

Maritime structures —

Part 1: Code of practice for general criteria

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Committees responsible for this British Standard

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- Association of Consulting Engineers
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- British Steel Industry
- Concrete Society Limited
- Department of the Environment (PSA)
- Federation of Civil Engineering Contractors
- Health and Safety Executive
- Institution of Civil Engineers
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Contents

	Page
Committees responsible	Inside front cover
Foreword	x
Section 1. General	1
1 Scope	1
2 Normative references	1
3 Definitions	4
4 Symbols	6
Section 2. Environmental considerations	13
5 General	13
5.1 Design parameters	13
5.2 Environmental impact	13
5.3 Scope	13
6 Survey control	13
6.1 General	13
6.2 Level control	14
6.3 Location control	14
7 Meteorology and climatology	15
7.1 General	15
7.2 Wind	15
7.3 Precipitation	17
7.4 Air temperature and humidity	17
7.5 Visibility	17
7.6 Atmospheric pressure	17
7.7 Solar radiation and hours of sunshine	18
8 Bathymetry	18
8.1 General	18
8.2 Echo sounder	18
8.3 Side-scan sonar	19
8.4 Direct measurement	19
8.5 Spacing and direction of sounding profiles	19
8.6 Wire sweep	20
8.7 Reduction of soundings	20
8.8 Coastal topography	20
9 Geological considerations	20
10 Water level	20
10.1 General	20
10.2 Tidal predictions	21
10.3 Meteorological effects	21
10.4 Tidal observations	22
10.5 Tidal analysis	22
11 Water movement	22
11.1 General	22
11.2 Measurement of currents	22
11.3 Measurement of diffusion	25
11.4 Presentation and analysis of field data	26
12 Waves	26

	Page
13 Water quality	26
13.1 General	26
13.2 Water temperature	26
13.3 Chemistry	27
13.4 Turbidity	27
13.5 Marine life	27
13.6 Pollution	28
14 Sediment transport	28
14.1 General	28
14.2 Sediment transport in currents	28
14.3 Sediment transport with waves	30
14.4 Accretion and scour	31
14.5 Bed-form migration	31
14.6 Models	31
Section 3. Operational considerations	33
15 General	33
16 Design working life	33
17 Ship data	34
17.1 General	34
17.2 Tonnage and displacement	34
17.3 Typical container ship and bulk carrier dimensions	34
18 Navigation in approach channels	34
18.1 General	34
18.2 Studies	35
18.3 Depth of channels	39
18.4 Width of channels	39
18.5 Other operational aspects	40
19 Ship handling	40
19.1 Manoeuvring inside harbours	40
19.2 Berthing	41
19.3 Mooring	41
Section 4. Sea state	43
20 General	43
21 Wave characteristics	43
21.1 Wave forms	43
21.2 Basic wave properties	44
21.3 Sea state properties	52
22 Offshore wave climate	55
22.1 Wave generation	55
22.2 Wave prediction	55
22.3 Wave decay and swell	64
22.4 Extrapolation of offshore wave data	64
23 Shallow water effects	64
23.1 General	64
23.2 Refraction and shoaling	64
23.3 Channel effects	67
23.4 Bottom friction	67
23.5 Wave breaking	69

	Page
24 Long waves	71
24.1 General	71
24.2 Moving pressure fronts	72
24.3 Wave grouping effects	72
24.4 Tsunamis	72
24.5 Conclusions	73
25 Storm surge	73
26 Wave recording and analysis	73
26.1 Existing data sources	73
26.2 Site measurements	74
26.3 Wave recorders	75
26.4 Analysis of records	76
27 Extrapolation of wave data	76
27.1 General	76
27.2 Extrapolation to extreme wave conditions	76
27.3 Extrapolation to individual maximum wave heights	78
27.4 Extrapolation of wave periods	81
28 Effects of breakwaters and sea walls on sea states	81
29 Harbour response	84
29.1 General	84
29.2 Wave diffraction for a flat seabed	84
29.3 Ray methods of wave diffraction and refraction	89
29.4 Harbour resonance	90
29.5 Physical models	90
29.6 Mathematical models	91
30 Acceptable wave conditions for moored small vessels	92
30.1 General	92
30.2 Marinas	92
30.3 Fishing harbours	92
30.4 Lighterage	92
31 Acceptable wave conditions for moored ships	93
31.1 General	93
31.2 Background information	93
31.3 Methods for determining acceptable sea states	94
31.4 Acceptable ship movements	97
31.5 Downtime	98
Section 5. Loads, movements and vibrations	99
32 General	99
32.1 Basic loads	99
32.2 Dynamic response	99
32.3 Spectral loading	99
32.4 Fatigue	100
33 Soil pressures	100
34 Winds	100
35 Snow and ice	100
36 Temperature variations	101
37 Tides and water level variations	101
38 Currents	101
38.1 General	101
38.2 Steady drag force	102

	Page
38.3 Flow-induced oscillations	103
39 Waves	107
39.1 General	107
39.2 Fatigue analysis	107
39.3 Design wave parameters	107
39.4 Wave forces	108
40 Earthquakes	117
41 Berthing	117
41.1 General	117
41.2 Operational factors	117
41.3 Fendering	117
41.4 Design of fendering	118
41.5 Assessment of berthing energy	118
42 Mooring	118
42.1 General	118
42.2 Evaluation of mooring loads	118
43 Docking and slipping	128
44 Cargo storage	128
44.1 General	128
44.2 Dry bulk stacks	128
44.3 Containers	129
44.4 Other loads	129
45 Cargo handling and transport systems	130
45.1 General	130
45.2 Fixed and rail-mounted equipment	130
45.3 Conveyors and pipelines	133
45.4 Rail traffic	133
45.5 Road traffic	133
45.6 Rubber-tyred port vehicles	133
46 Channelized loading in pavements and decks	137
47 Movements and vibrations	138
47.1 General	138
47.2 Assessment of movements	138
47.3 Acceptability criteria	143
Section 6. Geotechnical considerations	145
48 General	145
49 Site investigations	145
49.1 General	145
49.2 Existing data sources	145
49.3 Site reconnaissance	146
49.4 Exploratory drilling, sampling and in-situ testing	146
49.5 Layout of boreholes and trial excavations	147
49.6 Depth of boreholes	147
49.7 Groundwater investigations	149
49.8 Determination of earth pressure coefficient at rest	149
49.9 Detection of underground movements at depth	149
49.10 Geophysical surveys	150
49.11 Field trials	150
49.12 Studies related to constructional materials	150
50 Properties of the ground	151

	Page
50.1 Average properties for preliminary design	151
50.2 Selection of parameters for working design	152
51 Sheet-piled structures	159
51.1 General	159
51.2 Design	159
51.3 Distribution of lateral earth pressure and earth resistance	159
51.4 Effects of surcharge	169
51.5 Hydrostatic pressure distribution	170
52 Gravity structures	175
52.1 General	175
52.2 Masonry and brickwork	175
52.3 Plain concrete walls	175
52.4 Concrete blockwork	175
52.5 Monoliths	175
52.6 Caissons	176
53 Anchorage of structures	176
53.1 Function and location of anchorages	176
53.2 Methods of anchorage	178
54 Slope stability and protection	180
54.1 Environmental factors	180
54.2 Modes of failure	181
54.3 Design considerations for slopes and embankments	185
54.4 Monitoring stability	189
54.5 Slope protection	189
54.6 Maintenance of earthworks	192
54.7 Remedial works	192
55 Use of thixotropic liquids in excavations	192
55.1 Types of structure	192
55.2 Lateral earth pressure and earth resistance	193
55.3 Design of excavations for support by bentonite mud	193
55.4 Materials	194
Section 7. Materials	195
56 General	195
57 Stone for armouring or protection works	195
57.1 General	195
57.2 Tests of quality	196
57.3 Specification of size	196
58 Concrete	196
58.1 General	196
58.2 Type of construction	197
58.3 Durability from foundation soils, seawater and contaminants	198
58.4 Specification for materials and workmanship	203
59 Structural steel and other metals	211
59.1 General	211
59.2 Structural steel	212
59.3 Aluminium and its alloys	215
59.4 Other metals	216
60 Timber	216
60.1 General	216
60.2 Resistance to environmental hazards	216

	Page
60.3 Functional suitability	218
60.4 Fastenings	219
61 Piles	219
61.1 General	219
61.2 Bearing piles	219
61.3 Sheet piles	222
62 Pipes	223
62.1 General	223
63 Pavements	223
63.1 General	223
64 Rails	224
64.1 General	224
64.2 Crane rails	224
64.3 Adjustment of crane rails	225
64.4 Holding-down bolts	225
64.5 Rail clips	225
64.6 Heavy-duty crane rails	225
64.7 Bolted joints	225
65 Bituminous materials	225
65.1 General	225
65.2 Bituminous materials available	225
65.3 Composition, mix design and application techniques	226
65.4 Uses of bituminous materials	228
66 Protective measures	229
66.1 General	229
66.2 Coating systems	230
66.3 Concrete protection	230
66.4 Monel 400 sheathing	230
66.5 Steel wear plates	230
66.6 Wrappings	230
67 Maintenance	232
67.1 General	232
67.2 Records	232
67.3 Access	232
Annex A (informative) Physical properties of commonly sorted cargoes	233
Bibliography	235
Figure 1a) — Typical ship dimensions — Container ship — Approximate dimensions based on draught against DWT, and beam width against DWT	36
Figure 1b) — Typical ship dimensions — Container ship — Approximate dimensions based on draught against DWT, and TEU against DWT	37
Figure 2 — Typical ship dimensions — Bulk carrier	38
Figure 3 — Wave shoaling and estimation of wave height in the surf zone	45
Figure 4 — Relationship between design working life, return period and probability of wave heights exceeding the normal average	54
Figure 5 — Significant wave prediction chart — Fetch lengths up to 1 500 km	57
Figure 6 — Significant wave prediction chart — Fetch lengths from 200 km to 20 000 km	58
Figure 7 — JONSWAP wave spectrum	59
Figure 8 — Pierson–Moskowitz wave spectrum	60

	Page
Figure 9 — Significant wave height and peak period for wave spectra	63
Figure 10 — Schematic diagram of wave refraction	65
Figure 11 — Wave height reduction factor for bottom friction	68
Figure 12 — Breaker types	69
Figure 13 — Variation of $(H_{\max}/H_s)^2$ with N	80
Figure 14 — Run-up on graded riprap (see 57.3.3) slope	82
Figure 15 — Run-up on rubble-mound slope	83
Figure 16a) — Diffraction coefficients for breakwater gap of length B = one wave length, Pierson–Moskowitz spectrum, Cos^2 directional spread. (Acknowledgement: HR Wallingford)	85
Figure 16b) — Diffraction coefficients for breakwater gap of length B = two wave lengths, Pierson–Moskowitz spectrum, Cos^2 directional spread. (Acknowledgement: HR Wallingford)	86
Figure 17a) — Diffraction coefficients for island breakwater of length B = one wave length, Pierson–Moskowitz spectrum, Cos^2 directional spread. (Acknowledgement: HR Wallingford)	87
Figure 17b) — Diffraction coefficients for island breakwater of length B = two wave lengths, Pierson–Moskowitz spectrum, Cos^2 directional spread. (Acknowledgement: HR Wallingford)	88
Figure 18 — The six degrees of freedom of vessel movement	95
Figure 19 — Drag force coefficient values for circular cylinders	103
Figure 20 — Critical flow velocity for circular piles for in-line oscillations	105
Figure 21 — Wave pressure distribution at reflective walls for non-breaking waves	109
Figure 22 — Estimation of alpha values for calculation of wave pressure — Vertical distribution of wave pressure	110
Figure 23 — Estimation of alpha values for calculation of wave pressure — Coefficient of wave pressure at surface dependent upon wave period	112
Figure 24 — Estimation of alpha values for calculation of wave pressure — Coefficient of wave pressure at surface dependent upon shoaling	113
Figure 25 — Estimation of alpha values for calculation of wave pressure — Ratio between wave pressures at surface and at depth d'	114
Figure 26 — Current drag force coefficients, all ships, deep water case	120
Figure 27 — Envelope of wind force coefficients for dry cargo vessels and small tankers	122
Figure 28 — Wind force coefficients for very large tankers with superstructures aft	123
Figure 29 — Wind force coefficients for typical container ship	124
Figure 30 — Water depth correction factors for lateral current forces	125
Figure 31 — Water depth correction factor for longitudinal current forces on container ships	126
Figure 32 — Envelope of longitudinal force coefficients for VLCCs in shallow water	126
Figure 33 — Typical longitudinal projected areas of tankers	127
Figure 34 — Container ships: lengths and longitudinal projected areas	128
Figure 35 — Typical container crane dimensions	131
Figure 36 — Container crane bogie with alternative number of wheels	132
Figure 37 — Dimensions of RT vehicle	136
Figure 38 — Location and depth of boreholes for piled wharf	148
Figure 39 — Depth of boreholes in relation to retained height of soil and width of quay wall	149
Figure 40 — Plane strain shear diagram for sand	153
Figure 41 — Plane strain shear diagram for normally-consolidated clay	155
Figure 42 — Slab slide in rock	156

