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Actions from waves and currents on coastal structures (ISO 21650:2007, IDT)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 21650 was prepared by Technical Committee ISO/TC 98, *Bases for design of structures*, Subcommittee SC 3, *Loads, forces and other actions*.

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Introduction

This International Standard, which deals with the actions from waves and currents on structures in the coastal zone and in estuaries, is the first of its kind. Waves and currents and actions from waves and currents on structures in deeper water, especially structures for the petroleum industry, are dealt with in ISO 19901-1 and ISO 19902, ISO 19903 and ISO 19904-1. Some of the structural elements for deeper water structures and coastal structures are the same, especially elements with cylindrical shapes. There will thus be, to some extent, an overlap between this International Standard and other ISO standards on the wave and current actions on cylindrical structural elements. There is though, a difference in wave conditions and wave kinematics between coastal waves and deeper water waves.

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Actions from waves and currents on coastal structures

1 Scope

This International Standard describes the principles of determining the wave and current actions on structures of the following types in the coastal zone and estuaries:

- breakwaters:
  - rubble mound breakwaters;
  - vertical and composite breakwaters;
  - wave screens;
  - floating breakwaters;
- coastal dykes;
- seawalls;
- cylindrical structures (jetties, dolphins, lighthouses, pipelines etc.).

For the rubble mound structures it is not possible to determine the forces on and the stability of each individual armour unit because of the complex flow around and between each armour unit. But there are formulae and principles to estimate the necessary armour unit mass given the design wave conditions. Coefficients in these formulae are based on hydraulic model tests. Since the rubble mound structures are heavily used, they are included in this International Standard, although they may not be treated exactly in accordance with ISO 2394.

This International Standard does not include breakwater layout for harbours, layout of structures to manage sediment transport, scour and beach stability or the response of flexible dynamic structures, except vortex induced vibrations.

Design will be performed at different levels of detail:

- concepts;
- feasibility;
- detailed design.

This International Standard is aimed at serving the detailed design.

It is pointed out that the annexes are only informative and are not guidelines/manuals. The annexes have no regulatory power.

Wave and current conditions vary for different construction sites. It is very important to assess the wave and current conditions at a given site. Assessment procedures for these conditions and for their uncertainties are included.

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2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
actions
force (load) applied to the structure by waves and/or currents

2.2
anchors
units placed on the seabed, such as ship anchors, piles driven into the seabed or concrete blocks, to which mooring lines are attached to restrain a floating object from excessive movements

2.3
annual maximum method
method of estimating extreme wave heights based on a sample of annual maximum wave heights

2.4
armour layer
protective layer on a breakwater, seawall or other rubble mound structures composed of armour units

2.5
armour unit
relatively large quarry stone or concrete shaped unit that is selected to fit specified geometric characteristics and density

2.6
astronomical tide
phenomenon of the alternate rising and falling of sea surface solely governed by the astronomical conditions of the sun and the moon, which is predicted with the tidal constituents determined from harmonic analysis of tide level readings over a long period

2.7
breakwater
structure protecting a shore area, harbour, anchorage and/or basin from waves

2.8
buoyancy
resultant of upward forces, exerted by the water on a submerged or floating body, equal to the weight of the water displaced by this body

2.9
chart datum
CD
reference level for soundings in navigation charts

2.10
core
inner portion of a breakwater, dyke and rubble mound structures, often with low permeability

2.11
crest
1. highest point of a coastal structure

2. highest point of a wave profile

2.12
crown wall
concrete superstructure on a rubble mound

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2.13
datum level
reference level for survey, design, construction and maintenance of coastal and maritime structures, often set at a chart datum or national geodetic datum

2.14
deep water
water of such a depth that surface waves are little affected by bottom topography, being larger than about one-half the wavelength

2.15
design water level
DWL
water level selected for functional design, structural design and stability analysis of marine structures

NOTE Generally it is the water level that mostly affects the safety of the structures/facilities in question. DWL is chosen in view of the acceptable level of risk of failure/damage.

