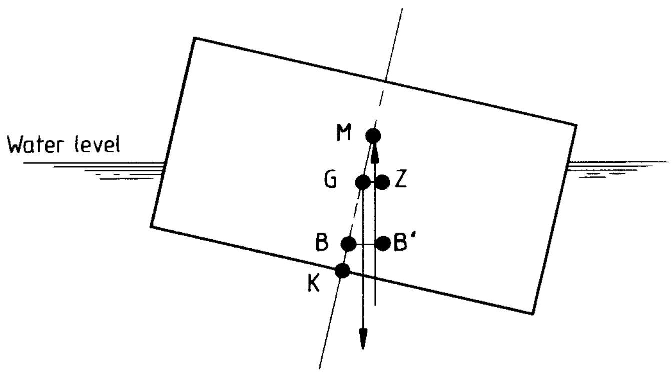
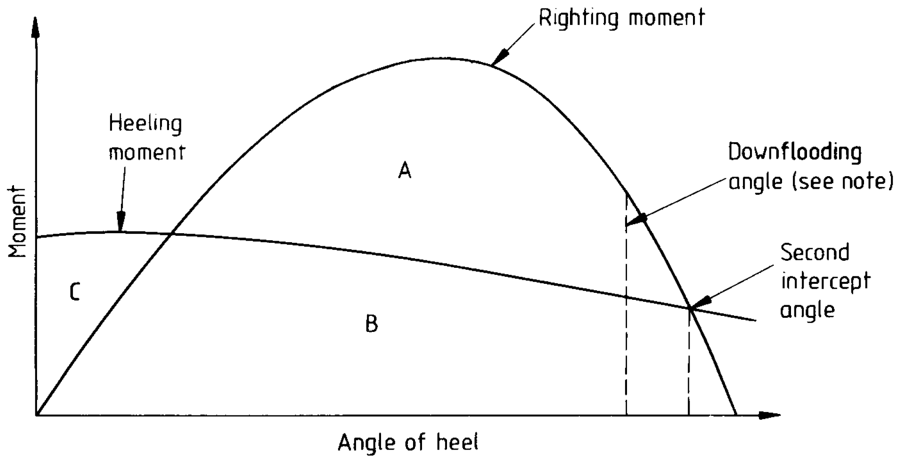


Figure 16 — Righting lever (*GZ*)



NOTE Downflooding angle is the angle at which water can enter the hull, superstructures or deck houses through openings which are not capable of being made weathertight.

Figure 17 — Areas for moment versus heel angle

4.4.3 Intact stability

Reference should be made to standard textbooks on naval architecture and the rules of classification societies for specific criteria for the floating structure. The following guidelines in general apply.

The metacentric height has to be at least positive at zero angle of heel (see **4.4.1**).

Curves of heeling and righting moments should be calculated for a sufficient number of angles of heel to define the stability of the structure in the in-service conditions which may give low stability. The heeling moments for a permanent installation should be based on the 50 year all year wind speed at the location.

The maximum heel of the structure under any possible in-service loading condition should also be calculated.

The area under the curve of righting moments should be at least 40 % in excess of the area under the wind heeling moment curve, considering both curves up to their second point of interception or angle of downflooding, whichever occurs earlier (see Figure 17).

4.4.4 Damage stability

It should be demonstrated that the structure has sufficient reserve buoyancy to remain stable and afloat when any one compartment is flooded. In the damaged condition the structure should have the ability to withstand the overturning moment due to extreme wind conditions from any direction without submerging any openings through which downflooding may occur. In instances where compartments are closely spaced, consideration should be given to simultaneous damage of more than one compartment.

4.5 Motion response

4.5.1 General

There are six degrees of freedom for a floating structure: motions in a horizontal plane arise from surge, sway and yaw and motions in a vertical plane arise from heave, pitch and roll. The horizontal motions are dependent on the mass of the structure, the stiffness of the moorings and the characteristics of the waves acting on the structure. The vertical motions are primarily dependent on the mass of the structure, the hydrostatic properties of the structure and the wave characteristics.

The response of a structure is highly dependent on the ratio of forcing frequency to natural frequency. The forcing frequency is derived from the wave characteristics. The natural frequencies of a structure are the frequencies of motion when the structure is excited in still water.

The response of a structure is usually summarized in terms of response amplitude operators (RAOs). The response amplitude operator defines the response to a wave of unit amplitude.

4.5.2 Basic design considerations

Structures and moorings should be designed so that the natural frequencies of motion are as far removed as possible from the frequencies of exciting forces (primarily sea and swell). Simple equations for estimating natural frequencies are provided in **4.5.3**.

The stiffness of anchor leg moorings can generally be neglected in sheltered locations. Estimates of motions can be made by considering the structure freely floating (see **2.4.4.2**). Conservative estimates of response can be obtained by assuming RAOs of unity. As a consequence, surge and sway amplitudes will equal the horizontal wave particle amplitudes, and heave amplitudes will equal the vertical wave particle amplitudes. Roll and pitch amplitudes will equal the maximum wave slope.

The simple assumptions stated above should not be used when natural frequencies are near the forcing frequencies.

The stiffness of an anchor leg mooring should be taken into account in exposed locations, since it can affect the response to second order wave forces. Estimates of response can be made using physical or computational models (see **2.4.5** and **2.4.6**). The simple equations in **4.5.4** may be used to check results produced from modelling a structure and moorings.

For stiff restraining systems such as mooring dolphins, the horizontal motions of a structure are theoretically governed by the stiffness of the restraining system. However, the deflections of structures such as dolphins are generally small, and it will normally be sufficient to assume that a floating structure will move within the tolerances of any fendering and guide system.

Stiff restraining systems should not be used in exposed locations since the forces required to prevent motions of the structure will generally be unacceptably high.

4.5.3 Equations for natural frequency

A simple equation for horizontal motion is:

$$f_N = \frac{1}{2\pi}\sqrt{\left\{\frac{K}{M}(1 - q^2)\right\}} \qquad (22)$$

where

f_N is the damped natural frequency (in Hz);

K is the stiffness of the mooring system (in KN/m);

M is the mass of water displaced (including added mass) (in t);

q is the damping ratio = $\frac{C}{2\sqrt{(MK)}}$

where C is the damping coefficient (in t/s).

In equation (22) the damping is assumed to vary linearly with velocity. The mass of water displaced includes the entrained water (generally referred to as added mass). Damping coefficients and added mass can be derived from data on similar structures, or from mathematical and physical models. For preliminary design of moorings, or design of moorings in sheltered locations, it will be sufficient to use approximate estimates of added mass and damping and to design taking account of the following general principles.

a) The natural frequency will increase with increasing stiffness of moorings.

b) The natural frequency will decrease with increasing mass.