	Page
Figure 43 — Wedge failure in rock	157
Figure 44 — Toppling failure in rock	157
Figure 45 — Cantilevered single-wall sheet pile structure	161
Figure 46 — Anchored single-wall sheet pile structure	162
Figure 47 — Distribution of earth pressure and earth resistance on cantilevered single-wall sheet pile structure	163
Figure 48 — Distribution of earth pressure and earth resistance on anchored single-wall sheet pile structure	164
Figure 49 — Double-wall sheet pile structures — Sheet piles driven into soil below seabed	165
Figure 50 — Double-wall sheet pile structures — Sheet piles terminated on rock at seabed	165
Figure 51 — Active pressure distribution on anchored single-wall structure where filling is placed before dredging	166
Figure 52 — Active pressure distribution on anchored single-wall structure where filling is placed after dredging	167
Figure 53 — Distribution of active pressure and passive resistance for total stress conditions in normally- and lightly over-consolidated clay	168
Figure 54 — Hydrostatic pressure distribution on waterfront structures where soil is retained to full height of structure	172
Figure 55 — Hydrostatic pressure distribution on waterfront structure where the soil is embanked behind the structure	173
Figure 56 — Hydrostatic pressure behind waterfront structure backed by clay	174
Figure 57 — Effects on hydrostatic and soil pressure distribution where seepage takes place beneath retaining structure	174
Figure 58 — Anchorage of lock or dry dock against hydrostatic uplift	177
Figure 59 — Failure of vertical anchor tendon due to uplift of cone of soil or rock	178
Figure 60 — Modes of failure of anchor tendons in rock — Massively bedded rock	179
Figure 61 — Modes of failure of anchor tendons in rock — Thinly bedded rock with horizontal or near-horizontal bedding joints	179
Figure 62 — Types of slope failure — Rotational shear slide on circular sliding surface	181
Figure 63 — Types of slope failure — Three-dimensional rotational slide	182
Figure 64 — Types of slope failure — Non-circular rotational slide	182
Figure 65 — Failure of embankment due to shear failure of supporting soil	183
Figure 66 — Compound slide	184
Figure 67 — Embankment built in stages with core material protected by dumped stone	188
Figure 68 — Slope protection by rock or concrete armouring backed by filter layer	191
Figure 69 — Schematic diagram of the chloride transport processes in a maritime structure (Acknowledgement: The Concrete Society.)	200
Figure 70 — Suggested severity ratings for chloride-induced corrosion of reinforcement on a scale of 1–12	202
Table 1 — Acceptable wave heights in marinas and fishing harbours	92
Table 2 — Guidance on maximum velocity criteria for safe mooring conditions	97
Table 3 — Guidance on maximum motion criteria for safe working conditions	98
Table 4 — Typical frequencies of environmental forces	99

	Page
Table 5 — Effective temperature range for maritime structure decks in British coastal waters	101
Table 6 — Modification factors for critical flow velocity	103
Table 7 — Drag and inertia force coefficients for common structural forms	106
Table 8 — Nominal bollard and fairlead loadings for vessels up to 20 000 t displacement	119
Table 9 — Typical stacking heights	129
Table 10 — Container loads expressed as uniformly distributed loads	129
Table 11 — Equivalent uniformly distributed loading for rubber-tyred port vehicles	133
Table 12 — FLT wheel loading: container handling duties	134
Table 13 — Side-loader jack reactions	134
Table 14 — Mobile crane outrigger reactions	135
Table 15 — RT loading: axle loads and effective wheel pressures	135
Table 16 — Loading due to tracked cranes	137
Table 17 — Typical throughputs for new cargo handling berths	137
Table 18 — Added mass of entrained water	140
Table 19 — Mobilized angle of friction	151
Table 20 — Physical characteristics of soils and rocks	158
Table 21 — Cements	204
Table 22 — Limiting values for composition and properties of concrete classes with normal weight aggregates of 20 mm maximum size exposed to risk of corrosion of reinforcement induced by UK seawater conditions for a required design working life of 50 years	205
Table 23 — Limiting values for composition and properties of concrete classes with normal weight aggregates of 20 mm maximum size exposed to risk of corrosion of reinforcement induced by UK seawater conditions for a required design working life of 100 years	206
Table 24 — Limiting values for composition and properties of plain concrete with normal weight aggregates of 20 mm nominal maximum size exposed to UK seawater conditions for a required design working life in excess of 50 years	208
Table 25 — Typical rates of corrosion for structural steels in temperate climates	213
Table 26 — Possible uses of bituminous materials in maritime protection works	228
Table A.1 — Typical dry bulk densities and angles of repose	233
Table A.2 — Typical stacked densities for common commodities	234

Foreword

This revision of BS 6349-1 has been prepared under the direction of the Technical Sector Committee for Building and Civil Engineering (B/-) and supersedes BS 6349-1:1984, which is withdrawn.

BS 6349-1:1984 was published in advance of the subsequent parts of the code, which are listed at the end of this foreword. In the new edition, subject matter that is now duplicated or dealt with more fully in other parts of the code has been curtailed or deleted. All sections of Part 1 have been updated in order to take account of new developments or increased knowledge and all amendments previously issued by BSI have been incorporated.

In Part 1 recommendations are given to assist clients and engineers to obtain the basic data relevant to the design of any maritime structure.

Offshore structures and structures in inland waters are not covered by this code, although certain aspects might be relevant to such projects.

Guidance is not given on financial criteria, although it should be recognized that the necessary and proper economic assessments should be made and considered for each project in conjunction with the engineering criteria covered by this code.

This code has been written in relation to conditions that pertain to the UK and, although the majority of the contents are directly applicable elsewhere, local conditions or sources might necessitate appropriate modifications.

In general, reference is made to British Standards and not to European Standards, because most relevant European Standards are still in the pre-standard (ENV) form. Only in the case of structural steel, for which ENs have been published, is reference made to European Standards (see clause 59).

This code of practice contains information and guidance for engineers and recommendations on good practice. As such, conformity with its recommendations is not obligatory and variations from its recommendations might well be justified in special circumstances. Engineering judgement should therefore be applied to determine when the recommendations of the code should be followed and when they should not.

This code of practice is intended for use by engineers who have some knowledge of the subject. It embodies the experience of engineers successfully engaged in the design and construction of the particular class of works, so that other reasonably qualified engineers can use it as a basis for the design of similar works.

A code of practice represents good practice at the time it is written and, inevitably, technical developments can 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 that have taken place subsequent to the publication of this code.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and experienced people.

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The standard is 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;*
- *Part 4: Code of practice for design of fendering and mooring systems;*
- *Part 5: Code of practice for dredging and land reclamation;*
- *Part 6: Design of inshore moorings and floating structures;*
- *Part 7: Guide to the design and construction of breakwaters.*

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to xii, pages 1 to 239 and a back cover.

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Sidelining in this document indicates the most recent changes by amendment.

Section 1. General

1 Scope

This part of BS 6349 gives guidance and recommendations on general criteria relevant to the planning, design, construction and maintenance of structures set in the maritime environment.

This part of the code is arranged on a topical basis. Section 2 discusses environmental factors, in which the environment is taken in its broader sense to include all naturally occurring phenomena likely to be found at a coastal site and guidance is given on methods of investigating and quantifying their effects. Section 3 gives prominence to the need to consider operational requirements throughout the planning of maritime works, although only limited guidance is given on some general aspects because the detailed functional requirements of individual structures are beyond the scope of this part of this code. Section 4 discusses sea state and gives guidance on the characteristics, prediction, recording and effect of waves. Section 5 deals with the selection and evaluation of design loadings arising from the environmental and operational effects discussed in the previous sections, taking due account of dynamic response and fatigue. Section 6 discusses geotechnical aspects, including ground investigations, soil parameters, and geotechnical design requirements. Section 7 gives guidance on the use and specification of appropriate materials and protective measures.

2 Normative references

The following normative documents contain provisions, which, through reference in this text, constitute provisions of this part of this British Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

BS 11, *Specification for railway rails.*

BS 12, *Specification for ordinary and rapid-hardening Portland cement.*

BS 105, *Light and heavy bridge-type railway rails.*

BS 146, *Portland blastfurnace cement.*

BS 500, *Steel railway sleepers for flat bottom rails.*

BS 812 (all parts), *Testing aggregates.*

BS 882, *Specification for aggregates from natural sources for concrete.*

BS 1211, *Specification for centrifugally cast (spun) iron pressure pipes for water, gas and sewage.*

BS 1370, *Specification for low heat Portland cement.*

BS 1400, *Specification for copper alloy ingots and copper alloy and high conductivity copper castings.*

BS 1579, *Specification for connectors for timber.*

BS 1881-124, *Testing concrete — Part 124: Methods for analysis of hardened concrete.*

BS 2870, *Specification for rolled copper and copper alloys: sheet, strip and foil.*

BS 2871, *Specification for copper and copper alloys — Tubes.*

BS 3148, *Methods of tests for water for making concrete (including notes on the suitability of the water).*

BS 3410, *Specification for metal washers for general engineering purposes.*

BS 3468, *Specification for austenitic cast iron.*

BS 3892-1, *Pulverized-fuel ash — Part 1: Specification for pulverized-fuel ash for use as with Portland cement.*

BS 4027, *Specification for sulfate-resisting Portland cement.*

BS 4246, *Specification for high slag blastfurnace cement.*

BS 4449, *Specification for carbon steel bars for the reinforcement of concrete.*

BS 4466, *Specification for scheduling, dimensioning, bending and cutting of steel reinforcement for concrete.*

BS 4482, *Specification for cold reduced steel wire for the reinforcement of concrete.*

BS 4483, *Steel fabric for the reinforcement of concrete.*

BS 4844, *Specification for abrasion resisting white cast irons.*

BS 4976, *Specification for polytetrafluoroethylene (PTFE) tubing extruded from coagulated dispersion powder (metric and imperial units).*

BS 5268-2, *Structural use of timber — Part 2: Code of practice for permissible stress design, materials and workmanship.*

BS 5290, *Determination of lead content of gasoline — Volumetric chromate method.*

BS 5328-2, *Concrete — Part 2: Methods for specifying concrete mixes.*

BS 5391-1, *Specification for acrylonitrile- butadiene-styrene (ABS) pressure pipe — Part 1: Pipe for industrial uses.*

BS 5392, *Specification for acrylonitrile-butadiene- styrene (ABS) fittings for use with ABS pressure pipe.*

BS 5400-2, *Steel, concrete and composite bridges — Part 2: Specification for loads.*

BS 5409-1, *Specification for nylon tubing — Part 1: Fully plasticized nylon tubing types 11 and 12 for use primarily in pneumatic installations.*

BS 5480, *Specification for glass reinforced plastics (GRP) pipes and fittings for use for water supply or sewerage.*

BS 5567, *Specification for apertures in tinplate containers to receive plug-in plastics closures.*

BS 5589, *Code of practice for preservation of timber.*

BS 5996, *Specification for acceptance levels for internal imperfections in steel plate, strip and wide flats, based on ultrasonic testing.*

BS 6399-1, *Loading for buildings — Part 1: Code of practice for dead and imposed load.*

BS 6399-2, *Loading for buildings — Part 2: Code of practice for wind loads.*

BS 6588, *Specification for Portland pulverized-fuel ash cement.*

BS 6699, *Specification for ground granulated blastfurnace slag for use with Portland cement.*

BS EN 485-1, *Aluminium and aluminium alloys — Sheet, strip and plate — Part 1: Technical conditions for inspection and delivery.*

BS EN 485-2, *Aluminium and aluminium alloys — Sheet, strip and plate — Part 2: Mechanical properties.*

BS EN 485-3, *Aluminium and aluminium alloys — Sheet, strip and plate — Part 3: Tolerances on shape and dimensions for hot-rolled products.*

BS EN 485-4, *Aluminium and aluminium alloys — Sheet, strip and plate — Part 4: Tolerances on shape and dimensions for cold-rolled products.*

BS EN 499, *Welding consumables — Covered electrodes for manual metal arc welding of non alloy and fine grain steels — Classification.*

BS EN 515, *Aluminium and aluminium alloys — Wrought products — Temper designations.*

BS EN 573-1, *Aluminium and aluminium alloys — Chemical composition and form of wrought products — Part 1: Numerical designation system.*

BS EN 573-2, *Aluminium and aluminium alloys — Chemical composition and form of wrought products — Part 2: Chemical symbol based designation system.*

BS EN 573-3, *Aluminium and aluminium alloys — Chemical composition and form of wrought products — Part 3: Chemical composition.*

BS EN 573-4, *Aluminium and aluminium alloys — Chemical composition and form of wrought products — Part 4: Forms of products.*

BS EN 586-1, *Aluminium and aluminium alloys — Forgings — Part 1: Technical conditions for inspection and delivery.*

BS EN 586-2, *Aluminium and aluminium alloys — Forgings — Part 2: Mechanical properties and additional property requirements.*

BS EN 603-1, *Aluminium and aluminium alloys — Wrought forging stock — Part 1: Technical conditions for inspection and delivery.*

BS EN 603-2, *Aluminium and aluminium alloys — Wrought forging stock — Part 2: Mechanical properties.*

- BS EN 604-1, *Aluminium and aluminium alloys — Cast forging stock — Part 1: Technical conditions for inspection and delivery.*
- BS EN 754-1, *Aluminium and aluminium alloys — Cold drawn rod/bar and tube — Part 1: Technical conditions for inspection and delivery.*
- BS EN 754-2, *Aluminium and aluminium alloys — Cold drawn rod/bar and tube — Part 2: Mechanical properties.*
- BS EN 754-7, *Aluminium and aluminium alloys — Cold drawn rod/bar and tube — Part 7: Seamless tubes, tolerances on dimensions and form.*
- BS EN 754-8, *Aluminium and aluminium alloys — Cold drawn rod/bar and tube — Part 8: Porthole tubes, tolerances on dimensions and form.*
- BS EN 755-1, *Aluminium and aluminium alloys — Extruded rod/bar, tube and profiles — Part 1: Technical conditions for inspection and delivery.*
- BS EN 755-2, *Aluminium and aluminium alloys — Extruded rod/bar, tube and profiles — Part 2: Mechanical properties.*
- BS EN 755-3, *Aluminium and aluminium alloys — Extruded rod/bar, tube and profiles — Part 3: Round bars, tolerances on dimensions and form.*
- BS EN 755-4, *Aluminium and aluminium alloys — Extruded rod/bar, tube and profiles — Part 4: Square bars, tolerances on dimensions and form.*
- BS EN 755-5, *Aluminium and aluminium alloys — Extruded rod/bar, tube and profiles — Part 5: Rectangular bars, tolerances on dimensions and form.*
- BS EN 755-6, *Aluminium and aluminium alloys — Extruded rod/bar, tube and profiles — Part 6: Hexagonal bars, tolerances on dimensions and form.*
- BS EN 755-7, *Aluminium and aluminium alloys — Extruded rod/bar, tube and profiles — Part 7: Seamless tubes, tolerances on dimensions and form.*
- BS EN 755-8, *Aluminium and aluminium alloys — Extruded rod/bar, tube and profiles — Part 8: Porthole tubes, tolerances on dimensions and form.*
- BS EN 932-6, *Tests for general properties of aggregates — Part 6: Definitions of repeatability and reproducibility.*
- BS EN 1301-1, *Aluminium and aluminium alloys — Drawn wire — Part 1: Technical conditions for inspection and delivery.*
- BS EN 1301-2, *Aluminium and aluminium alloys — Drawn wire — Part 2: Mechanical properties.*
- BS EN 1301-3, *Aluminium and aluminium alloys — Drawn wire — Part 3: Tolerances on dimensions.*
- BS EN 1367-2, *Tests for thermal and weathering properties of aggregates — Part 2: Magnesium sulfate test.*
- BS EN 1744-1, *Tests for chemical properties of aggregates — Part 1: Chemical analysis.*
- BS EN 10088 (all parts), *Stainless steels.*
- BS EN 12163, *Copper and copper alloys — Rod for general purposes.*
- BS EN 12164, *Copper and copper alloys — Rod for free machining purposes.*
- BS EN 12165, *Copper and copper alloys — Wrought and unwrought forging stock.*
- BS EN 12166, *Copper and copper alloys — Wire for general purposes.*
- BS EN 12167, *Copper and copper alloys — Profiles and rectangular bar for general purposes.*
- prEN 206, *Concrete — Performance, production, placing and compliance criteria.*
- DD ENV 1991-1, *Eurocode 1: Basis of design and actions on structures — Part 1: Basis of design (together with United Kingdom national application document).*
- DD ENV 1992-1-1, *Eurocode 2: Design of concrete structures — Part 1-1: General rules for buildings.*
- PD 6484, *Commentary on corrosion at bimetallic contacts and its alleviation.*

PD 6484, Commentary on corrosion at bimetallic contacts and its alleviation.