2.16
density driven currents
currents induced by horizontal gradients of water density generated by changes in the salinity and/or temperature, which are caused by the influx of fresh water from run-off from land through an estuary, heat flux from coastal power stations, or other reasons

2.17
diffractions coefficient
ratio of the height of diffracted waves to the height of incident waves

2.18
directional spreading function
function expressing the relative distribution of wave energy in the directional domain

2.19
directional wave spectrum
function expressing the energy density distribution of waves in the frequency and directional domains, being expressed as the product of frequency wave spectrum and the directional spreading function

2.20
drag coefficient
coefficient used in the Morison equation to determine the drag force

2.21
dyke berms
nearly horizontal area in the seaward and landward dyke slope which are primarily built to provide access for maintenance and amenity and which reduce wave run-up and overtopping

2.22
dyke toe
part of a dyke that terminates the base of the dyke on its seaward face

NOTE Various toe constructions are used to prevent undermining of the dyke.

2.23
extreme sea state
extreme waves
state of waves occurring a few dozen times a year to once in many years, expressed with the significant wave height and the mean or significant wave period at the peak of storm event

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2.24
filter
intermediate layer, preventing fine materials of an underlayer from being washed through the voids of an upper layer

2.25
floating breakwater
moored floating object to reduce wave heights in the area behind the floating breakwater

2.26
foreshore
shallow water zone near the shore on which coastal dykes, seawalls and other structures are built

NOTE In beach morphology the term foreshore is used to denote the part of the shore lying between the crest of the seaward berm and the ordinary low water mark.

2.27
frequency wave spectrum
function expressing the energy density distribution of waves in the frequency domain

2.28
geotextile
synthetic fabric which may be woven or non-woven used as a filter

2.29
highest astronomical tide
HAT
tide at the highest level that can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions

NOTE HAT is not reached every year and does not represent the highest sea level that can be reached, because storm surges and tsunamis may cause considerably higher levels to occur.

2.30
highest wave height
height of the highest wave of a given wave record or that in a wave train under a given sea state

2.31
impulsive wave pressure
water pressure of high peak intensity with a very short duration induced by the collision of the front surface of a breaking wave with a structure or the collision of a rising wave surface with a horizontal or slightly inclined deck of a pier

2.32
inertia coefficient
coefficient used in the Morison equation to determine the inertia force

2.33
international marine chart datum
IMCD
chart datum set at the lowest astronomical tide level, as adopted by the International Hydrographic Organization (IHO)

2.34
jetty GB
pier US
deck structure supported by vertical and possibly inclined piles extending into the sea, frequently in a direction normal to the coastline

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2.35
lift coefficient
coefficient used to determine the lift force

2.36
lowest astronomical tide
LAT
tide at the lowest level that can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions

NOTE LAT is not reached every year and does not represent the lowest sea level which can be reached, because storm surges (negative) and tsunamis may cause considerably lower levels to occur.

2.37
mean high water springs
MHWS
average height of high waters, occurring at the time of spring tides

2.38
mean low water springs
MLWS
average height of low waters occurring at the time of the spring tides

2.39
mean sea level
MSL
average height of the sea level for all stages of the tide over a 19-year period, generally determined from hourly height readings

2.40
mean water level
MWL
average elevation of the water surface over a given time period, usually determined from hourly tidal level readings

NOTE The monthly mean water level varies around seasons by a few tens of centimetres.

2.41
mean wave period
average period of all waves among a given wave record

NOTE The mean wave period is often estimated from the spectral information obtained from a wave record. See 5.2.1.

2.42
moorings
ropes, wires or chains to hold a floating object in position

2.43
overtopping
passing of water over the top of a structure as a result of wave run-up or surge actions

NOTE This definition could serve as a general definition and should not be given individually for each structure.

2.44
parapet
low wall built along the crest of a seawall

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2.45
peaks-over-threshold method
POT method
method of estimating extreme wave heights based on a sample of peak heights of storm waves exceeding some threshold level

2.46
peak wave period
period corresponding to the peak of frequency wave spectrum

2.47
permeability
capacity of bulk material (sand, crushed rock, soft rock *in situ*) in permitting movement of water through its pores

2.48
pipeline
structure for carrying water, oil, gas, sewage, etc.

2.49
piping
erosion of closed flow channels caused by water flowing through soil usually underneath the dyke body

NOTE Soil particles are carried about by seepage flow, thus endangering the stability of the dyke.