A simple equation for roll or pitch is:

$$f_N = \frac{1}{2\pi k}\sqrt{\{g(GM)\}} \qquad (23)$$

where

f_N is the undamped natural frequency (in Hz);

k is the radius of gyration (longitudinal for pitch and transverse for roll) (in m);

(GM) is the metacentric height (longitudinal for pitch and transverse for roll) (in m);

g is the acceleration due to gravity (9.81 m/s^2).

Equation (23) is only valid for small motions (typically less than 10°).

A simple equation for heave is:

$$f_N = \frac{1}{2\pi}\sqrt{\left(\frac{\rho g A}{M}\right)} \qquad (24)$$

where

f_N is the undamped natural frequency (in Hz);

ρ is the mass density of water (in t/m^3);

A is the waterplane area (in m^2);

M is the mass of water displaced (including added mass) (in t).

The following should be noted.

1) For a given mass, the natural frequency of roll or pitch will increase with increasing (*GM*).

2) For a given mass, the natural frequency of heave will increase with increasing waterplane area.

3) Natural frequencies increase with decreasing mass.

4.5.4 Equations for horizontal and angular displacement

A simple equation for horizontal displacement x for a system of linear stiffness, subject to a harmonic force is:

$$x = \left(\frac{P}{K\sqrt{[\{1-(f_c/f_N)^2\}^2 + (2qf_c/f_N)^2]}} \right) \cos(2\pi f_c t - \beta) \qquad (25)$$

where

- P is the amplitude of the harmonic force (maximum wave force) (in kN);
- f_c is the frequency of cyclic loading (in Hz);
- f_N is the natural frequency (in Hz) (see **4.5.3**);
- K is the stiffness of the mooring system (in kN/m);
- q is the damping ratio;
- t is time (in s);
- β is the phase angle =

$$\tan^{-1}\left[\frac{2qf_c/f_N}{\{1-(f_c/f_N)^2\}}\right] \text{(in rad).}$$

When the length of a structure in the direction of wave travel is small compared to the wavelength, the angular displacement ϕ, caused by the waves, can be predicted from

$$\phi = \frac{f_N^{\,2}\,\alpha}{(f_N^{\,2} - f_c^{\,2})} \sin(2\pi f_c t) \qquad (26)$$

to which should be added any angular displacement in the same plane caused by, for example, the movement of a vehicle or other loading likely to cause oscillation. If ϕ_0 is the angular displacement in still water caused by the vehicle movement or other excitation the combined amplitude becomes

$$\phi = \phi_0 \sin(2\pi f_N t + \beta) + \frac{f_N^{\,2}\,\alpha}{(f_N^{\,2} - f_c^{\,2})} \sin(2\pi f_c t) \qquad (27)$$

where

ϕ and ϕ_0 are measured in radions;

NOTE ϕ_0 is a dynamic and not a static change in trim.

f_N is the natural frequency (in Hz);

t is time (in s);

β is the phase angle (in rad);

α is the maximum wave slope (in rad);

f_c is the frequency of cyclic loading (in Hz).

Equations (25), (26) and (27) are only valid for small angles of displacement (typically less than 10°).

4.6 Longitudinal strength

4.6.1 General

The strength of a floating structure should be checked to ensure that there is adequate resistance to loading from buoyancy forces and mass. In many cases a static analysis of the longitudinal strength of the structure when a wave crest or trough is at the centre will be sufficient. An outline procedure for calculating longitudinal strength is given in **4.6.2**. Further information can be found in basic text books on naval architecture [19].

When a structure is likely to be exposed to severe wave action, consideration should be given to a motion response analysis which will predict bending moments and shear forces under dynamic load [20].

4.6.2 Static analysis

The assumption is made that the structure is head on to a wave and is at rest. The wave is assumed to have a trochoidal profile (see Figure 18) with a length equal to the length of the structure and a height equal to one-twentieth of its length. Two standard conditions are considered. They are hogging (with the wave crest at the centre of the structure) and sagging (with the wave trough at the centre).

A mass curve is produced for the structure for both the hogging and sagging cases. The line loads used should be those which give the maximum possible hogging and sagging. The structure is then balanced on the trochoidal wave. The trochoidal profile can be obtained using the coefficients given in Table 10. The length of the structure is divided into 20 equal spaces and the wave profile is obtained from the product $F \times H$ where F is the trochoidal wave profile factor, and H is the wave height.

Table 10 — Derivation of trochoidal profile

Station		Trochoidal wave profile factor F	
Aft	Forward	Hogging	Sagging
0	20	1.000	0
1	19	0.982	0.034
2	18	0.927	0.128
3	17	0.839	0.266
4	16	0.720	0.421
5	15	0.577	0.577
6	14	0.421	0.720
7	13	0.266	0.839
8	12	0.128	0.927
9	11	0.034	0.982
10		0	1.000

The balancing of the structure in the wave normally involves a "trial and error" procedure, when the displacement is adjusted until the total immersed volume equals the mass of the ship, and the centre of buoyancy is in line with the centre of gravity. Once the final displacement of the structure is obtained, the immersed areas at each section are used to obtain a buoyancy curve which is plotted alongside the mass distribution. Finally, a load curve representing the difference between mass and buoyancy at any point along the length of the structure is produced, and from this curve shear force and bending moment curves can be produced and a stress analysis performed. Typical curves are shown in Figure 19.