3 Definitions

For the purposes of this part of BS 6349 the following definitions apply.

NOTE For other terms not separately defined the meanings follow the general usage of the maritime engineering industry.

3.1 Tides

3.1.1

semi-diurnal tides

tides that have two high waters and two low waters in a lunar day of approximately 25 h

3.1.2

diurnal tides

tides that have one high water and one low water in a lunar day

3.1.3

range

difference in height between one high water and the preceding or following low water

3.1.4

spring tides

two occasions in a lunar month when the average range of two successive tides is greatest

3.1.5

neap tides

two occasions in a lunar month when the average range of two successive tides is least

3.1.6

mean high water springs (MHWS)

average, over a long period of time, of the heights of two successive high waters at springs

3.1.7

mean low water springs (MLWS)

average, over a long period of time, of the heights of two successive low waters at springs

3.1.8

mean high water neaps (MHWN)

average, over a long period of time, of the heights of two successive high waters at neaps

3.1.9

mean low water neaps (MLWN)

average, over a long period of time, of the heights of two successive low waters at neaps

3.1.10

mean sea level (MSL)

average level of the sea surface over a long period, preferably 18.6 years (one cycle of the moon's nodes), or the average level that would exist in the absence of tides

3.1.11

lowest astronomical tide (LAT)

lowest level that can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions

NOTE It is often the level selected as the datum for soundings on navigational charts.

3.1.12

highest astronomical tide (HAT)

highest level that can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions

3.2 Ship tonnages

3.2.1

gross registered tonnage (GRT)

gross internal volumetric capacity of the vessel as defined by the rules of the registering authority and measured in units of 2.83 m³ (100 ft³)

3.2.2

deadweight tonnage (DWT)

total mass of cargo, stores, fuels, crew and reserves with which a vessel is laden when submerged to the summer loading line

NOTE Although this represents the load-carrying capacity of the vessel it is not an exact measure of the cargo load.

3.3

displacement

total mass of the vessel and its contents

NOTE This is equal to the volume of water displaced by the vessel multiplied by the density of the water.

3.4

belting

substantially horizontal continuous narrow rigid fender that projects from a vessel's side above the water line

3.5 Waves

3.5.1

wave height

height of a wave crest above the preceding wave trough

3.5.2

wave period

time for two successive wave crests to pass a fixed point

3.5.3

wave length

distance between consecutive wave crests

3.5.4

phase velocity

speed at which a wave propagates

NOTE The terms "wave celerity" and "velocity of wave propagation" can also be used to describe phase velocity.

3.5.5

wave diffraction

sharp change of direction and loss of energy of a wave as it passes a breakwater head due to diffraction when encountering an obstacle

3.5.6

wave refraction

slow change of direction and closer alignment with the seabed contours when a wave enters shallow water

3.5.7

wave gradient

wave height divided by the wave length

3.5.8

group velocity

velocity of propagation of a train of waves, i.e. the velocity at which the energy of the wave train travels

3.5.9

significant wave height

average height of the highest one third of the waves

3.5.10**significant wave period**

average of the periods of the highest one third of the waves

3.5.11**zero-crossing period of primary waves**

average period of all the waves with troughs below and crests above the mean water level

3.6**spectral density**

measure of the energy of the sea state expressed as a function of wave frequency and direction

3.7**design working life**

assumed period for which a structure is to be used for its intended purpose with planned maintenance

3.8**return period**

period that, on average, separates two occurrences

4 Symbols

The following symbols are used in this part of this code. 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	Cross-sectional area.
A_L	Longitudinal projected area of vessel above waterline.
A_n	Area normal to flow.
a	Exponent in JONSWAP spectral density function.
B_e	Breadth of earth-retaining structure.
B_v	Beam of vessel.
b	Wave ray separation.
b_a	Wave ray separation at arrival point.
b_0	Wave ray separation in deep water.
C_B	Block coefficient.
C_{CL}	Depth correction factor for longitudinal current forces.
C_{CT}	Depth correction factor for transverse current forces.
C_c	Shallow water correction factor.
C_D	Drag force coefficient.
C_I	Inertia force coefficient.
C_{LC}	Longitudinal current drag force coefficient.
C_{LW}	Longitudinal wind force coefficient.
C_M	Hydrodynamic mass coefficient.
C_S	Slamming coefficient.
C_{TC}	Transverse current drag force coefficient.
C_{TW}	Transverse wind force coefficient.
c_u	Undrained shear strength of soil.
c'	Effective cohesion.

D_{50}	Median size of graded stone (other subscripts for different percentages passing).
d	Still water depth.
d_A	Depth of lowest trough below wave chart mean line.
d_B	Depth of second lowest trough below wave chart mean line.
d_b	Depth of water $5 \times H_s$ from wall (H_s calculated for depth “ d ”).
d_c	Maximum displacement under cyclic loading.
d_e	Effective depth of sheet pile penetration.
d_m	Depth of water over mound.
d_m	Mean draught of vessel.
d_p	Sheet pile penetration.
d_t	Depth of tension crack.
d_x	Effective embedment of sheet piles.
d_0	Deep water depth.
d_1	Water depth at one wave length from wall.
d'	Depth below still water level of bottom of wall.
E	Effective kinetic energy of berthing vessel.
e	The exponent function.
f	Wave frequency.
F_B	Bed friction stress.
f_c	Frequency of cyclic loading.
F_D	Drag force.
F_H	Horizontal soil friction force.
F_I	Inertia force.
F_{LC}	Longitudinal current force.
F_{LW}	Longitudinal wind force.
f_m	Frequency at which peak occurs in spectrum.
f_N	Natural frequency of structure or member.
Fr	Froude number.
F_S	Vertical wave slam force.
F_{TC}	Transverse current force.
F_{TW}	Transverse wind force.
F_V	Vertical soil friction force.
F_W	Total wave force.
F_1	Soil force (similarly F_2 and F_3).
g	Acceleration due to gravity.
H	Wave height
H_A	Height of highest crest above wave chart mean line.
H_a	Wave height at arrival point.
H_B	Height of second highest crest above wave chart mean line.

H_b	Breaking wave at structure.
h_c	Height of top of wall above still water level.
H_D	Design wave height.
H_{inc}	Incident wave height.
H_L	Limiting wave height in probability distributions.
H_{max}	Maximum wave height.
H_n	The n th height or height interval in a rank-ordered set of n_x values.
H_R	Retained height of structure.
H_r	Height of retained soil.
$H_{r,\theta}$	Wave height at position (r,θ) .
H_s	Significant wave height.
H_{sd}	Significant height of set-down.
$H_{s,n}$	The n th significant wave height in a set.
H_{so}	Significant wave height offshore.
$H_{s,1}$	Component significant wave height from wave chart (similarly $H_{s,2}$).
H_w	Height of wave run-up above still water level.
H_z	Height of wind measurement above sea surface.
H_0	Wave height in deep water

i	Number designating a stress range.
$I(f,\phi)$	Spectral density function.
$I_D(\theta)$	Wave diffraction intensity factor.
$I_o(f,\phi)$	Offshore spectral density function.

K	Stiffness of equivalent spring.
K	A constant.
k	Permeability.
K_A	Coefficient of active earth pressure.
K_b	Bed friction factor.
K_d	Wave diffraction coefficient.
K_f	Wave height reduction factor due to bed friction.
k_J	Coefficient in JONSWAP spectral density function.
k_P	Coefficient in Pierson–Moskowitz spectral density function.
K_p	Coefficient of passive earth resistance.
K_r	Wave refraction coefficient.
K_s	Wave shoaling coefficient.
K_0	Coefficient of at-rest earth pressure.
K_1	Empirical added mass coefficient (similarly K_2 and K_3).

L	Length of vessel.
L	Wave length.
l	Length of cylinder.
L_{BP}	Length of vessel between perpendiculars.

l_e	Effective length of anchorage.
L_F	Fetch length.
L_s	Submerged length of member.
L_W	Waterline length of vessel.
L'	Overall length of pile from deck to apparent fixity.
l'	Length of cylinder from water level to apparent fixity.
L_0	Wave length in deep water.
l_0	Ineffective length of anchorage.
$\bar{m}$	Equivalent excited effective mass per unit length
m_c	Machine payload capacity.
m_D	Displacement of vessel.
m_e	Equivalent mass of structure.
m_L	Mass per unit length of member.
m_s	Mass of cellular structure and contained soil.
m_0	Zero moment.
m_{50}	Median mass of graded stone.
N	Number of waves in design condition duration.
n	A number between 1 and n_x .
N_i	Number of waves in i^{th} stress range during design life.
n_i	Number of waves in the i^{th} stress range during design life.
N_s	Scale factor.
n_T	Total number of stress ranges.
n_x	A number.
N_z	Number of zero up-crossings on wave record.
P	Maximum applied cyclic load.
p	Probability.
P_A	Active soil force per unit length of wall.
$P_{h,1}$	Maximum hydrodynamic pressure on wall at still water level.
$P_{\max}$	Maximum water pressure on wall at seabed.
$P_{\min}$	Minimum water pressure on wall at seabed.
P_n	Probability of n th value being equalled or exceeded.
P_u	Pore water pressure.
P_u	Effective uplift wave pressure at foot of wall.
P_{w1}	Average maximum wave pressure on wall at still water level.
P_{w2}	Average maximum wave pressure on wall at its foot.
q	Proportion of critical damping.
R	Resistance per unit area to shear along soil slip surface.
r	Radius.

r	Polar co-ordinate.
Re	Reynolds number.
s	Bed slope (tangent of angle relative to horizontal).
$S(f)$	One-dimensional spectral density function.
T	Wave period.
t	Variable used in normal distribution.
t	Time variable.
T_m	Mean wave period.
T_o	Period over which observations are taken.
T_p	Period at which peak occurs in wave spectrum.
T_{po}	Peak period offshore.
T_R	Return period.
T_s	Significant wave period.
T_z	Zero-crossing period of primary waves.
t_{90}	Time required for 90 % of original bacteria in a sample to die.
U	Instantaneous water particle velocity normal to the member.
$\dot{U}$	Instantaneous water particle acceleration normal to the member.
u	Horizontal component of water particle velocity.
$\dot{u}$	Horizontal component of water particle acceleration.
U_w	Wind speed 10 m above sea surface.
U_z	Wind speed at z m above sea surface (other subscripts for different heights).
V	Incident current velocity.
v	Vertical component of water particle velocity.
$\dot{v}$	Vertical component of water particle acceleration.
V_B	Velocity of vessel normal to berthing face.
V_C	Design current velocity.
v_c	Velocity of wave propagation.
v_{cg}	Wave group velocity.
v_{cga}	Wave group velocity at arrival point.
v_{cg0}	Wave group velocity in deep water.
V_{crit}	Critical current velocity.
v_{c0}	Velocity of wave propagation in deep water.
v_s	Average fall velocity of sediment in still water.
V_W	Design wind speed.
V_c'	Average current velocity over mean depth of vessel.
V_η	Vertical velocity of water surface.
v^*	Friction velocity.
w_F	Fetch width.

w_p	Water particle orbit width at surface.
W_s	Width or diameter of submerged structure or member.
x	Rectangular co-ordinate.
X_i	Component of radial in direction parallel to mean wind.
x_w	Wave prediction parameter.
y	Variable used in normal distribution.
Y_a	Dimension of submerged member.
Y_b	Dimension of submerged member.
Y_c	Dimension of submerged member.
Z	Tidal lag.
z	Pile wall thickness.
α	Angle of current off bow.
α_c	Angle of current relative to member axis.
α_0	Angle of wind off bow of vessel.
α_r	Angle of wind radial relative to mean wind direction.
α_s	Angle of slope from horizontal.
α_1	Coefficient of wave pressure at surface dependent upon wave period.
α_2	Coefficient of wave pressure at surface due to shoaling.
α_3	Ratio between wave pressures at surface and at depth d' .
β	Angle of resultant wind force off bow of vessel.
β	
$\beta_0, \beta_1,$ and $\beta_{\max}$	Angle between direction of wave approach and normal to breakwater.
$\beta_0^*, \beta_1^*,$ and $\beta_{\max}^*$	
	Coefficients used in calculation of significant wave height in surf zone.
	Coefficients used in calculation of maximum wave height in surf zone.
γ	Term in JONSWAP spectral density function.
γ	Effective bulk weight density of soil.
γ_d	Drained bulk weight density of soil.
γ_s	Submerged bulk weight density of soil.
γ_w	Weight density of groundwater.
Δ	Logarithmic decrement of structural damping.
δ	Angle of wall friction.
δ_m	Mobilized angle of friction between soil and structure.
$\delta_{\max}$	Maximum angle of friction between soil and structure.
δ_s	Angular ray separation at harbour entrance.