2.50
pore pressure
interstitial pressure of water within a mass of soil or rock

2.51
porosity
percentage of the total volume of a soil and/or granular material occupied by air/gas and water

2.52
pulsating wave pressure
wave pressure with a period comparable with the wave period

2.53
refraction coefficient
ratio of the height of waves having been affected by the refraction effect in shallow water to their height in deep water with the shoaling effect eliminated

2.54
reflection coefficient
ratio of the height of reflected waves to the height of incident waves

2.55
revetment
cladding of concrete slabs, asphalt, clay, grass and other materials to protect the surface of a sea dyke against erosion

2.56
rip-rap
usually, well-graded quarry stone, randomly placed as an armour layer to prevent erosion

2.57
rock
aggregate of one or more minerals

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2.58
run-up/run-down
phenomenon of waves running up and down the seaward slope of a sloping structure, their height being measured as the vertical distance from the still water level

2.59
***R*-year wave height**
extreme wave height corresponding to the return period of R years

NOTE When used, the specific value of R is indicated such as 100-year wave height.

2.60
scour
removal of underwater sand and stone material by waves and currents, especially at the base or toe of a structure

2.61
sea state
condition of sea surface within a short time span, being expressed with characteristic wave heights, periods and directions

2.62
seaward dyke slope
slope of the dyke on the seaward side that is generally flatter than 1:4 to reduce wave run-up, protected by a revetment made of clay and grass, concrete slabs, asphalt, or stones to prevent erosion

2.63
shallow water
water of such a depth that surface waves are noticeably affected by bottom topography, being less than about one-half the wavelength

NOTE Region of water in which waves propagate is sometimes classified into three categories of deep water, intermediate depth, and shallow water. According to this classification, shallow water represents the zone of depth less than about one-twentieth of the wavelength.

2.64
shoaling coefficient
ratio of the height of waves affected by the depth change in shallow water to their height in deep water with the refraction effect eliminated

2.65
shoreward dyke slope
slope of dyke on the landward side, generally no steeper than 1:3 to prevent erosion by wave overtopping

NOTE It is generally protected by a revetment made of clay/grass.

2.66
significant wave height
average height of the one-third highest waves of a given wave record

NOTE The significant wave height is often estimated from the spectral information obtained from a wave record. See 5.2.1.

2.67
significant wave period
average period of the one-third highest waves of a given wave record

2.68
slamming actions
actions when a water surface and a structure suddenly collide

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2.69
still water level
SWL
level of water surface in the absence of any wave and wind actions, is also called the undisturbed water level

2.70
stone
quarried or artificially broken rock for use in construction, either as an aggregate or cut into shaped blocks as dimension stone

2.71
storm surge
phenomenon of the rise of the sea surface above astronomical water level on the open coast, bays and on estuaries due to the action of wind stresses on the water surface, the atmospheric pressure reduction, storm-induced seiches, wave set-up and others

2.72
swell
wind-generated waves that have advanced out of the wave generating area and are no longer affected by winds

2.73
tidal currents
alternative or circulating currents associated with tidal variation

NOTE Tides and tidal currents are generally strongly modified by the coastline.

2.74
toe
lowest part of sea- and port-side breakwater slope, generally forming the transition to the seabed

2.75
total sample method
method of estimating extreme wave heights by extrapolating a distribution of all the wave heights measured at a site of interest

2.76
tsunami
long waves with the period of several minutes to one hour and the height up to a few tens of meters, which are generated by the vertical movement of sea floor associated with a submarine earthquake, by plunging of large mass of earth into water by land slide or volcanic eruption, and other causes

2.77
uplift
upward water pressure exerted up the base of a structure or pavement due to waves, excluding buoyancy

2.78
vortex induced vibration
VIV
vibration induced by vortexes shed alternatively from either side of a cylinder in a current and/or waves

2.79
wave climate
description of wave conditions at a particular location over months, seasons or years, usually expressed by the statistics of significant wave height, mean or significant wave period, and wave direction

2.80
wave induced currents
currents in the nearshore zone, which are induced by the horizontal gradient of wave energy flux being attenuated by wave breaking

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2.81
wave pressure
water pressure exerted on a structure induced by the action of waves, excluding hydrostatic pressure

2.82
wave set-up
rise of water level near the shoreline associated with wave decay by breaking

NOTE Wave set-up may amount to more than 10 % of the offshore significant wave height.