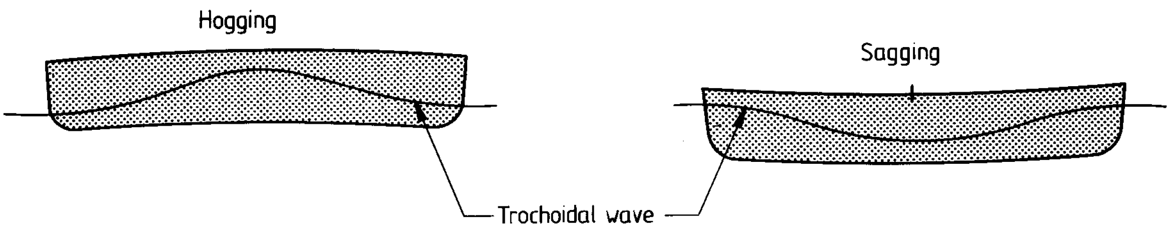


Figure 18 — Trochoidal profile

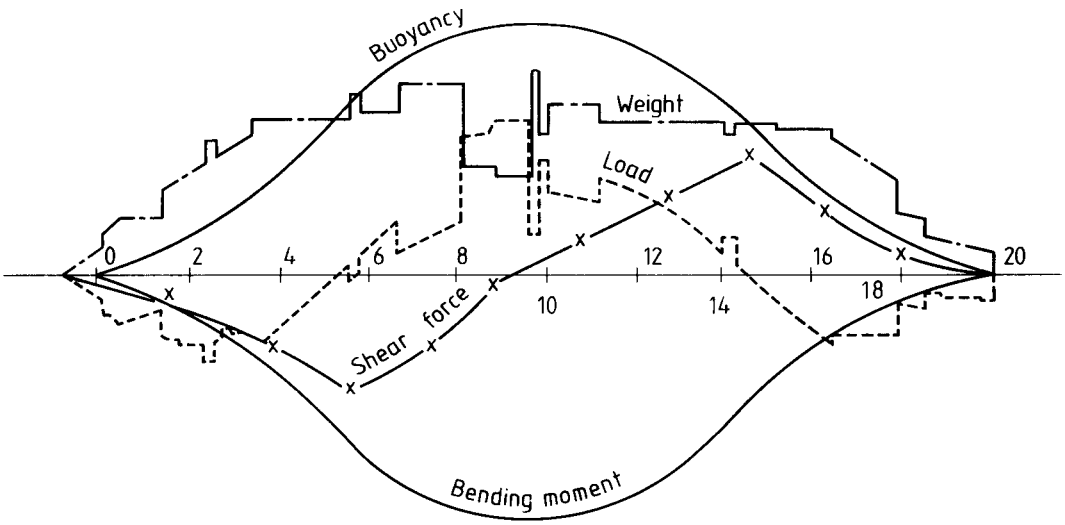


Figure 19 — Typical curves for longitudinal strength

Section 5. Pontoons, floating docks and floating breakwaters

5.1 General

This section provides general information on pontoons, floating docks and floating breakwaters. It is intended to be used in conjunction with the detailed information on environmental loads, moorings and floating structures contained in sections 2, 3 and 4 and reference is made to these sections, where appropriate.

5.2 Pontoons

5.2.1 General

Examples of the use of floating pontoons at ports are illustrated in Figure 20. They include landing stages for pedestrians and small cargo, vehicle pontoons for roll-on roll-off (Ro-Ro) berths [21] and pontoons used for mooring small boats. Pontoons are most commonly installed when live loads are small and the tidal range is high. They have the attraction of being relatively cheap compared to fixed structures, and can easily be added to or relocated. Fabrication can often take place in controlled conditions remote from site. They are not generally feasible at exposed locations due to difficulties of providing moorings to resist wave forces.

The most common construction material for pontoons is steel. Concrete and GRP are also used. Steel pontoons are lighter than concrete pontoons, but generally require more maintenance.

5.2.2 Siting

5.2.2.1 *Navigation.* Floating pontoons should be sited so as not to cause a hazard to navigation. When pontoons are located near to or in a navigation channel the risk of collision should be assessed, and the effects of the wake of passing ships considered.

5.2.2.2 *Ship manoeuvres.* Sufficient area should be provided for safe manoeuvring at the berth. The influence of weather or strong currents and the effects of limited underkeel clearance should be considered.

5.2.2.3 *Moorings.* If anchor leg moorings are to be used, sufficient area needs to be provided to install lines of a length that will prevent uplift on the anchors.

Moorings should, where possible, be sited in sheltered locations, so as to minimize the risk of failure.

5.2.2.4 *Access.* Pontoons should be sited so as to minimize the risk of damage to accessways by ship collision.

5.2.2.5 *Dredging.* The ability to carry out maintenance dredging may be affected by the presence of anchor leg moorings.

5.2.3 Loads

5.2.3.1 *Types of loads.* Section 2 deals with environmental loads and **4.2** gives clarification on types of loads. For information on vehicle and equipment loads see clause **45** of BS 6349-1:1984 and for berthing loads see BS 6349-4.

5.2.3.2 ***Load combinations***

5.2.3.2.1 *Normal loading.* Under normal loading conditions, pontoons for landing stages and Ro-Ro berths should be designed for the following load combinations:

a) *for vessels berthing*: dead load + imposed load + maximum environmental conditions for berthing + berthing load;

b) *for normal operating (no berthing)*: dead load + imposed load + maximum environmental conditions for operating.

In a), the maximum environmental conditions for berthing should be assumed to be the maximum environmental conditions whilst operating, unless otherwise specified. The berthing load should be the load from any vessel likely to operate at the berth. The nominal imposed load should include anything stored on the pontoon, such as vehicles that have broken down.

In b), the imposed load giving the worst combined loading should be considered. For extreme loads the nominal imposed load should include minor items stored on the pontoon.

5.2.3.2.2 *Extreme loading.* Under extreme loading conditions, pontoons for landing stages and Ro-Ro berths should be designed for the following load combinations:

dead load + nominal imposed load + extreme environmental conditions.

5.2.3.3 *Load factors and factors of safety.* The load factors to be used in limit state design are given in Table 8. Recommendations on factors of safety for mooring equipment are given in **3.4.6**.

5.2.4 Design considerations

5.2.4.1 *Structural design.* The structural design of pontoons should be in accordance with the most relevant codes and classification society rules (see **4.3**).

5.2.4.2 *Motion response.* The stability and motion response of pontoons should be calculated in accordance with **4.4** and **4.5**. The stability and response of systems of combined pontoons are difficult to evaluate. Care should be taken to ensure that any assumptions or simplifications in analyses are compatible with the design details, especially in relation to connections between pontoons.