η	Instantaneous height of water surface above still water level.
η^*	Elevation above still water level to which wave pressure is exerted.
θ	Polar co-ordinate.
θ_0	Angle of incident wave relative to breakwater axis.
λ	Term used in wave chart analysis ($= \log_e N_z$).
λ	Coefficient of local wave pressure.
μ	Coefficient of friction.
π	Ratio of circumference to diameter of circle.
ρ	Mass density of water.
ρ_A	Density of air.
σ	Stress normal to plane of sliding.
τ_0	Shear stress exerted on bed by flowing water.
ϕ	Angle defining wave direction.
ϕ_m	Mean wave direction.
ϕ_o	Offshore wave direction.
φ_r	Angle of soil shearing resistance.
ϕ_1	Limiting wave direction (similarly ϕ_2).
φ'	Effective angle of soil shearing resistance.
ψ	Angle between wave front and bed contour.
ψ_0	Angle between wave front and bed contour in deep water.
ω	Term in spectral density functions.

Section 2. Environmental considerations

5 General

5.1 Design parameters

A fundamental prerequisite to designing a maritime structure is the understanding and assessment of the naturally occurring phenomena to which that structure is exposed. Information concerning these phenomena might already be available from existing sources, although such data can often be limited in scope and application, and further detailed investigations might be required to permit the selection of design parameters.

5.2 Environmental impact

The construction, operation, maintenance and decommissioning of maritime structures can cause a substantial impact on both the marine and terrestrial environment. Although the primary interface with the environment is through change in water regime in the vicinity of the structure, there are many other mechanisms by which environmental harm can result. In order to determine the potential effects of a structure an environmental assessment should be carried out in order to review all such mechanisms, whether they cause primary or secondary, direct or indirect, long term or short-term effects. The maritime structure can then be planned and designed so as to incorporate measures to minimize any undesirable environmental impact.

Consideration should be given to environmental conditions at all stages of construction, as well as for the completed structure. During construction, maritime works are particularly sensitive to adverse weather conditions, which can hinder access to the works, prevent the use of floating plant and cause damage to work both above and below high water level. Weather conditions can limit construction activity to certain seasons or “windows” and affect various transient load conditions such as towing, sinking and grounding of floating elements.

In evaluating environmental impacts specific expertise should be obtained from competent bodies. Detailed guidance on the types of impacts to be considered is available in a number of publications [1] [2]. World Bank Technical Paper No 126 [3] provides a checklist on the range of topics that should be considered.

5.3 Scope

This section describes the various environmental phenomena that should be considered for investigation at a coastal site and gives information and guidance on methods of data collection.

6 Survey control

6.1 General

The validity of many measurements undertaken on site is dependent on the accuracy to which they have been positioned and levelled. Whenever possible, investigation work should be related to the established land survey system, which in the UK would be the Ordnance Survey National Grid. Should this not prove possible then a local grid system orientated by azimuth should be established prior to all other site operations, with sufficient permanently monumented survey stations to allow recovery of the survey grid throughout at least the construction time of the structure. It should always be borne in mind that, although a simple and relatively inaccurate scheme of survey control might suffice for the purposes of the initial investigations, it might at a later date be necessary to control other work connected with the structure, and at that stage a far more rigorous approach will be required.

6.2 Level control

Most investigations connected with surveys for maritime structures require a vertical reference in the form of a water level or tide gauge. Such a gauge should be established as close as practicable to the scene of the investigations, the required degree of closeness being largely dependent on the nature and range of the tide in the locality. Siting of the gauge is important and the following factors should be considered:

- a) the gauge should be in sufficiently deep water to avoid drying out;
- b) it should be sheltered as far as possible from the effect of sea and swell;
- c) it should not be in a position where water is impounded as the tide drops;
- d) it should be reasonably close to a national or local land levelling datum reference point;
- e) it should be sheltered from accidental damage by vessels and should not be mounted or fixed on members that are subject to settlement.

Types of gauges are described in 10.4.2.

6.3 Location control

6.3.1 General

Various techniques are available for determining the positioning of measurements undertaken over water in relation to the land survey system established ashore.

They fall into four main categories, namely:

- visual;
- satellite;
- radio-positioning;
- laser.

Range capabilities extend from a few hundred metres to several hundreds of kilometres.

6.3.2 Visual methods

The overall accuracy of visual positioning methods normally decreases with increasing distance and the maximum range for these techniques is approximately 8 km.

Sounding sextants provide probably the most economical means of positioning in situations where distances to co-ordinated targets are not more than about 4 km and where visibility is not a problem. In experienced hands, sextants can provide a positioning accuracy of ± 3 m or better although such accuracies are unlikely to be obtained at a range of 4 km. It has to be emphasized that accurate sextant work is a skill acquired only through practice and experience and that inexperienced observers can produce erroneous results.

Theodolites set up ashore can be used to position a boat offshore by intersection. Although a theodolite can measure to an accuracy of 25 mm, a higher order of positioning accuracy is not necessarily achieved. Lack of synchronism between the land-based and sea-based elements of the survey work is the main source of error. Use of theodolites also reduces the flexibility of a survey operation, because it might be necessary to have frequent changes in the position of the theodolites in order to maintain well-conditioned intersections.

6.3.3 Satellite methods

Global positioning systems have largely superseded visual and radio-positioning methods for the location and surveillance of traffic. These systems are based on the use of radio signals from earth satellites, which are under the control of military authorities. These authorities have the ability to deliberately degrade the radio signals so as to reduce location accuracy.

The deliberate degradation of system performance can be removed, however, by “differential” techniques. Differential corrections are determined by comparison of observed signal measurement at a known location with calculated data; the difference between the calculated and the observed is the correction. The corrections are then broadcast to a survey boat in the vicinity. Differential techniques also help to remove errors caused by other factors such as atmospheric conditions. The accuracy of the corrections diminishes with increasing range from the reference station.

One problem with satellite systems is that in some territories the relationship between the satellite and local co-ordinate systems has not been defined.

Even when defined, the accuracy achieved depends on the proficiency of the operator.

6.3.4 Radio-positioning methods

Most radio-positioning methods operate in a range-range mode, measuring the ranges from shore reference stations to a master station on the survey vessel. The position of the vessel is given by the simultaneous measurement of two or more ranges, the position being that of the intersection of the range arcs.

The systems in general use for coastal work can be used for up to 30 km range with a positioning accuracy of from 1 m to 3 m.

The range-bearing type is used for relatively short range survey work, where the position of the vessel is given by simultaneous measurement of range and bearing from a single shore station. Accuracy is about 1 m at a range of 8 km to 10 km.

Radio-positioning methods are described in greater detail in BS 6349-5:1991.

6.3.5 Laser systems

Certain types of laser device are sometimes useful in situations where it is required to run a survey craft along a line of constant bearing. The instrument is set up ashore or on a fixed structure and the observer in the survey craft can steer visually along the narrow beam produced by the instrument.

Laser tracking systems are useful in a variety of survey situations. A system set up on shore can determine range and angle to a vessel up to 10 km from shore.

Laser instruments have also been developed that can provide a single range and angle from a moving craft to any surface capable of reflecting the laser beam. This type of instrument can be particularly useful for work in confined areas such as docks or close to harbour walls.

7 Meteorology and climatology

7.1 General

Clause 7 describes the meteorological and climatological considerations that should be taken into account during the data collection, design, construction and operational stages of a proposed maritime structure. The type and method of collection of information and some possible formats for the final presentation of data are also outlined.

Authoritative meteorological and climatological data can normally be obtained from the meteorological office covering the area under consideration. The Meteorological Office, Bracknell, Berkshire, England can also provide data for most overseas locations. Another valuable source of data for overseas locations is the Admiralty Pilot series of publications [4].

Of particular interest to the construction industry is the quick reply climatological service developed by the Meteorological Office, Bracknell, to assist tendering and planning in the UK especially in estimating the time likely to be lost because of adverse weather. The service gives estimates of average monthly and annual values of rainfall, low temperatures and strong winds applicable to the site. The information provided by this service is not usually adequate for detailed planning and a further site-specific data search should be undertaken.

7.2 Wind

7.2.1 General

Wind loading is discussed in Section 5, whilst the forecast of waves from wind measurements is discussed in Section 4. With regard to the latter, it is important that wind direction is known so that the fetch can be adequately defined, thereby avoiding the error of forecasting high waves from strong winds blowing off the land.

During coastal construction, long-term wind records are vital, for predicting weather windows and likely delays during site investigation, construction and operation. The effect of the wind on water set-up and storm surge generation is of importance.

Reliable records of wind speeds and directions are available covering most parts of the world, including the oceans, for a large number of years. Such records should provide adequate information for the derivation of the relevant design parameters, where not already available from local wind-loading codes of practice. Records required should include those relating to:

- a) fetch areas where incident waves could be generated;
- b) cyclone or cyclonic depressions, for correlation with surge occurrences;
- c) typhoon or hurricane tracks and intensities in the vicinity of the site or relevant fetch areas;
- d) wind speeds and directions in the vicinity of the site.

Both maximum gust and average wind speeds should be obtained as well as wind direction (see 7.2.4). Records should be checked to ensure that corrections appropriate to the particular recording station have been applied (see 7.2.3).

7.2.2 Wind sensors

Wind speed and direction are usually measured by means of some form of anemometer and wind vane. The output can be either recorded or read at regular intervals.

7.2.3 Exposure and level of measurements

Care should be taken when siting an anemometer, because eddies created by obstructions such as trees and buildings can produce unreliable measurements of the wind speed and direction and therefore inaccurate estimates of the local wind regime.

In order to allow the comparison of wind records from different locations and heights, measurements should be referred to the standard height of 10 m above ground level.

Whenever possible, measurements are made at 10 m or at a greater height to obtain an exposure clear of surrounding obstacles. Each instrument siting should be given an effective height. This is defined as the height over open level terrain in the vicinity that, it is estimated, would have the same mean wind speeds as those actually recorded on the anemometer. For comparison with an effective height of 10 m a correction has to be applied. This will vary with different averaging time intervals and site conditions, so expert advice should be sought before measured values are corrected.

7.2.4 Presentation and use of wind data

Standard wind records can be used as follows.

- a) As a basis for wave prediction (see Section 4) and the design of moorings (see Section 5).
- b) To calculate averages and maxima, for example as shown in percentage frequency tables.
- c) To prepare wind roses or similar diagrams, which provide a pictorial summary of the frequency distribution of wind direction and speed measurements.
- d) To calculate extreme wind speed values by plotting measured maxima on a probability scale and extrapolating along the line of best fit. A return period or recurrence interval can thus be defined for a given wind speed such that it is likely to be exceeded on the average only once in that period. Data can also be plotted on a linear percentage diagram to illustrate the probability of a given measured wind speed either being greater or less than a certain limit.
- e) To prepare persistence diagrams to show the expected duration and number of occurrences of particular wind speeds that are likely to be experienced.

7.2.5 Alternative wind information

If no measured wind data is available, reference can be made to the sources of data given in 7.1.

7.3 Precipitation

7.3.1 General

The effect, type and intensity of precipitation should be assessed when considering the following aspects of design.

- a) *Drainage design.* Estimates of maximum expected rainfall from a 50 yearly or 100 yearly storm should be made.
- b) *Dead weight loading.* The accretion of snow or ice exerts load on a structure. The amount and expected duration of snowfalls should be considered.
- c) *Cargo handling.* The intensity and amount of rainfall is important with reference to the type of cargo handled, handling rates and the storage facilities in a port.
- d) *Penetration.* A high frequency of driving rain can necessitate special protection for buildings.
- e) *Construction delays.* Frequent rain increases construction time substantially, especially earth-moving operations.

7.4 Air temperature and humidity

7.4.1 General

Estimates should be made of minimum and maximum air temperatures and the variations in relative humidity that are likely to be encountered during the life of the structure. To provide suitable design data four temperatures should be measured at regular intervals, i.e. minimum and maximum, and wet and dry bulb.

7.5 Visibility

7.5.1 General

Poor visibility can have severe consequences in relation to navigation in inshore waters and estimates of the expected duration should be made. The reduction of atmospheric transparency and therefore visibility is caused by two predominant factors:

- a) a suspension of extremely small dry particles, called haze;
- b) suspended microscopic water droplets or wet hygroscopic particles, known as mist.

Fog is a term conventionally applied when the horizontal visibility at the earth's surface is reduced to less than 1 km.

Visibility often changes sharply near the coast between the widely different regions of sea and land. At coastal stations of the UK Meteorological Office, however, the visibility over the land is recorded as standard even if this is different from the visibility over the sea. The latter is recorded as a remark if it can be estimated. Caution should be used when studying visibility reports from a station not directly on the coast as the phenomenon known as sea fog is usually not experienced more than 3 km to 4 km inland and erroneous data can therefore be extracted for navigation and piloting purposes.

7.6 Atmospheric pressure

7.6.1 General

The pressure of the atmosphere at any point is the weight of the air that lies vertically above a unit area. The atmospheric pressure is recorded in millibars¹⁾ and is usually corrected to mean sea level, to remove the influence of altitude on the measurements.

The pressure distribution is used as a basic input parameter in the preparation of weather and, therefore, sea state forecasts. In particular, the influence of pressure on water level is of importance. A high or low pressure decreases or increases, respectively, the depth of water to cause what is known as a storm surge, either negative or positive (see clause 10).

¹⁾ 1 mbar = 100 N/m² = 100 Pa
1 000 mbar ≈ 29.5 in Hg.

7.7 Solar radiation and hours of sunshine

7.7.1 Measurement

The intensity of solar radiation is usually measured with radiometers using a thermopile element, which generates a millivolt signal output that can be directly related to the energy received at the sensor. Radiometers can be designed to be sensitive in particular wave lengths of interest, for example incoming short wave lengths or outgoing long wave lengths or in the specific bands of ultraviolet or infrared.