2.83
wave transmission coefficient
ratio of the height of waves transmitted behind a structure to the height of incident waves

2.84
wind waves
waves generated by and/or developed by wind

2.85
wind driven current
currents induced by the wind stress on the sea surface

NOTE In coastal waters, wind driven currents are influenced by the bottom topography and the presence of the coastline.

2.86
wind set-up
rise of water level at the leeward side of a water body caused by wind stresses on the water surface

3 Symbols

$H_{1/3}$ significant wave height or the average height of highest one-third waves

H_{max} highest wave height

H_{m0} significant wave height estimated from wave spectrum

m_n n-th moment of wave spectrum such as m_0 and m_2

$T_{1/3}$ significant wave period

T_m mean wave period

$T_{m0,2}$ mean wave period estimated from the zero-th and second moments of wave spectrum

T_p period corresponding to the peak of frequency wave spectrum

4 Basic variables for actions from waves and currents

4.1 Water levels

4.1.1 Tides

The astronomical tide levels at a design site shall be calculated with the tidal constituents obtained through the harmonic analysis of a long-term tide record at the site or those estimated from a nearby tide station.

The highest and lowest water levels that have occurred at or near the site should be taken into account in the evaluation of the actions from waves and currents.

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The datum level for maritime structures shall be established with reference to the International Marine Chart Datum and/or the national geodetic datum levels.

4.1.2 Storm surges and tsunamis

The characteristics of storm surges at a design site should be duly investigated and be taken into consideration in evaluation of the action of waves and currents.

Investigation of storm surges may include data collection and hindcasting of storm surges in the past, and numerical evaluation of hypothetical storm surges in the future.

Sets of storm surge water levels and/or storm tides should statistically be analysed for extreme distribution functions so as to determine R-year storm surge levels.

In the locality where the action of a tsunami is not negligible, tsunami characteristics at the site should be duly investigated by means of data collection and hindcasting of tsunamis in the past, and/or numerical evaluation of hypothetical tsunamis in the future.

4.1.3 Joint probability of waves and high water level

Evaluation of the action of waves should be made with due consideration for the joint probability of wave height and water level, especially at a site where the water is relatively shallow and breaker heights are controlled by the depth of water under influence of the tide.

The wave measurement data obtained at the location where the largest wave height is limited by the water depth should not be used for extreme statistical analysis for the estimation of storm wave conditions at the water deeper than the site of measurements.

4.2 Waves

4.2.1 Wave heights and periods

The characteristic heights of wind waves and swell for evaluation of the action of waves should be the significant wave height $H_{1/3}$ and the highest wave height H_{max}, which are defined by the zero-crossing method in the time domain analysis. Other definitions of wave heights may be used as the characteristic wave heights when a method of evaluation requires the use of such wave heights. The significant wave height may be estimated from the zero-th moment of wave spectrum, m_0, as being equal to 4,0 $m_0^{1/2}$. When this estimation is employed, the symbol Hm_0 should be used instead of $H_{1/3}$ so as to clarify the estimation method of the significant wave height, because they may differ by several percent or more (see B.1.2).

The characteristic periods of wind waves and swell for evaluation of the action of waves are the significant wave period $T_{1/3}$ and the mean period T_{m}, which are defined by the zero-crossing method in the time domain analysis, and the spectral peak period T_{p}, which is obtained from the frequency-domain analysis. The mean period may be estimated from the zero-th and second moments of wave spectrum as being equal to $(m_0/m_2)^{1/2}$. When this estimation is employed, the symbol $T_{\mathrm{m}0,2}$ should be used so as to clarify the estimation method of the mean wave period, because the spectrally estimated mean period is generally smaller than the individually counted mean period.

Because of the random nature of wind waves and swell, the heights and periods of individual waves in a given sea state are distributed over broad ranges of variation. Statistical distributions of individual wave heights and periods should be taken into consideration when evaluating actions from waves in shallow water (see B.1).

4.2.2 Wave spectrum

Characteristics of wind waves and swell may also be represented with the directional wave spectrum, which is expressed as the product of the frequency spectral density function and the directional spreading function (see B.2).

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When evaluating the action of waves, the information on the wave spectrum being employed should be clearly stated.

The extent of the directional spreading of waves becomes narrower in shallow water than in deep water because of the wave refraction effect. This change should be taken into consideration when evaluating the action of waves in shallow water.