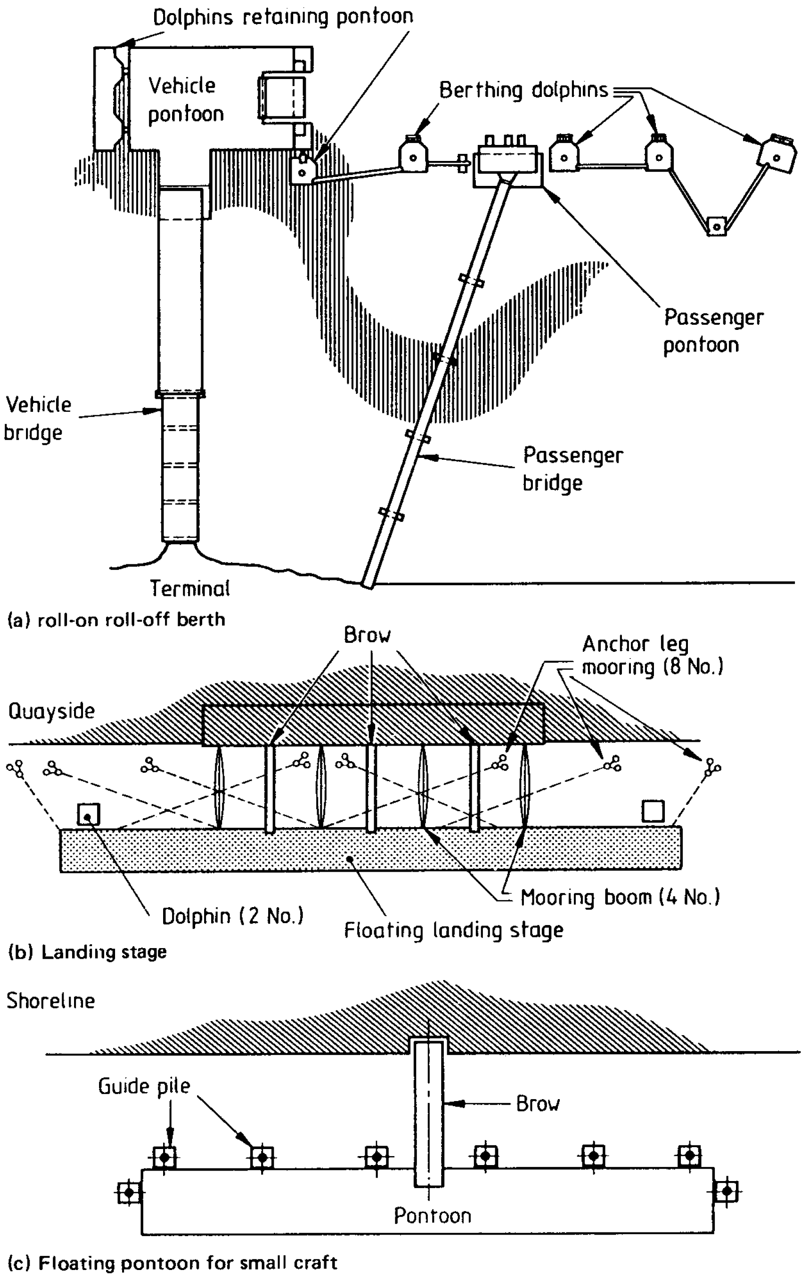


Figure 20 — Typical use of pontoons

5.2.4.3 *Longitudinal strength.* The longitudinal strength of pontoons subject to wave action should be calculated (see **4.6**).

5.2.4.4 *Fendering.* Pontoons should be adequately fendered to protect them against damage from vessels berthing and small boats likely to moor alongside. The effects of bulbous bows should be considered for vessels approaching head on to Ro-Ro ramps.

5.2.5 Mooring of pontoons

Moorings for pontoons should be selected and designed in accordance with section 3. In sheltered locations it may be possible to design moorings to take berthing loads. In exposed locations consideration should be given to providing separate berthing and mooring restraints.

The consequences of connections between pontoons and mooring structures failing should be considered.

Where anchor legs are employed, the consequences of anchor drag or a line failure should be considered.

5.2.6 Accessways

5.2.6.1 *General.* Where possible, independent vehicle and pedestrian access should be provided. The accessways should, where possible, be independent of the restraining system for the structure, and be connected to the structure so as to avoid undue stresses from motions of the structure or movement under impact loads. Motions or movement due to extreme loads should be allowed for, whilst at the same time ensuring that the accessway cannot be completely disconnected.

5.2.6.2 *Vehicle access.* The maximum gradient of a vehicle access should not exceed 1 in 10 for the worst possible combination of draught of the structure and tidal range.

5.2.6.3 *Pedestrian access.* For information on pedestrian access, see section 9 of BS 6349-2:1988. Walkways to floating structures should allow for vertical as well as horizontal motions.

5.3 Floating docks

5.3.1 General

Floating docks exist in a variety of sizes of up to 50 000 t lifting capacity or more. The majority of docks are of steel construction, and are built to classification society rules [13] and [14] (see **4.3.1**). Figure 21 shows a section through a floating dock. Docks can be maintained either by towing to a dry dock or by self-docking. In the latter case, the method of self-docking will affect the form of construction. Some docks have detachable sections which can be inspected inside the floating dock. In some cases, detachable sections are provided which can be placed under the dock and lift it sufficiently out of the water for the bottom to be inspected.

The general construction of a floating dock is such that the caisson or pontoon portion is suitably subdivided longitudinally and transversely for strength purposes and to provide a suitable arrangement of ballast tanks. The dock walls are built on top of the pontoon deck, and the upper portion of these, above a watertight deck, houses repair services and pump room equipment. The top of the walls or working deck provides a track for travelling cranes. Docks are usually self-contained in respect of services, since they are often required to operate for lengthy periods in conditions remote from normal repair facilities.

Pontoon tanks are fitted with an escape pipe running above the weather deck of the side walls. The air can escape to the side walls, so that a cushion of air is trapped below the top deck of the tanks and prevents the dock from sinking in the event of pump or other equipment failure. Hence the top deck of the side wall tanks is known as the "safety deck".

5.3.2 Siting

5.3.2.1 *Navigation.* Floating docks should be sited so as not to cause a hazard to navigation.

5.3.2.2 *Ship manoeuvres.* Adequate area should be provided for manoeuvring of ships into and around the dock. The influence of weather or strong currents and the effects of limited underkeel clearance should be considered.

5.3.2.3 *Moorings.* If anchor leg moorings are to be used, sufficient area has to be provided to install lines of a length that will prevent uplift on the anchors.

Siting of docks beam on to the prevailing winds should be avoided if possible.

5.3.2.4 *Access.* The effect of the siting of a dock on the degree of access and consequent safety standards for evacuation should be considered.

5.3.2.5 *Dredging.* During siting of a dock, consideration should be given to providing an area which can be dredged if adequate water depth is not available. The area of dredging and depth should be sufficient to include for excursion of the dock under berthing and environmental loads, and should accommodate the dock when ballasted to maximum draught.

The underkeel clearance at maximum draught will vary according to the location. The ability to carry out maintenance dredging may be affected by the presence of the dock and the anchor leg moorings.

5.3.3 Loads

5.3.3.1 *Types of loads.* Section 2 gives recommendations for environmental loads, and includes classification of types of loads.
See BS 6349-4 for berthing and mooring loads due to ships alongside a dock.

5.3.3.2 ***Load combinations***

5.3.3.2.1 *General.* Particular care should be taken to ensure that the worst combination of dead and imposed load are considered. Various arrangements of cranes and repair equipment should be considered together with various ballasting arrangements and ship sizes and shape.