The duration of bright sunshine is normally defined and recorded by the length of the burn or burns produced by focusing the sun's rays on to a special card and reported as hours of sunshine.

7.7.2 Uses

The incoming, reflected and emitted radiation is of prime importance in thermal balance equations and can be used to estimate the cooling capacity of an area of water and the potential evaporation.

The life expectancy of bacteria released to the sea is thought to be highly dependent on the intensity of solar radiation, particularly in the ultraviolet wave lengths. The calculation or measurement of this mortality is important in sea outfall design for effluents such as domestic sewage. The effect of light intensity on marine fouling is well illustrated by the vertical sequence of species found with changing depth on immersed structures.

8 Bathymetry

8.1 General

Bathymetric surveys are produced by taking a series of measurements of water depth at known locations over the area of interest. Information on the various techniques available and guidance on their application to maritime engineering is given in this clause. Guidance on location control is given in clause 6.

More detailed guidance on bathymetric surveys in relation to dredging and land reclamation work is given in BS 6349-5:1991.

Automatic systems, which receive inputs for location and water depth, should be regularly calibrated as part of a quality control system. Care should be taken to ensure that raw data is stored and that any averaging of data is defined.

Published bathymetric charts provide the designer with very limited data for his purposes. Charts are produced for safe navigation and features that can be of particular significance to the engineer might not necessarily be shown. Charts are only as accurate as the data from which they were compiled. Data is often taken from old surveys not conducted to modern standards or at scales not suited to modern requirements. Possible changes due to siltation, dredging, dumping, shipwrecks or other causes should be considered and proving surveys should be carried out to check existing charts where there is any doubt as to their reliability.

8.2 Echo sounder

8.2.1 General

The prime method of measuring water depth is by echo sounder, which records a continuous profile of the seabed as the survey craft moves over it. Only purpose-built hydrographic echo sounders should be used if accuracies that are acceptable for engineering purposes are to be obtained. A typical hydrographic echo sounder produces a large-scale paper trace providing a permanent graphic analogue record of the seabed profile. The instrument is fitted with a range of controls to enable the operator to adjust and calibrate it to suit the conditions in which it is operating and built to a specification that enables it to maintain reliable and accurate recordings. Echo sounders can give misleading results in areas of very soft mud, which sometimes occur in estuaries, and in these cases other methods should be used, depending on the application.

8.2.2 Calibration

The echo sounder measures depth by sending out a short ultrasonic pulse of sound and measuring the time taken for this pulse to reach the seabed and be reflected back to its source. The accuracy of depth measurement therefore is dependent on the allowance made for sound velocity through the water.

Calibration is normally effected by lowering a target to a set depth below the sound source, i.e. the transducer, of the echo sounder and comparing the recorded depth against the actual measured depth of the target. The echo sounder can then be adjusted to record true depth. This method, commonly known as a bar check, is effective for calibration down to depths of about 20 m.

Alternatively, electronic methods can be used to determine the velocity of sound in water.

Whichever technique is used, the importance of regular calibration cannot be over-stressed. Further guidance is given in BS 6349-5:1991.

8.2.3 Transmission frequency and beam width

Considerations affecting the choice of transmission frequency and beam width are covered in BS 6349-5:1991.

Some echo sounders operate on dual frequencies, typically 33 kHz and 210 kHz in order to identify areas of soft sediments. Acoustic energy at 33 kHz passes through fluid mud and is reflected off the underlying strata; energy at 210 kHz is reflected from the top of a layer of fluid mud. It is thus possible to assess the thickness as well as the depth to fluid mud or other very soft sediments. (See 18.3 regarding effects of seabed density.)

8.2.4 Swathe bathymetry

Swathe bathymetry uses the principles of side-scan sonar, which is described as follows, but mathematically adjusts the soundings to create a band of soundings across the direction in which the boat is travelling. The system gathers more data than a conventional echo sounder and gives coverage under adjacent vessels. The equipment is however expensive and is only economic to use when large amounts of data are required.

8.3 Side-scan sonar

Working on similar principles as an echo sounder, side-scan sonar systems transmit a fan-shaped beam of acoustic energy perpendicular to the track of the survey craft. The reflected signals from rock outcrops, sand waves, pipelines and any other projections on the seabed are recorded as changes in density on the continuous paper roll record produced. Changes in the nature of the seabed materials can also be detected.

More specific information on side-scan sonar systems is given in BS 6349-5:1991.

Although some indication of bathymetric changes can be gained from analysis of the side-scan records, it is essentially a search device. Complete coverage of the seabed by echo sounder would usually involve an excessive amount of work and is not normally justifiable. Use of side-scan sonar enables the surveyor to examine the entire seabed between sounding profiles and to run additional profiles where side-scan records show significant changes in the bathymetry taking place.

8.4 Direct measurement

Direct measurements are occasionally required when the echo sounder records are doubted. This can occur when sounding over a particularly soft seabed or when large quantities of weed or kelp are present. It might also be necessary when establishing the least depth over a rock or obstruction. Such measurements are usually made by hand leadline, graduated pole or sweeping with a horizontal wire (see 8.6).

8.5 Spacing and direction of sounding profiles

The appropriate spacing of sounding profiles depends partly on the purpose of the survey and partly on the depth and nature of the seabed.

Where the bathymetric information is required for the study of wave and current effects or for the study of navigation channels where the average depth is greater than 1.5 times the draught of the largest ship expected, a chart scale of the order of 1:10 000 is normally sufficient. Lines of soundings should be spaced at about 100 m intervals with a locational fix spacing not greater than 300 m.

Surveys required for the study of wave effects should cover the transitional zone relative to the wave periods expected at the site.

For navigation channels, sweeping surveys can be considered as an alternative to detailed sounding surveys where the depth is greater than 1.2 times maximum draught (see 8.6).

In rock and coral areas, more detailed surveys are advisable for navigation channels if the average depth is less than twice the maximum draught of the ship.

Where the bathymetric information is required for the siting of structures, measurement of dredging and checking navigation channels in shallow water, a detailed survey should be carried out to produce a chart to a scale of between 1:500 and 1:2 000.

Typically, a survey for a maritime structure would be made at a profile spacing of 10 m to 25 m in and around the proposed position of the structure and 50 m in the approach areas with locational fixes taken at approximately three times the profile spacing. Side-scan sonar could be used in conjunction with the echo sounder to obtain a qualitative record of the seabed between profiles, revealing any features undetected by the sounder.

The direction in which profiles are run is again dependent on the purpose of the survey. The usual purpose is to delineate depth contours as accurately as possible. This is achieved by running across the anticipated contours as near as possible at right angles. It is good survey practice to run additional profiles at right angles to the chosen direction at a wider spacing, for example 5 times to 10 times. These lines serve the purpose of check lines and reveal the presence of features such as sand waves, which, because of the original choice of direction, might not have been identified.

8.6 Wire sweep

A wire sweep survey might be necessary for determining the least depth over an obstruction or to prove the absence of obstructions in a particular area.

The former can be achieved by suspending fore and aft from the vessel a horizontal bar, which drifts over the known obstruction. After each pass, the bar is lowered or raised by its calibrated support wires and, by noting the bar's depth setting and applying the tide correction, the least depth over the obstruction can be determined.

As an alternative to side-scan sonar, for ensuring that an area is free of underwater obstruction, a fine-wire sweep survey can be conducted. The fine wire is suspended between two boats and weighted to maintain a predetermined depth. The boats proceed at 1 m/s to 1.5 m/s (2 knots to 3 knots) along the necessary course lines to ensure full sweep coverage of the area.

8.7 Reduction of soundings

Due to the vertical movement of the water level, soundings obtained have to be reduced to a standard reference plane (see also clause 10).

The datum to which the soundings are reduced should always be noted on the drawing or chart, together with its relationship with the relevant land datum.

The bathymetric plan should preferably be plotted on the same grid system as any adjacent land survey.

8.8 Coastal topography

Depending on the survey area and the scale of presentation, the final bathymetric plan should portray the coastline and prominent features, in order to allow immediate visual recognition.

Should the bathymetry be conducted over the high water period it is usually possible to determine the low water contour from the sounding results. To obtain the high water contour it would be necessary to carry out levelling, by land survey practice, over the area not already covered during the sounding operation.

The bathymetric plan should preferably be plotted on the same grid system as any adjacent land survey.

9 Geological considerations

A thorough understanding of subsurface conditions is an essential preliminary in any maritime construction project. Section 6 includes guidance on the type and extent of geotechnical studies required.

10 Water level

10.1 General

The underlying long-period fluctuations in general water level result from astronomical tides, which are generated primarily by the cyclic variations in gravitational attraction of the moon and the sun on the water masses of the earth. Superimposed shorter period fluctuations and non-periodic variations can be caused by such factors as wind, atmospheric pressure, wave effects, local run-off and evaporation. A further factor that should be taken into account is the long-term rise in general sea level.

Tidal ranges vary widely around the world and are affected by geographical factors. The shallow waters surrounding the British Isles have the effect of increasing the height of the tidal wave considerably; in the Severn estuary ranges can exceed 15 m. Tidal ranges in the open ocean, however, are often less than 1 m.

Predictions of extreme water levels are required in several aspects of the design of maritime structures, including overtopping, hydrostatic pressures and the level of action of waves, currents, mooring and berthing loads. Values of rates of rise and fall might also be required in relation to soil pore water pressures, flood relief valve discharge capacities and for the prediction of tidal flows.

10.2 Tidal predictions

Admiralty tide tables list daily predictions of times and heights of high and low waters at a selected number of standard ports [5]. These predictions are of universal application and are usually based on continuous observations of the tide over a period of at least one year at that standard port. The tables also list data for secondary ports, enabling predictions to be calculated from the predictions listed for standard ports.

Harbour authorities and others also publish almanacs and tide tables. It should be noted that whereas Admiralty tide tables give heights referred to chart datum, i.e. the datum of soundings on the latest edition of the largest scale Admiralty chart, it is not unusual for locally produced tide tables to be based on a different datum. Certain commercial companies also offer tide prediction services.

NOTE Commercial and harbour authorities often obtain their predictions from the Proudman Oceanographic Laboratory (formerly the Institute of Oceanographic Sciences), Bidston, Birkenhead, England when information is required in a more detailed or specific format than is provided by the Admiralty tide tables.

10.3 Meteorological effects

10.3.1 General

Tide predictions are based on average meteorological conditions. Variations in predicted heights occur with changes in the meteorological regime. The main effects are described in 10.3.2, 10.3.3, 10.3.4 and 10.3.5.

10.3.2 Atmospheric pressure

Changes in level due to variations in atmospheric pressure seldom exceed 0.3 m. However, when combined with other effects such as strong winds and intensified by geographical constrictions, this effect can be important.

10.3.3 Wind

A strong wind blowing on shore tends to pile up water against the coast, resulting in a water level higher than the predicted tide height. Winds blowing along a coast tend to set up long waves, which travel along the coast raising the sea level at the crest and lowering the sea level in the trough. Grouping of waves from distant storms can produce variations of mean sea level within the group. This results in a long period, low amplitude wave travelling at the same velocity as the group, which, when it approaches the shore, can cause a higher sea level and thus allow the waves to run further inshore before they break. A combination of pressure and wind effects can cause the phenomenon known as a “storm surge”.

10.3.4 Seiche

The passage of an intense depression can cause oscillations in sea level. The period between such waves can be anything from a few minutes to 2 h and the height from a few centimetres to 2 m to 3 m. The shape, size and depth of some harbours makes them very susceptible to such waves, increasing their height often to destructive proportions.

10.3.5 Water levels

Water levels in estuaries can be raised by river flow originating from surface water run-off or artesian sources. Special factors, such as the opening of sluice gates upstream and seasonal flow patterns, should also be considered.

10.4 Tidal observations

10.4.1 General

Where predictions are not already available, records of the water level should be taken at the proposed site over the minimum period discussed in 10.5. Various methods of automatic tide recording are available (see 10.4.2). The apparatus should filter out short period level fluctuations due to wind or wash waves. Even in situations where predictions are already available a permanent tide gauge is necessary to provide a reference for other data gathering operations (see 6.2).

10.4.2 Types of gauge

The basic type of tide gauge is the tide pole or staff. This is a simple graduated pole set up vertically on a fixed structure in the water so that the changing level of the sea surface can be read by an observer. It is important to install a tide pole, wherever possible, regardless of any other automatic gauge that might be installed, because it provides a calibration and checking standard for automatic gauges.

There are many types of automatic gauge that provide a continuous record, such as:

- a) float operated;
- b) pressure;
- c) bubbler;
- d) acoustic;
- e) electric resistance (step gauge).

10.5 Tidal analysis

If a sufficiently large database is obtained, an analysis of the records can produce the astronomic tidal harmonic constituents, which can then be used to predict astronomic tidal heights. These predictions assume that no other changes occur at the relevant site and their accuracy depends on the size and accuracy of the original database. It is possible to obtain the basic harmonic constituents for a site from only 14 days tidal data but this requires favourable circumstances. Continuous records covering 28 days to 30 days give an adequate analysis and subsequent predictions. A full tidal analysis from a minimum of one year's continuous data would produce more than 114 tidal constituents, which is a sufficient number to predict accurate astronomical tidal heights.

Such analyses and predictions are explained in detail elsewhere [6]. It has to be stressed that predictions can only give astronomic tidal heights and that actual water levels can differ significantly due to meteorological effects (see 10.3).

11 Water movement

11.1 General

The largest scale global water movements are the essentially permanent ocean currents. These currents are the result of the response of the ocean and atmosphere to the global distribution of solar energy and the resultant flow of energy from the tropics to the poles. The surface ocean current systems correspond quite closely to the generalized global atmospheric circulation and shift seasonally with the passage of the overhead sun. Good local descriptions of these basic water movements can be found in the Admiralty Pilots series of publications [4].

For a fixed structure in coastal water, the parameters of water movements important for design are the speed and direction of water movement at a point and how this is affected when the water impinges on the structure. The permeability of the structure, its resistances to motion and the possibility of sediment scour or accretion should be considered.