5.3.3.2.2 *Normal loads*

The following load combinations should be considered:

a) *for docking conditions*: dead load + imposed load (including ship load) + maximum environmental conditions for docking;

b) *for operating after docking*: dead load + imposed load (including ship load) + maximum environmental conditions whilst operating.

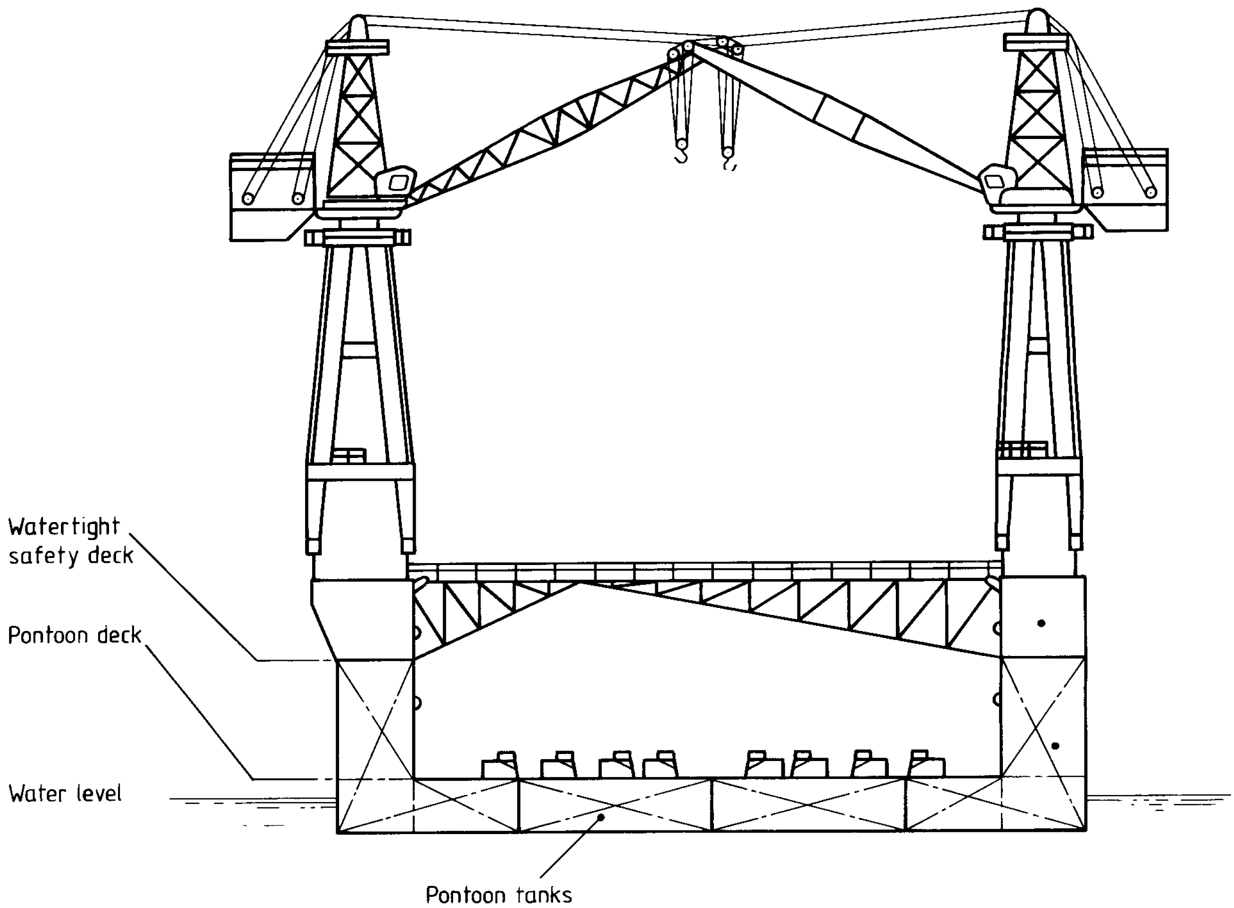


Figure 21 — Typical section through floating dock

5.3.3.2.3 *Extreme loads*

The following load combinations should be considered:

a) *in transportation*: dead load + imposed load (pay load during transportation) + extreme environmental conditions;

b) *at mooring*: dead load + imposed load (including ship load) + maximum environmental conditions at mooring site.

5.3.3.3 *Load factors and factors of safety.* The load factors to be used in limit state design are given in Table 8. Recommendations on factors of safety for mooring equipment are given in **3.5.5**.

5.3.4 Design considerations

5.3.4.1 *General.* The hull should be divided into compartments such as ballast water tanks and pump room "in-wells", generator rooms and workshops. Accommodation should be on the safety deck. A watertight deck should be provided on top of each wing wall.

The strength of the dock should be sufficient for the condition when a ship of given displacement and size is supported on the keel blocks, the centre of the ship's length being over the mid-length of the dock.

The longitudinal stiffening will normally consist of one central longitudinal watertight bulkhead and two intermediate longitudinal bulkheads on each side.

The space below the safety deck should be divided into compartments by transverse watertight bulkheads. Between these watertight bulkheads, the walls should be stiffened internally by longitudinal and transverse bulkheads; the latter should be in line with the transverses of the pontoon.

Consideration should be given to making the wing walls of open construction at their ends to permit access by ladders to the top deck from the pontoon deck.

Scupper pipes should be provided at the outboard deck extensions and led down along the outer wing wall to a height above the pontoon deck level for the drainage of water on the top deck.

The dock should be designed for towage from its construction site to its operational site.

5.3.4.2 *Lifting capacity.* The nett lifting capacity of the dock should be specified. It is equal to the displacement of the heaviest ship which the dock may be designed to lift. From this value, the dimensions of the dock may be determined. In determining the size of the dock the following should be considered:

a) specific gravity of the water (fresh or salt);

b) minimum freeboard at maximum draught (damaged stability should be taken into account);

c) position of the cranes and other mobile equipment (usually located at one end);

d) whether fuel tanks and fresh water tanks are full or empty;

e) quantity and location of compensating ballast water;

f) influence of water in ballast tanks which cannot be discharged.

The actual lifting capacity of the dock should be obtained from the difference between the calculated displacement of the dock at the working (loaded) draught and the light displacement (i.e. unloaded) obtained from the sinkage trial in normal conditions.

5.3.4.3 *Trim and stability.* The dock should be designed so as to have enough stability and not to trim or heel excessively in normal working conditions. Guidance on the calculation of stability is given in **4.4**.