11.2 Measurement of currents

11.2.1 General

Indirect methods of calculating water movement are normally not suitable for inshore work and direct methods of measurement should be used. These methods rely upon either measuring the velocity of water at fixed points, for example by current metering, or following the trajectory of a float or dye tracking.

11.2.2 *Current meter observations*

11.2.2.1 *General*

Although this method of measurement provides a direct reading of current speed, its application to mass transport in coastal waters is restricted because observations made at one point cannot be assumed to be representative of a larger area. Other limitations are practical ones, for example low current speeds might be beneath the threshold of the instrument and transmitted vessel or moorings movement can have a significant effect on the readings.

The operational principles of the many types of meter available are described in 11.2.2.2 and 11.2.2.3.

11.2.2.2 *Direct reading current meters*

Direct reading current meters are operated, usually manually, but occasionally via a telemetry link, from a moored vessel or existing structure. Water speed is normally calculated from a count made of the number of revolutions of an impeller or Savonius rotor during an accurately measured time interval. Horizontally mounted propeller or cup assemblies have been used as the revolving element but were found to be more fragile. Current direction is measured by the alignment of the hull of the meter or vanes relative to an internally housed, free moving compass card. Care has to be taken in operating current meters in the presence of waves, due to transmitted boat and suspension gear movement and wave action on the meter itself. In particular, the Savonius rotor instruments tend to over-register speed under wave influence because of their omnidirectional response. Using one relatively cheap instrument, it is possible to obtain rapidly a detailed velocity profile of the water column by lowering the instrument from near surface to near bed and making measurements at several intermediate levels.

11.2.2.3 *Recording current meters*

Recording current meters are typically between 2 times and 10 times more expensive than the direct reading current meters and record the velocity internally on a medium such as magnetic tape, photographic film or solid state memory. There is thus no requirement for constant vessel and operator attendance and good moorings should enable data to be collected under worse sea conditions than would be possible by an instrument suspended from a floating craft.

Traditionally the recording current meters measure speed with either an impeller or Savonius rotor and record the number of revolutions during intervals of typically 5 min, 10 min, 15 min or 30 min, therefore obtaining an average water speed over each sample period. In theory the instrument is permanently aligned with the direction of water movement by one or more large vanes and the instantaneous direction held at the end of a sample interval is recorded. In practice, however, wave orbital motions affect speed and direction measurements made by the traditional type of current meter. In order to measure such short period motions, other types of equipment have been developed that resolve the current into two perpendicular directions, so that measurements of direction are independent of the orientation of the meter. Two of the most widely used are electromagnetic and acoustic current meters. The former measure changes in an induced magnetic field and the latter the apparent variations in the speed of sound due to the water movement. These meters normally measure the current velocity at frequent intervals, for example once or ten times per second, and either record a burst of data, for example 10 min every hour, or perform a vector average to remove the orbital currents before recording.

11.2.3 *Float tracking*

This method of tracing water movement involves the introduction of readily identifiable material that moves with the water, thus directly indicating its path. The size and shape of the floating object affects its reaction to the surrounding water movement and therefore whether it faithfully follows that movement. The standard float assembly consists of a vaned drogue usually made out of canvas, wood, metal or plastics, joined by thin rope or wire to a surface buoy. The length of rope determines the depth of water at which the drogue lies and follows the water motion. The drogue is typically 0.5 m to 1.0 m long and, when suspended at a depth of say 2 m, its path is an expression of the average horizontal movement of a water parcel between 2 m and 3 m below the surface.

A major problem with float tracking is relocation. A large surface buoy or marker such as a flag or radar reflector is subject to windage and, in the case of a buoy, to influence from the surface water currents in which it is floating. These top marks should therefore be kept as small as possible consistent with the need for good visibility. In order to aid relocation, small radio transmitters or underwater acoustic devices can be used together with radio direction finding antennae or acoustic receivers. Location by sonar has the advantage that the surface float can be smaller. These devices are most useful in the dark and easier to find than the flashing lights previously employed. Methods have been developed to remove the windage influence from the resultant track of a float but further work is necessary before the techniques are widely adopted.

A logship is a particular design of float used to show average horizontal motion over a greater depth of water, such as 6 m to 10 m. It consists of a long thin member with identification on one end and weights at the other, so that it floats vertically just under the water surface. Typical materials used are telegraph poles, tree trunks, bamboo poles or lengths of aluminium. Logships are particularly useful in navigation studies and harbour layout planning because their lengths can be adjusted to be representative of the relevant vessel draught.

Floats can also be used to obtain point-specific information by releasing them at the bows of a moored vessel and timing their passage over the known distance to the stern. Alternatively, floats attached to an anchored vessel by a known length of floating cord can be allowed to drift astern. The velocity can be calculated from the time for the float to run to the end of its tether and the current direction can be found by taking the bearing of the float. In both of these applications it is likely that the presence of the vessel will modify the current speed and direction and therefore the float path. A crude estimate of current velocity can be obtained from the log reading and compass heading of a vessel moored so that it is free to lie with the current.

The standard drogue float can be modified to follow surface water movement by reducing the length of rope between the drogue and the top mark so that the top of the vane assembly is just on the sea surface. To follow movement in the top 100 mm or to estimate the true path of a surface phenomenon such as a grease or oil film, however, specially designed surface floats should be used. These can consist of disc shapes or spheres that float on the surface, neutrally buoyant bottles, cards or even finely chopped vegetables. A major problem is relocation and it is usually advisable to keep the floats constantly in sight. Aerial tracking and/or photography can provide a useful method of recording float positions but is too expensive for most applications. Drogues with visible top marks can be used to indicate the approximate position of the surface floats but these are not always entirely reliable, due to differences between the paths of the identified water layers.

As stated, the floats do not follow the same turbulent flow paths as the water itself and so only indicate the average horizontal movement. Another limitation of float track information is the portrayal of a linear picture of water movement with no real cover of the water depth. However, float tracking can give a rapid and relatively cheap impression of general water movement. Several floats can be followed at any one time with repeated releases from one position, or multiple releases with drogues set at different depths. Tidal residuals can easily be determined by tracking a float over a complete tidal cycle and determining the distance between its release and recovery positions.

Floats can be deployed unattended if a net movement is required rather than knowledge of the path taken to arrive at the end point. Commonly the floats have messages attached asking the finder to record the time and place of the float recovery and to return the information. To reduce the chance element of the recovery beachwalkers can be employed to search for the landed floats. Similar methods can be used to tag bottom currents when boat following is impossible without, for example, acoustic links. The method can only yield minimum possible water speeds, as without other valid information it has to be assumed that the float took the shortest distance between the points of release and recovery and that the float was recovered as soon as it arrived at its final location.

11.3 Measurement of diffusion

11.3.1 General

Much research over many years has been carried out to develop various methods of tracing water movement, in particular for the disposal of effluent into the sea where the rate and extent of dispersion together with mass transport are important criteria [7]. An indicator was sought with physical properties similar to those of the water to be labelled. Acceptable techniques that were developed were the use of dyes, bacterial organisms and radioactive materials. The last technique, which involves the use of radioactive materials, is no longer feasible because of public health restrictions on the strength of isotopes that could be released.

These techniques all have specific advantages and limitations and a problem can often best be solved by a combination of methods but before resorting to any form of artificial indicator, consideration should be given to the use of natural tracers or those not specifically introduced.

Artificial or added tracers can be used to label an existing water body such as sewage or process water discharge or to indicate water movement in an area that is being considered as a receiver for an effluent. In the first case, the existing discharge position can often be identified and the tracer can be injected at this location. For example, an effluent could be labelled by the addition of the tracer at the final pumping station or collection point and, with either natural or artificially induced mixing, the total discharge would be tagged before it reached the sea. This is particularly valuable with diffuser outlets as their efficiency in initial dilution can be estimated. The tracer can be added as a single batch, in repeated discrete batches or continuously, depending on the mode of effluent discharge, the tracing facilities and the aim of the study.

Artificial tracers are probably most useful for estimating dispersion rates and mass movement for a proposed discharge at sea before construction. The timing of the release can be organized as considered previously, although because of its lower cost the repeated discrete batch technique is often used for initial studies, such as determining the optimum location and length for an outfall. Provided that the pattern of circulation is steady or repeated regularly under tidal oscillations, the dispersion from a continuous effluent source can be calculated by integration of the results obtained from repeated batch injections of tracer. Alternatively, the batch releases can be used to provide a summary of the water movement and indicate the most important or critical period for effluent discharge and a continuous release can be made over that period for confirmation. For example, the minimum time or distance of travel to the land and the corresponding effluent concentration on the shoreline might be of special interest.

In theory the tracer can be prepared at the same density as the proposed effluent and released at the same level, usually close to the seabed, but unless volume flows are also reproduced density effects can still produce misleading results.

Batch releases of dye can best be traced by a vessel keeping them constantly under surveillance and traversing the patch at frequent intervals, recording the tracer concentration and simultaneously fixing its position. The patch can be crossed and recrossed in zigzag fashion, commencing and terminating when the detectors show zero tracer concentration above background. It should be remembered with dye tracing that the boundaries thus recorded are wider than those estimated visually, because the sensitivity of the measuring instruments is greater than that of the eye.

Alternatively, or in addition, a regular grid within the area of expected travel can be sampled or if sufficient craft are available they can moor at separate locations and measure the change of concentration with time at these fixed points. This technique can be extended by recovering samples for subsequent analysis if there are insufficient measuring instruments available. Grid sampling is the only method for use with bacterial tracing, as lengthy laboratory procedures are required before the number of organisms present can be determined.

Measurements of dye concentration can easily be made at any depth, by either lowering the detector or raising a sample of water. Alternatively, towed multi-level arrays can provide simultaneous measurement of dye concentration at several depths. Samples for bacterial testing can also be collected at depth, but extreme care has to be taken to avoid contamination. Sealed sterilized bottles are lowered to the required depth, opened to take the sample and resealed to avoid transfer of water to or from the bottle on the return journey.

Considerable progress has been made in recent years in the development of computer models for studying water movement and in particular effluent mixing and dispersion. These models rely mainly on prototype information on currents and density structure and to a lesser extent on the dispersion characteristics of the location. Specific field studies are recommended in order to ensure that adequate data is available for model verification and calibration.

11.4 Presentation and analysis of field data

The effort and cost of data collection can be significant. It is important that the method of interpretation is considered during the design of the fieldwork, to avoid spending time and money on data that are irrelevant or unnecessary. In particular, the method of position fixing (see 6.3) and its accuracy relative to the requirements of the tracing method should be considered. Interpretation of the data can range from visual intuitive examination of a few results to sophisticated computation of a large quantity of information. It is important to remember the aims and ultimate objectives of the study both when considering the method of data presentation and during interpretation.

Raw data should be archived so that others can make use of it.

Charts play a major role in the presentation of water movement information, irrespective of which method of tracing is adopted. At the simplest level, the chart only shows the position of measurement. A pictorial representation of the measured data can be a useful addition, such as a scatter or central vector diagram for current observations or a record of tracer concentration. Charts are obviously essential for presenting data such as float tracks or for showing vessel tracks during dye traverses. Several spot readings can be contoured to show similarities and trends and this can be a useful technique for the discussion of bacterial counts. A summary chart showing water movement in broad terms as derived by the survey can be a useful aid to understanding the current regime of the area. Additional information on other variable environmental conditions such as sea state, wind and tidal levels should be readily available for reference.

Although charts and pictorial presentations of data are still necessary, increasing use is made of computer graphics for data presentation.

12 Waves

Exposure to wave attack can have a profound influence on the selection of sites for maritime structures and the consideration of designs and construction methods requires detailed knowledge and understanding of the wave activity and persistence, in average as well as extreme conditions.

Detailed consideration of wave form, generation, recording, analysis and prediction is included in Section 4.

13 Water quality

13.1 General

The interaction between water quality and maritime structures can be considered from two opposite viewpoints. The effect of water quality on the safe and efficient functioning of the structure should be evaluated and this would require the gathering of the usual data on temperature, corrosive elements, suspended solids, marine growth, etc. The influence of the structure on the water quality and other features of the surrounding environment, i.e. the environmental impact, is covered in Section 2. The environmental effects, which are reviewed in the following paragraphs, are with reference to the effect of water quality on a maritime structure.

13.2 Water temperature

13.2.1 General

In coastal regions there is usually a well-defined seasonal temperature variation, although throughout the year the water column tends to be isothermal due to strong turbulent mixing. Significant stratification can exist, however, in areas where there is a thermal effluent or in estuaries with high freshwater discharge.

Temperature variation has effects as follows.

- a) *Ice formation.* Sea icing can become a problem when the water temperatures fall below -2°C . Floating ice masses that are formed elsewhere can survive though when the water is considerably warmer. When considering icing on a structure, wind strength and air temperature are of prime importance; however icing is unlikely to occur until sea surface temperatures fall below 6°C .
- b) *Corrosion.* Higher temperatures increase the rate of iron oxide formation and can have a significant effect on bacterial corrosion.
- c) *Marine growth.* The rate of encrustation on a structure and the species of organism present depend on the temperature of the environment, higher temperatures promoting more vigorous growth.
- d) *Effluent dispersion.* The density of seawater is a function of its temperature and salinity and is a fundamental parameter to be considered when modelling the behaviour of an effluent immediately after release.

13.2.2 Measurement

Different applications require different methods of measurement. Surface temperature variations over a large area can be determined using infrared techniques from either an aircraft or satellite. Variation at a point can be monitored by comparison of multiple passes of the remote sensing apparatus. On a smaller scale or where depth profiles are required, continuous or repetitive measurements are taken using thermal sensors, such as thermistors, resistance bulbs, thermocouples and mercury-in-glass thermometers.

13.3 Chemistry

The chemistry of the water should be determined at an early stage of the site investigations, with particular attention being paid to potentially corrosive elements such as chloride and sulfate ions (see also 49.12).

Coastal water is normally fully saturated with oxygen at the surface but if there is little vertical mixing the oxygen content decreases with depth. Under normal circumstances this decrease is unlikely to have a significant effect unless anaerobic conditions are reached but the local distribution and seasonal variation should be considered when siting outfalls to discharge effluents that could act as reducing agents.

The important chemical parameters are usually analysed directly or measured with selective ion electrodes, either in the field or in the laboratory.

13.4 Turbidity

Turbidity is usually caused by suspended clay or silt particles, dispersed organics and micro-organisms. A lower water temperature increases the amount of sediment that can be transported in suspension due to the viscosity change.

Turbidity should be considered in harbour design, with special reference to sediment movement and siltation studies and when abstracting water for commercial purposes, particularly with regard to wear on pumps and blockages.

The most rapid changes in turbidity usually occur during dredging operations and the consequences should be borne in mind during the planning of the initial site preparation and maintenance dredging. Guidance is given in BS 6349-5:1991.

Dredging operations can also cause the release of harmful substances that are locked into fine sediment particles and can remain attached when dredging operations put the material into suspension. The possibility of degradation of the structure caused by redeposited harmful substances should be considered. Detailed consideration should also be given to the area of spoil disposal, because of the possibility of dispersion with possible redeposition back in the dredged area.

13.5 Marine life

Many forms of marine organisms including algae, molluscs, bacteria, crustacea and others attach themselves to a maritime structure. The organisms can cause blockage of intake and discharge pipes, impose or increase mechanical stresses (see 47.2.2), accelerate degradation (see 59.2.2), retard flow or simply impede inspections for maintenance or certification purposes [8]. Methods of controlling marine growth include the use of anti-fouling paints, scraping with the hand or mechanical removal by water- or air-jetting. As well as surface-attaching species, structures with timber elements can be affected by boring organisms (see 60.2). The presence of molluscs on the surface of a steel structure can inhibit corrosion and their removal is not always beneficial [see 66.1e].

13.6 Pollution

The effects of water-borne pollution on the structure should be considered. Some trade effluents, if insufficiently diluted, can accelerate the deterioration of concrete and steel. The effect of oil spillages is usually benign with respect to structural condition, but the surface coating makes inspection difficult. Pollution can act as nutrients or deterrents to bacteria, significantly affecting microbial induced corrosion.

14 Sediment transport

14.1 General

In any operation involving the alteration of the inshore hydrodynamic regime, the subsequent effects on sediment movement have to be considered. It is in the inshore zone that energy generated at sea is transmitted to the land in the form of waves, tidal currents, etc. and it is the sediments, rocks and man-made structures of the area that are responsible for attenuating this energy. The sediment of the littoral and sublittoral zones is moulded into a topography and, as long as the balance of forces is maintained, the system will be in dynamic equilibrium. If one of the system components is altered, the remainder of the system has to adjust in order to achieve a new dynamic equilibrium. Such is the delicate balance of nature that what can appear to be a minor alteration can bring about large scale changes to the system as a whole often with expensive and dangerous consequences.

The natural parameters that define the rate and direction of sediment transport are the prevailing currents (both tide- and wind-generated), waves, bathymetry and the properties of the seabed or beach sediment. Waves and currents are the agents responsible for entraining, transporting and depositing sediment. Of these, waves are the most powerful and important agent. Bathymetry imposes constraints on currents and waves and therefore on erosion and deposition. The size distribution of the indigenous sediment normally reflects the competence of the transporting agents, subject to the availability of material.

A general appreciation of sediment transport in an area can be gained by studying old charts and photographs, including aerial views and, in the cases of beaches, by carrying out a preliminary inspection. A comparison between historic information and modern details can then be made, and changes of depth and apparent movement of features such as offshore sandbars can be studied to indicate the transport of sediment. In a preliminary beach inspection, features such as spits and accretion or scour against existing structures are indicative of the direction of the drift and intensity of sediment transport.

Care should be taken to avoid being misled by seasonal or short-term effects.

14.2 Sediment transport in currents

14.2.1 General

When the current flows over a bed of erodible sediment, a certain minimum current is required to initiate movement. For flat beds composed of fine or medium sand (grain diameter 0.1 mm to 0.6 mm) the threshold current appears to be about 0.15 m/s measured at 0.3 m above the bed, although that required to move silts (size <0.06 mm) and gravels (size >1.0 mm) has been found to be greater.

When the current exceeds the threshold value, the bed begins to erode, the displaced particles being carried over the bottom by sliding, rolling or saltation, i.e. bed transport, or by being lifted into the body of the water by turbulence, i.e. suspended transport. For fine-grained sediments, both modes are usually present at the same time and it is difficult to distinguish the boundary and the level at which suspended transport is initiated. It is normally considered that suspension becomes appreciable when $v_s/v^* \approx 1$ where v_s is the average fall velocity of the particles in still water and the friction velocity $v^* = \sqrt{(\tau_0/\rho)}$ where τ_0 is the shear stress exerted by the water on the bed and ρ is the water density.

Beds subject to erosion usually form small-scale ripples and larger-scale dunes. These dunes are usually short-crested and migrate slowly in the direction of the current. Although they display a certain average wave length and height, they vary in size. They have flat upstream slopes and steep downstream slopes.

14.2.2 Measuring suspended sediment load

14.2.2.1 General

Most satisfactory results are achieved if sediment transport is regarded in terms of sediment flux. This is usually measured directly in the field at several stations at frequent intervals, usually half-hourly, on both neap and spring tides. The flux is obtained by the integration of the product of the water velocity and the concentration of suspended solids over the depth.

Devices for measuring suspended load are described in 14.2.2.2, 14.2.2.3 and 14.2.2.4. For the sampler described in 14.2.2.2 and 14.2.2.3, the grain size distribution is determined by standard sieving, settling column, Coulter counter or laser diffraction techniques and the subsequent numerical integration can then be performed.

14.2.2.2 Depth integrating sampler

This collects and accumulates a sample as it is lowered to the seabed and lifted back again. The sampler should be moved at a uniform rate in a given direction, but not necessarily at equal rates in both directions. This equipment is restricted in use to shallow depths by its capacity to store the water sample.

14.2.2.3 Point integrating sampler

This operates in almost the same manner, except that it has an inlet valve, which can be opened or closed as required. Thus, it is possible in deep water, to point sample at known depth intervals and then integrate over the entire depth.

14.2.2.4 Silt meter

The meter incorporates a light source (usually infrared) and a photo detector. Variations of suspended solids concentration cause fluctuation in the amount of light reaching the photocell, which is connected to a meter. A calibration curve should be established so that meter readings can be converted to concentrations of solids for the particular material in suspension. Because the bed features usually make it impractical to measure closer than about 0.3 m above the seabed, where the concentration is high, an extrapolation to lower heights above the bed is often made, based on theoretical arguments.

14.2.2.5 Acoustic devices

Considerable progress has been made in recent years in the development of acoustic Doppler devices for measuring sediment concentration profiles. The use of multi-frequency systems, together with powerful computer processing, is leading to the capability of determining in-situ concentration and particle size characteristics of the complete profile.

14.2.3 Measuring bed transport

For fine sand and silt, bed transport is usually small in comparison with suspended transport, but can become significant with increasing grain size. There are essentially two methods for studying the movement of bed load: those that use laboratory-derived bed load formulae (see 14.2.4) and those that rely on field measurements (see 14.2.5). Direction and rate of bed transport can be estimated by employing fluorescent tracers, and the bed load can be sampled by using sediment traps or specialized equipment, such as the Arnhem or Dutch pressure difference bed load samplers. The practical difficulties of using these traps and samplers in the field and consideration of their efficiency have reduced their popularity, with a corresponding increase in the use of bed load formulae.

14.2.4 Bed load formulae

The main types of bed load formulae consider transport rates from relationships of shear stresses, flow and statistical considerations of lift forces. All equations rely to some extent on experimental data from flume studies to determine their various integral coefficients. For details of these equations and their applications, reference should be made to specialist texts [9].

14.2.5 Field tracer studies

14.2.5.1 General

Much research has been carried out in the past in order to develop various methods of tracing sediment movement in the field. Techniques used were to employ coloured, radioactive or natural heavy mineral tracers. As in the case of water movement tracing (see 11.3.1) radioactive materials are no longer permitted.

Field tracer studies for determination of bed movement are now rare. Coloured tracers are used for very small-scale studies, usually on beaches. Artificial pebbles, which are radio-tagged, are also used in small-scale studies.

Problems of depositing the labelled material arise because in theory it should be fully integrated with the bed throughout the movable depth. An initial tidal bias can also be introduced depending on the time of release, although this can in part be overcome by injecting half the tracer at high water slack and the other half at low water slack. These problems can both be minimized by allowing time for the labelled sediment to mix thoroughly with the seabed and by ignoring the first few days' results.

All tracing experiments indicate only the movement that has occurred during the period of the experiment.

Unless weather and wave conditions are similar to those of the long-term average, non-typical results can be produced. The direction of sediment movement is usually much easier to determine than its magnitude, which can be considerably in error, depending on circumstances. It should be noted that the techniques described could also be employed to study suspended sediment transport of non-cohesive grains.

14.2.5.2 Coloured tracers

Coloured tracers involve the coating of non-cohesive sediments with either a distinguishing coloured paint or a fluorescent substance. Indigenous sediment can be used for this purpose, but where it is not practicable to treat a large quantity of local sand, material of a similar density and size distribution can be substituted, provided that it responds to the hydraulic processes in exactly the same way as the indigenous sediment.

The sampling routine depends on the environment being studied. With sand-size material, a simple method is to press a grease-coated card into the sediment. In the laboratory, the grains are counted by eye either in natural light or, in the case of the fluorescent grains, under an ultraviolet light, to yield the concentration of tagged grains. The distribution of labelled sediment can then be plotted on a chart and contoured to show the displacement from the injection point.

14.2.5.3 Radio tagging

Radio tagging is carried out by embedding a radio microtransmitter in an artificial pebble, which is moulded using a reinforced epoxy resin. A radio detector mounted on a mobile tracked vehicle is used to locate and map the individual pebbles.

14.2.5.4 Heavy minerals

Heavy minerals represent the accessory and varietal minerals of igneous and metamorphic rocks and are operationally defined as those minerals that have a specific gravity greater than 2.85. They probably account for no more than 0.1 % to 0.5 % of terrigenous sedimentary rocks and providing there is a source rock relatively near to the study area, their distribution and relative quantities can be useful in indicating the general direction of sediment movement. If sediment cores are taken, the vertical distribution of the heavy minerals can also be determined and this could yield much useful information on past sediment movement. Heavy mineral analysis can be expensive and great care has to be exercised in the selection of indicator minerals with due regard being taken of the complexity and potentially long timescale of geological processes.

14.3 Sediment transport with waves

14.3.1 Movement due to waves

Waves alone can initiate movement of sediment when the maximum orbit velocity they induce near the bed exceeds about 0.15 m/s, as for currents alone. For fine sand, the particles rock backwards and forwards and form ripples with crests parallel to the wave crests. These are typically more symmetrical and periodic than those formed under steady currents (see 14.2.1). As the orbit velocity increases, the ripples become steeper and the sand is taken into suspension by eddies shed from the crests. In the presence of tidally induced currents, it appears that the oscillatory motions caused by waves act as an additional stirring agent at the bed and the concentration of suspended sediment is increased [10], [11].

Wave-induced currents associated with diffraction at the sheltered side of the breakwaters (see 29.2.3) can cause large eddy effects and they are thought to be capable of redistributing sediment within harbours.

14.3.2 *Littoral drift*

In the longshore direction, the tangential momentum of waves breaking at an angle to the shoreline can induce currents. Such currents are restricted mainly to the area inshore of the breaker zone. Typically their strengths are low, which suggests low transport rates. However, the breaking waves create considerable bottom turbulence, which lifts material up into the longshore current where it can be transported some distance, resulting in a high net sediment movement. Several empirical formulae have been proposed relating longshore drift sediment to the breaker height and specialist texts should be consulted [12]. Littoral drift can also be measured using the tracer techniques discussed in 14.2.5.

Littoral drift can be an important agent in the shaping of the local coastline. It requires careful study whenever construction that might disturb the dynamic equilibrium of the local drift regime is contemplated (see 14.1, 14.4, 14.5 and 14.6).

14.3.3 *Rip currents*

There often appears to be little convection of water between the offshore area and the breaker or surf zone, but along some shorelines rip currents, consisting of concentrated jets that carry water seaward through the breaker zone, can occur. These are caused by the interaction of wave set up and edge waves (see 24.3). Rip currents with speeds exceeding 1.0 m/s have been reported and it is noteworthy that they are the only currents easily capable of transporting sediment seawards. At present it is not possible to predict the strength or spacing of rip currents and there is insufficient information to indicate quantitatively how important they are as sediment transporting agents in the context of net movement.

14.4 Accretion and scour

14.4.1 *General*

Whilst these techniques give an estimate of the rate and direction of sediment transport in an area, in many engineering problems it is necessary to produce an estimate of the amount of accretion or scour. It should be noted that predictions of this type are only approximations.

14.4.2 *Trial trench method*

The most obvious method of estimating accretion or scour rates is by trial dredge.

14.5 Bed-form migration

The direction of sediment transport and a qualitative appreciation of the rate of transport can be gained by observing the migration of current-produced bed forms. Bed-form migration appears to be controlled by the time-velocity asymmetry of bottom tide-generated currents and the sediment grain size.

The method of study depends on the required resolution. The most accurate measurements can be made using photogrammetric methods which, under favourable conditions, can be resolved to a scale of millimetres with complete area cover. Precise levelling by divers, coupled with a tracer experiment, can give point measurements accurate to a scale of centimetres, but this technique gives lower overall accuracies dependent on the line spacing. Conventional time-lapse underwater photography can offer reasonable point or line accuracies under good visibility. Remote techniques such as echo-sounding and side-scan sonar surveys offer less resolution but, bearing in mind the qualitative nature of the results, are probably more practicable. These techniques can produce good results with the larger bed features such as sand waves.

14.6 Models

For certain operations, such as in the construction of breakwaters or causeways, it might be desirable to design a physical or mathematical model of the system in order to predict any changes to the sediment transport paths for various proposed schemes. With a physical moveable bed model, the objective is to produce an accurately scaled model of the prototype. This is achieved by undertaking field observations and measurements, which can be related to the model by a dimensional study of the prototype characteristics. The model is proved when it accurately reproduces known past and existing conditions. It can then be used to predict changes in the system brought about by future alterations to the environment.