In general, the transverse metacentric height of the combined ship and dock, after all free surface corrections are made, should be not less than 1.5 m for docks with a capacity of 10 000 t. This may be reduced to a minimum value of 1.0 m for docks with a capacity of 50 000 t or more. (Reference should be made to the classification society.)

When the dock is substantially complete, an inclining experiment should be carried out to ascertain the position of the centre of gravity of the dock and the metacentric height.

An operation manual should be furnished at the time of delivery for recommended distributions of ballast water to ensure proper trim, heel stability, longitudinal deflection and strength data during service.

The wing wall space above the safety deck should be suitably divided by watertight bulkheads. In the event that a wing wall is pierced at full draught, the volume of water flooding any one compartment above the safety deck should not cause sinking or instability of the dock.

When docking a ship the longitudinal centre of gravity of the ship should be vertically above the longitudinal centre of gravity of the dock. The latter is usually marked on the dock side. Thus the dock and ship form a single unit from the stability point of view. In Figure 22 the stability is a maximum at waterline 3, a minimum at waterline 2 and has an intermediate value at waterline 1. It should be noted that the effective waterplane area differs considerably between conditions 1, 2 and 3 (see **4.4.2** for stability calculations).

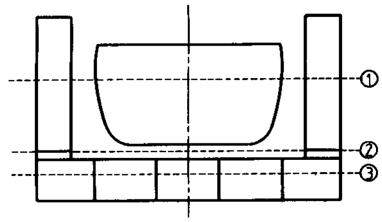


Figure 22 — Stability of floating dock

5.3.5 Floating dock moorings

Moorings for a floating dock should be designed in accordance with section 3. The following factors of particular relevance to floating docks should be considered:

a) wind loads at light displacement; quartering winds which can act on both side walls simultaneously;

b) the maximum and minimum draughts of the dock, and their influence on the effect of a catenary mooring;

c) the allowable excursions of the floating dock (i.e. is it located alongside a quay or is it free to drift within a channel area?);

d) the requirement to remove the moorings at regular intervals for maintenance purposes or because the dock needs to be moved for operational reasons;

e) the effect of catenary or taut-line moorings on restricting access around the dock for ships entering the dock or moored alongside;

f) berthing forces on the dock from work vessels or vessels that are mooring for repair;

g) the methods of installing the mooring system and of regular tensioning if excursions of the dock are restricted.

A configuration for a dry dock mooring remote from a quay is shown in Figure 23.

5.3.6 Construction and trials

5.3.6.1 *General.* When the dock is completed, sinkage trials (described in **5.3.6.2**) and an inclining test (described in **5.3.6.2.4**) should be carried out.

5.3.6.2 ***Sinkage trials***

5.3.6.2.1 *General.* Prior to the trial, all stagings, dunnage and other things which do not form part of the floating dock should be cleared and put ashore. The condition of the dock at sinkage trials should be as follows:

a) fresh water tanks and fuel oil tank should be full;

b) deck cranes should be so positioned that the dock has no trim (i.e. it is floating level).

The density of the sea water should be recorded.

5.3.6.2.2 *Normal conditions.* All ballast water should be emptied so far as possible, only rest-water remaining. The draught forward and aft, port and starboard, should be recorded. The readings on deflection meters should be taken. The deflection of the dock along the top of keel blocks should be measured and compared with acceptable design values. Adjustment of the meters should be made if necessary, so that they record the built-in permanent deflection in the normal condition. The light displacement should be evaluated from these readings.

5.3.6.2.3 *Sagging conditions.* The sagging condition should be produced by suitable loading of ballast water. The sagging bending moment so produced should be equivalent to that of the dock when the dock is loaded on the keel blocks with a ship which the dock has been designed for. The deflection meter readings should be recorded and allowing for the permanent deflection obtained from the sinkage trial in the normal condition, the sagging deflection should be obtained.

5.3.6.2.4 *Inclining test.* An inclining test should be performed in order to calculate the (*GM*) of the dock and verify the overall stability (see **4.4.2.1**).

5.4 Floating breakwaters

5.4.1 Suitability and limitations

Floating breakwaters may be suitable for sites such as estuaries, reservoirs, lakes and rivers, where short-period wind, wave or boat wake protection is required.

The limiting design wave for successfully installed systems is of the order of 1 m in height, and 4 s or 5 s period. Floating breakwaters cannot be installed in exposed locations, because of the very high wave forces that would act on the structure and moorings. In addition, floating breakwaters will have little effect on long waves (of swell period or greater).

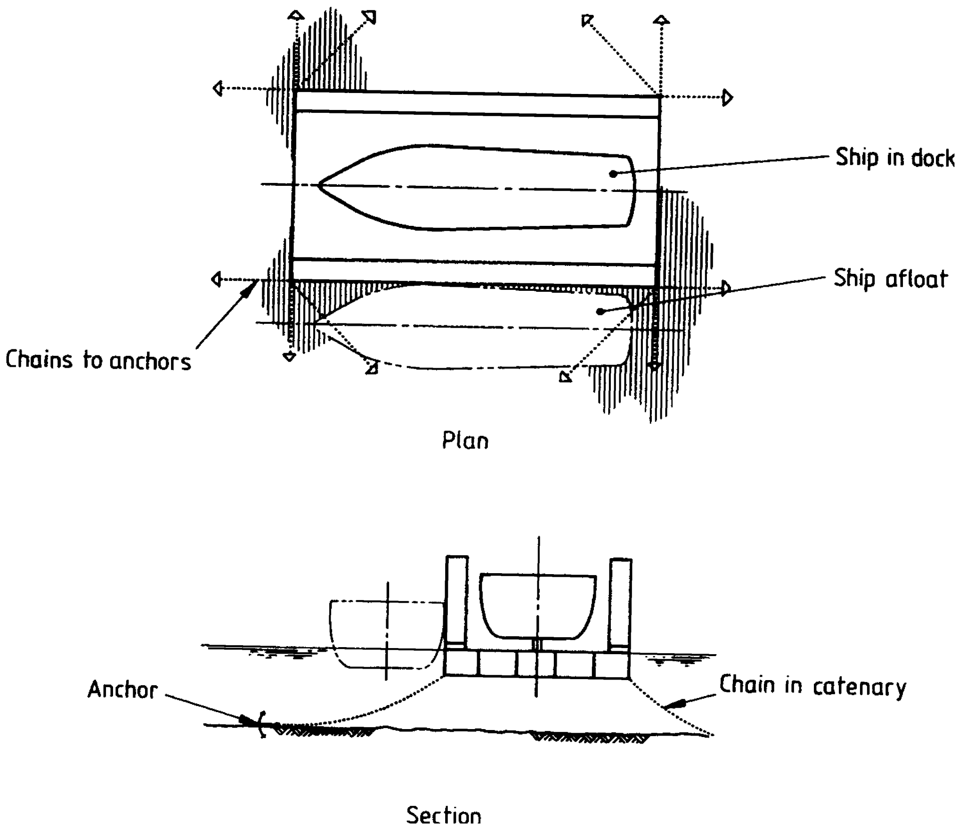


Figure 23 — Mooring arrangement for a floating dock

Where conditions are favourable, floating breakwaters may offer advantages in terms of cost, mobility and ease of fabrication, when compared to fixed breakwaters. They may, in addition, cause less interference with the hydraulic regime and be practicable in water depths which are too great for fixed breakwaters.