A mathematical model operates by defining the processes and responses of the system in terms of mathematical relationships and, by necessity of the complexity of the model, is run on a computer. Validity is tested, as with the physical model, and prediction is performed by adjusting the relevant variables such as boundary conditions, wave height and current strength.

Both types of model have virtues and inherent limitations. The first disadvantage of the physical model concerns distortion resulting from the inability to scale certain system characteristics. For example, it is difficult to scale sediment movement because, if the sediment size is scaled, the viscous forces on the grains become relatively too large and the grains become so small that cohesive forces predominate. The second disadvantage is the inability (because of cost) to run many variations in layout.

On the other hand a mathematical model might be an oversimplification or even misinterpretation of reality. Knowledge of the mechanisms of sediment transport and therefore the governing equations is as yet incomplete; thus a mathematical model of sediment transport has to be an approximation. The best solution to the problems of modelling is probably a combination of the two techniques.

The accuracy of model predictions, whether mathematical, physical or a combination of both, varies widely, depending on both the complexity of the site situation, and the accuracy and quality of field data used in setting up and determining the validity of the models. Models are often indispensable for determining which of several proposals is the most suitable for site application as they can give a guide to the probable long term changes in the bathymetry. They are less able to determine how quickly such changes take place and therefore the rates of accretion or scour.

Section 3. Operational considerations

15 General

This section gives guidance on the general aspects of design life of structures, ship data, navigation in approach channels, ship handling in harbours and other operational considerations.

Many of the operational requirements of a maritime structure are specific to the particular function or functions of the individual structure and guidance on these aspects may be found in subsequent parts of this code of practice. However, in all projects, there should be consultation between the port operator, ship operators and ship handlers (the pilots and tugmasters). Consultation should be carried out at the concept stage before the layout of a port or a berth has been fixed. At the concept stage the use of simulation studies (see 18.2) is strongly advised in order to ensure that the maximum operational benefits can be obtained in terms of safe and economic functioning of the finished installation. The following subjects should be considered for possible individual study in each case:

- a) numbers, types, sizes and shapes of present and/or expected vessels;
- b) provision of tugs, navigational aids and marine traffic control;
- c) pilotage;
- d) berthing;
- e) mooring patterns, practices, systems and load measurements;
- f) berth occupancy, ship queuing times, port downtime and the effects of sea and weather conditions;
- g) requirements of cargo handling, roll-on roll-off (ro-ro) traffic, storage and other activities, including the need or otherwise to allow for future change, or flexibility in operational usage;
- h) regulations affecting any of the previous operations a) to g).

In considering the safety aspects of a facility the initial construction techniques and the requirements for future maintenance should also be included. The Construction (Design and Management) Regulations, 1994 require designers to consider the health and safety implications of any design decision in order to minimize risks during construction and maintenance activities. Designers have specific duties to consider risk minimization and inform clients of the requirements of the Regulations. Designers should refer to the Regulations prior to commencing the design process.

Because safety is a prime concern in the operation of facilities, liaison during the early design stages is vital to ensure adequate transfer of information and appreciation of operational procedures.

16 Design working life

The design working life of a structure can be taken as the specified period for which a structure is to be used for its intended purpose with planned maintenance (see ENV 1991-1).

It should be noted that this requires knowledge of ambient conditions, loadings and rates of deterioration of the elements of the structure throughout its life.

Normally a design working life of the order of 50 years or more is expected of maritime structures such as quay walls, jetties and docks but for flood protection works it is not uncommon for a 100-year life to be required.

For structures associated with industrial installations or the exploitation for a non-renewable natural resource the design working life might only need to be 15 years (see ENV 1991-1).

It should be noted that the design life is not necessarily the same as the return period of the design condition, because such an equality implies a 63 % probability of the design condition occurring during the design working life (see 21.3.8).

The design working life is significant when assessing:

- 1) time-dependent factors running against the security of the structure such as fatigue loading, corrosion, marine growth and soil strength reductions;
- 2) probability levels for limit state design and for design condition return periods;
- 3) economic feasibility of the project and future developments.

In view of the variable and often unpredictable character of the forces to which maritime structures are subjected, it is frequently unrealistic to expect substantial cost savings to result from attempting to design them for short lives. Greater overall economy is usually achieved by choosing simple robust concepts and appropriate reliable construction procedures.

17 Ship data

17.1 General

Where possible, details and dimensions should be obtained from the relevant authorities, owners and operators for the actual vessels to be accommodated and those likely in the anticipated lifetime of the structure.

Vessel characteristics that should be considered include type, size and shape, ship handling requirements, cargo or passenger handling requirements and vessel servicing requirements.

Characteristic dimensions and hull forms of many ships vary considerably according to function, age and operational region. This is particularly noticeable for passenger ships and naval craft.

Approximate dimensions of the larger bulk carriers and container ships are given in **17.3**. These values are approximations and should only be used for preliminary planning purposes. General guidance on vessel dimensions can be obtained from the registration particulars [13].

Ship handling considerations are discussed in clause **18** and clause **19**.

17.2 Tonnage and displacement

While naval vessels are customarily described by displacement tonnage, the size of other vessels is frequently quoted in terms of gross registered tonnage (GRT) and deadweight tonnage (DWT). The latter values are significant for registration and in assessing the carrying capacity of the vessel. However, for computing berthing energies (see clause **41**) and other hydrodynamic calculations the displacement of the vessel is required.

For the purposes of preliminary planning the following relationships can be used to obtain full load displacement from GRT or DWT. These values are approximations and should not be used for detailed design unless confirmed by the actual vessel characteristics.

- a) Fishing boats:
 - small: $\text{GRT} \times (2.5 \text{ to } 2.0)$;
 - large: $\text{GRT} \times (2.0 \text{ to } 1.5)$.
- b) General cargo:
 - $\text{GRT} \times 2.0$; or
 - $\text{DWT} \times (1.6 \text{ to } 1.4)$.
- c) Passenger liners: $\text{GRT} \times 1.1$.
- d) Container ships: $\text{DWT} \times 1.4$.
- e) Bulk carriers: $\text{DWT} \times (1.3 \text{ to } 1.2)$.

Where two values are quoted in the previous relationships, the first approximates to the smaller vessels of a given type.

17.3 Typical container ship and bulk carrier dimensions

For the purposes of preliminary planning, Figure 1 and Figure 2 can be used to obtain typical values of container ship and bulk carrier dimensions respectively. These values are approximations and should not be used for detailed design unless confirmed by actual vessel characteristics.

18 Navigation in approach channels

18.1 General

From the operational viewpoint ideal accessibility to a harbour implies:

- a) a straight, wide approach channel, the direction of which coincides with the direction of currents, winds and of the highest waves;
- b) a wide harbour entrance;
- c) a large area within the harbour for turning and manoeuvring to jetties and quays.

Such an ideal layout can seldom be achieved, particularly for harbours on the open coast, for the two following reasons. Firstly, the dominant currents rarely coincide with the direction of the highest seas and, secondly, aligning the channel with the highest seas tends to maximize the wave penetration into the harbour. Ports located in estuaries, where the hydraulic conditions are determined mainly by the tides, normally offer better protection for seagoing navigation and many of the larger sea ports are situated in such locations. Access problems can still arise, however, because vessels can be required to follow the sinuous course of a natural channel and finally cross the tidal currents to the harbour entrance or riverside quays. Often extensive dredging works have to be carried out to meet the increasing navigational demands of larger vessels and considerable maintenance dredging costs can be incurred to remove siltation both in the artificially deepened access channel and in the harbour itself. The demand for deeper channels and reduction in dredging costs is tending to bring about the construction of new port facilities for larger vessels nearer to deep water at sea.

18.2 Studies

Where access channels are to be aligned or alternative routes found, the opinions of experienced masters and pilots are essential. Such advice can be supplemented by model and/or simulation studies.

In one method, model vessels having similar hydrodynamic behaviour to the full-scale vessels are studied in small-scale harbour models in which different designs of harbour entrance, breakwaters, quays, jetties and other structures, can be tested. The speed of the model vessel, its rudder settings and any bow and stern thrusters provided to simulate the action of tugs are usually radio controlled and the manoeuvres recorded by overhead photography.

This type of experiment is of limited value, partly because the operator has a bird's eye view of the situation and his response is almost immediate and partly because a skilled operator rapidly learns to manoeuvre the vessel safely in a given situation. The experiments can, nevertheless, be useful in developing a strategy for coping with difficult navigational conditions of current, wave and wind.

Another method uses larger manned ship models, which can be controlled by one or two operators, one of whom might be an experienced mariner. This method overcomes the problem of the operator's bird's eye view by presenting him with a more realistic view of the situation. The problems of a contracted timescale are not entirely overcome, however, although the bigger the model, the smaller the problem.

Computer simulation is now widely used to reproduce ship handling characteristics and the hydrodynamic effects of seabed proximity, currents, wind and wave loadings and towage forces. These simulations have the capability of operating in real time or fast time modes with the ability for the simulated ships to be operator driven or, in the case of channel design studies, can be run using an automated steering to represent the actions of the pilot/helmsman. This particular facility has value when numerous channel transits are to be made for the purposes of a statistical analysis of grounding risk. Typically, these simulator programs operate with a bird's eye view, which is the more usual mode for assessing ship manoeuvring requirements in restricted areas, although a ship's bridge view can be used for assessing the optimum location for buoys or other aids to navigation.

The final and perhaps most comprehensive method of evaluating ship handling in or near a proposed harbour or waterway is by means of a ship simulator in which vessel behaviour, bridge layout and view from the bridge are all realistically reproduced. The central feature of these simulators is a computer, which is programmed for the seabed profile and different ship types. This is done with the aid of information obtained from full-scale observations and from model tests carried out in basins in which waves and currents can be reproduced. The simulator enables typical ships to be manoeuvred along proposed approach channels in real time and therefore overcomes the timescale problems mentioned previously. In addition such a facility allows a realistic assessment to be made of the safety of the waterway from the point of view of navigation.

Reduced water depth causes the ship under way to respond more slowly to changes in engine revolutions and helm than when the ship is in deep water. Stopping distances and bend design would need to make allowances for these effects, which become noticeable when the water depth is less than about 1.5 times the ship draught.

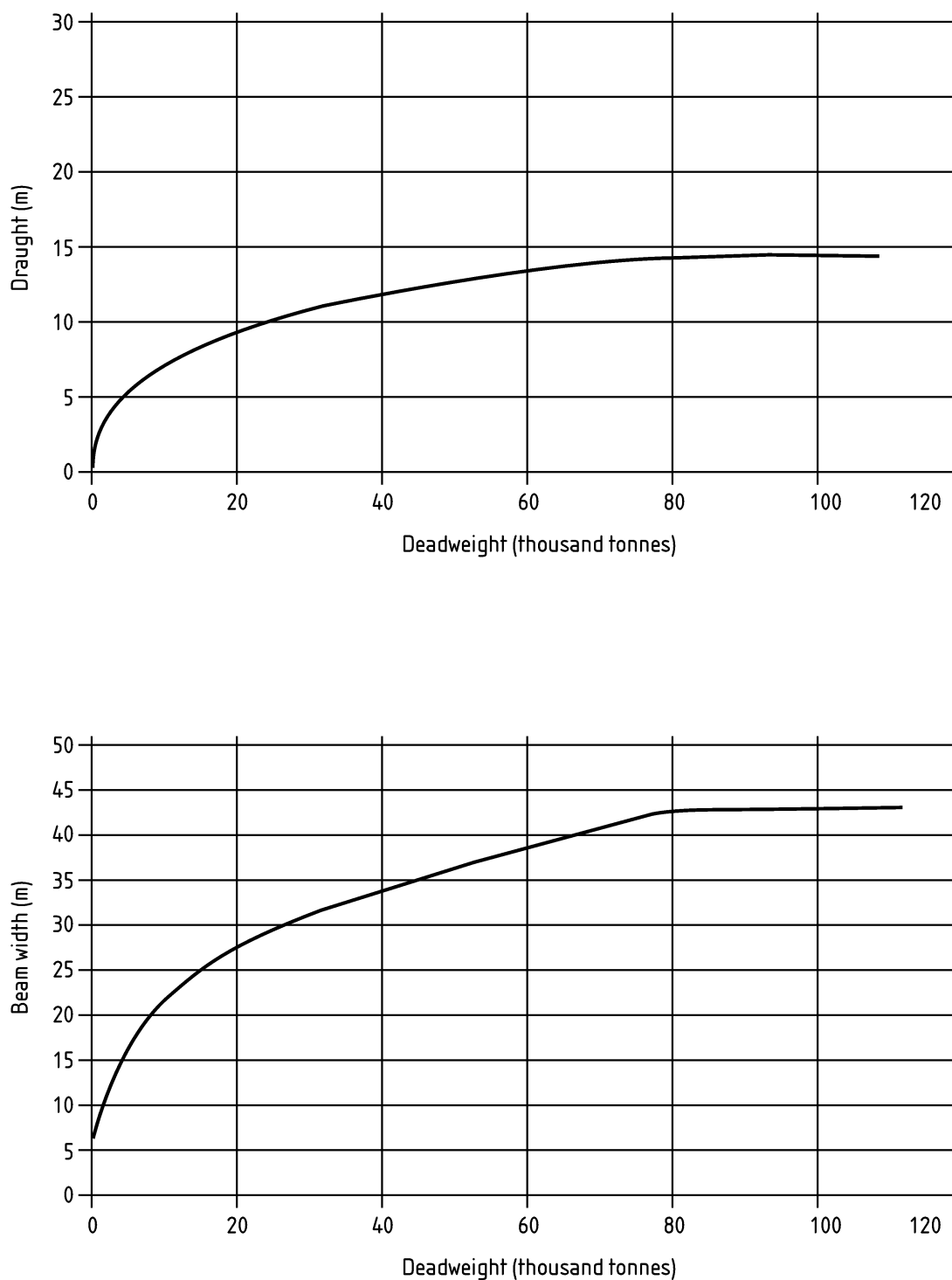


Figure 1a) — Typical ship dimensions — Container ship — Approximate dimensions based on draught against DWT, and beam width against DWT