The main disadvantage of floating breakwaters is the limited experience of successful performance. Failures of either the breakwater structure or moorings are relatively common, and regular maintenance is generally required. The low success rate of floating breakwaters is due in part to the difficulty of predicting wave forces. Physical models should be used wherever possible (see **5.4.4.3**). Models will however only provide approximate estimates of wave forces and the nature of wave loading. Allowance should be made for tests at the installation stage and monitoring of long-term performance.

5.4.2 Layout

Breakwaters can be arranged as a single line of defence or as a series of lines that reduce the waves to an acceptable height.

5.4.3 Types

5.4.3.1 *General.* Information on breakwaters modelled and constructed can be found in references [22, 23, 24, 25, 26, 27, 28].

5.4.3.2 *Box and pontoon breakwaters.* Solid box type breakwaters of reinforced concrete or steel barges and pontoon type breakwaters are relatively robust and can be expected to have a longer design life than flexible mat or tethered float type breakwaters. The disadvantages are high construction costs, compared with mat type break-waters, and high maintenance costs if dry docking for repairs is necessary. Mooring forces are usually higher than for mat type structures, due to the fact that waves are generally reflected off the breakwater, rather than being dissipated. Particular care should be taken in designing the connections between units.

5.4.3.3 *Flexible mat or tethered float breakwaters.* Flexible mat or tethered float breakwaters are relatively cheap and are easily removed and beached for maintenance. The most common form consists of old tyres. They have the disadvantage of often requiring additional flotation units which are difficult to maintain. Floating debris often collects in the breakwaters. They are generally not as robust as box or pontoon breakwaters. Waves are attenuated primarily by the dissipation of energy.

5.4.4 Design

5.4.4.1 *Wave theory.* The theory of wave attenuation by reflection and/or wave energy dissipation is documented in standard texts [22, 23, 25]. The extent to which waves will be attenuated will depend on the wave characteristics, the form of the breakwaters and the stiffness of the moorings. The nature of the wave loading has to be understood in order to evaluate the efficiency of a breakwater and the forces on the breakwater and moorings. The magnitude of the wave loading should, where possible, be evaluated using model and/or prototype tests.

Short waves are more easily attenuated and cause lower forces than long waves. As a consequence, care should be taken to ensure that the longest waves likely to occur are considered.

5.4.4.2 *Computational models.* Computational models are generally of limited use in assessing the efficiency and loads on breakwaters due to the complexity of many breakwater structures and the difficulty of modelling breaking waves and friction (viscous) effects.

5.4.4.3 *Physical models.* Physical models have been used extensively for testing breakwaters [22, 23, 24]. They are suitable for establishing the fundamental properties of a breakwater and the nature of the wave forces. However, estimates of forces on the structure and moorings are usually only approximate, due to difficulties of scaling and measuring the various types of forces that can occur. Particular care should be taken if shock loads due to breaking waves are likely to occur.

5.4.5 Mooring design

Moorings for floating breakwaters should be designed in accordance with section 3. In general, mooring forces increase with increasing reflection of waves. Estimates of mooring line forces should be made using physical model tests, and/or prototype tests on similar installations.

5.4.6 Installation

Prototype tests on breakwaters should be carried out at the installation stage, in order to ascertain the efficiency and safety of the breakwaters.

5.4.7 Long-term performance

The likely long-term performance of a breakwater can be assessed from surveys of other breakwater performance [26, 27]. The limited experience of operation and maintenance of floating breakwaters makes it essential that the performance of breakwaters is carefully monitored, and remedial action taken when necessary. The possibility of a breakwater not being able to perform adequately in the long term has always to be considered.

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Appendix B Wind speed map

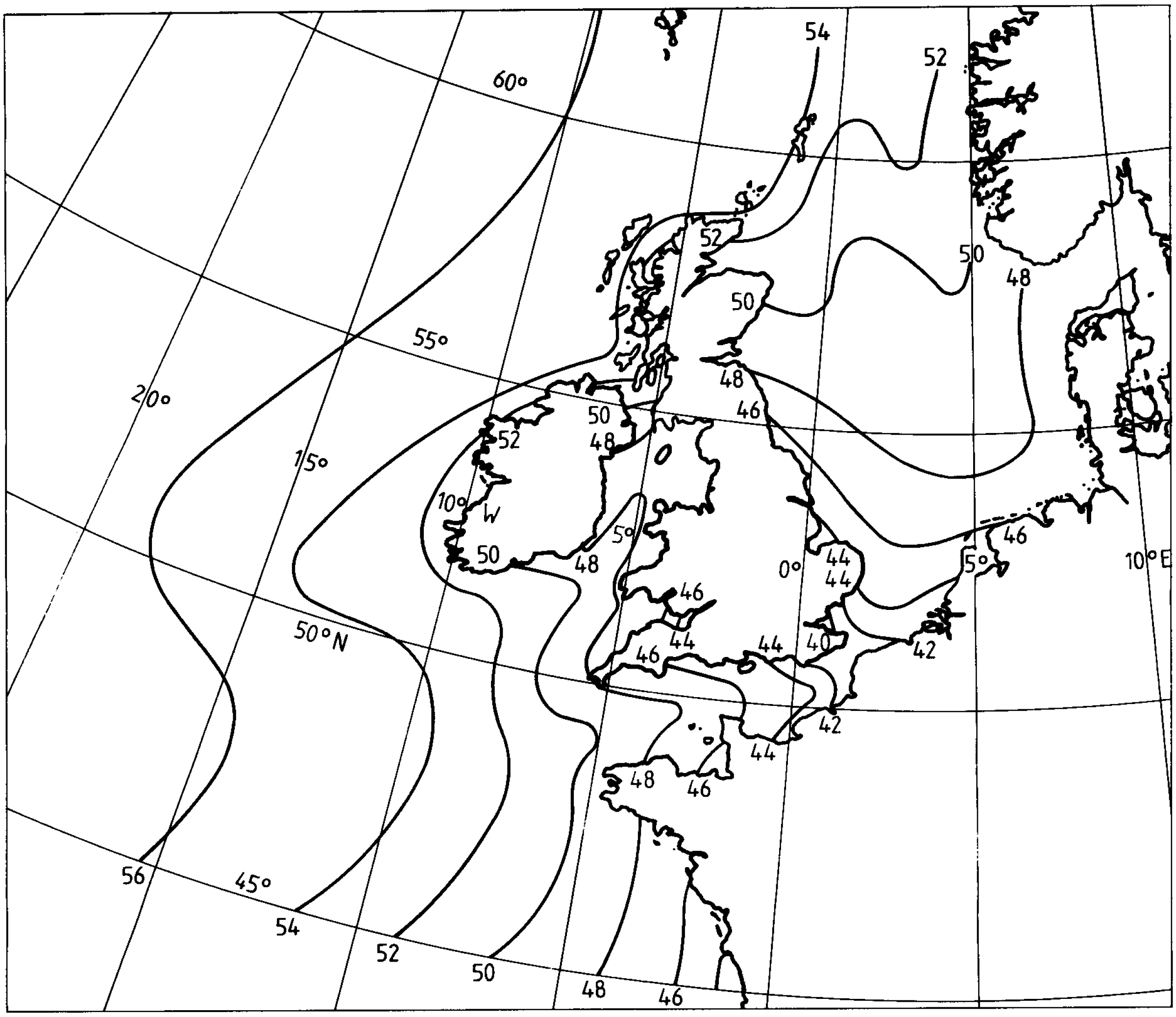

Figure 24 — Maximum 3 s gust speed in metres per second at 10 m above the sea surface with an average recurrence period of 50 years

Appendix C Typical drag embedment anchors

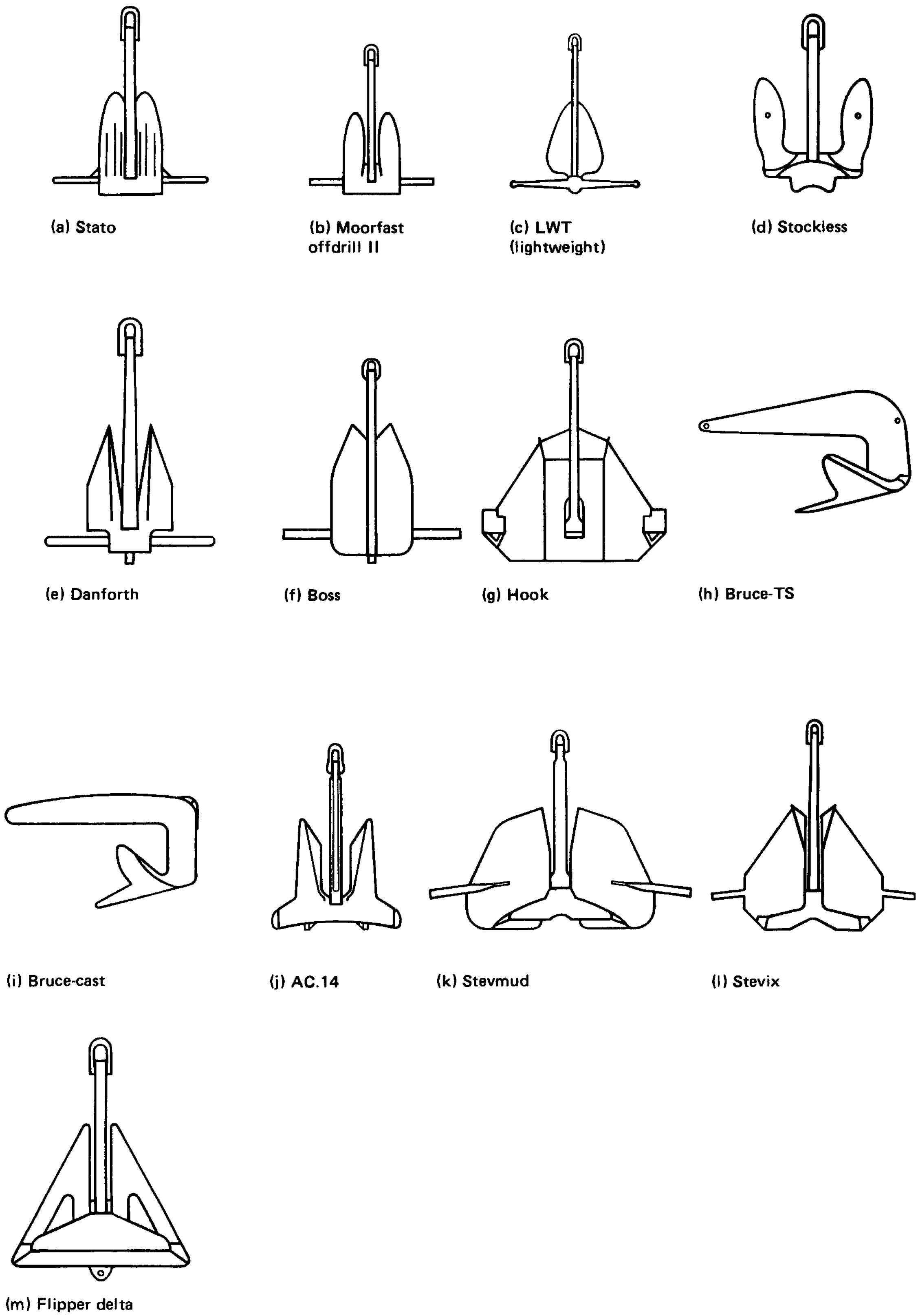

Figure 25 — Typical drag embedment anchors

Publications referred to

BS 302, *Stranded steel wire ropes.*
BS 729, *Specification for hot dip galvanized coatings on iron and steel articles.*
BS 4128, *Recommendations for the selection, use and care of man-made fibre ropes in marine applications.*
BS 5400, *Steel concrete and composite bridges.*
BS 5493, *Code of practice for protective coating of iron and steel structures against corrosion.*
BS 6349, *Code of practice for maritime structures.*
BS 6349-1, *General criteria.*
BS 6349-2, *Design of quay walls, jetties and dolphins.*
BS 6349-4, *Design of fendering and mooring systems.*
BS 8110, *Structural use of concrete.*
CP 3, *Code of basic data for the design of buildings.*
CP 3:Chapter V, *Loading.*
CP 3-2, *Wind loads.*
CP 1021, *Code of practice for cathodic protection.*

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