Where wind waves and swell coexist, wave spectra exhibit multiple peaks. Wave heights may be estimated from the zero-th moment of the wave spectrum (see B.1.2). Difficulty is encountered in defining the significant wave period and the spectral peak period as well as the wave direction in case of multi-peaked wave spectra. Evaluation of the action of waves of multi-peaked spectra can be made by calculating contributions of components, constructed by superimposing the spectra of wind waves and swell in question.

4.2.3 Statistics of extreme sea state

Statistics of extreme sea state at a specific site should be established on the basis of instrumentally measured wave data and/or hindcasted wave data, coupled with necessary refraction/shoaling analysis, which cover the duration as long as possible and not less than 15 y (see B.4.1).

The method of wave hindcasting should have successfully been calibrated with several storm wave data by instrumental measurements around the site of interest.

Caution should be taken for the water depth at which waves have been measured, because a shallow water depth imposes an upper limit to the largest wave height owing to wave decay by breaking.

The preferred method of producing the data set of extreme waves is the peaks-over-threshold (POT) method. The annual maximum method may be employed, but the use of the total sample method is discouraged.

When estimating the wave height corresponding to a given return period, the confidence interval to account for sample variability should be evaluated and reported.

The wave period associated with the return wave height can be determined by referring to empirical joint distributions of wave height and period of extreme wave data.

The highest wave height corresponding to a given return period can be estimated from the result of extreme statistical analysis for the significant wave height, by converting the latter to the former on the basis of the Rayleigh distribution of individual wave heights and the wave transformation analysis.

4.2.4 Wave transformation

4.2.4.1 General

Waves undergo various transformation processes while travelling from deep water toward the shore. The processes include wave shoaling, refraction, diffraction, reflection, transmission, breaking and others. When waves propagate into a region with currents of appreciable strength, the wave heights and direction change. Considerations to be given to these wave transformation processes are described in 4.2.4.2 to 4.2.4.8.

4.2.4.2 Wave shoaling

The process of wave shoaling may be evaluated using the linear wave theory. The shoaling coefficient of wind waves and swell can be calculated by means of either the monochromatic wave method or the spectral method, because the difference between the results by the two methods is a few percent at most.

When evaluating wave loading on structures however, it is preferable to take into account the wave non-linearity effect that can cause a large increase of wave height beyond the prediction by the linear wave theory.

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4.2.4.3 Wave refraction

Wave transformation by refraction should be evaluated by the directional spectral calculation. For preliminary analysis however, the calculation with monochromatic waves can be employed for the cases of simple bathymetry because of a relatively small difference between the two calculation methods for such cases (see B.5.2).

4.2.4.4 Wave diffractions

Wave transformation by diffraction behind barriers such as islands and breakwaters shall be evaluated using the directional spectral calculation. Diagrams of multidirectional random wave diffractions can be referred to for the purpose of preliminary analysis. Care should be taken for the directional spreading characteristics of wind waves and swell at the site of interest, because they are the governing factor of random wave diffraction.

When it is expected that wave diffraction takes place in association with wave refraction over shoals, an appropriate method of numerical analysis and/or hydraulic model tests should be employed (see B.5.3).

4.2.4.5 Wave reflection and transmission

The coefficients of wave reflection and transmission of a maritime structure can be estimated by means of hydraulic model tests and/or the knowledge gained through model tests of similar structures in the past.

The influence of reflected waves on harbour tranquillity, structural stability and others should be examined when evaluating the action of waves.

4.2.4.6 Wave breaking

Decay and variation of wave height caused by breaking in the nearshore zone shall be evaluated by taking into account the random nature of waves.

The nearshore zone is characterized by gradual changes in the functional shape of wave height distribution, rise of the mean water level (called wave set-up) and its long-period fluctuation (called the surf beat) by wave actions, and non-zero wave height at the initial shoreline of zero depth. A numerical model for random wave breaking in the nearshore zone should be capable of reproducing such features.

4.2.4.7 Wave transformation by currents

Changes in the heights and directions of waves by currents depend on the current strength and the angle of encounter. Appropriate numerical models and/or hydraulic model tests should be used to evaluate these changes when changes are expected to be significant.

4.2.4.8 Other transformations

Other processes of wave attenuation by bottom friction, soft subsoil damping, and others may be taken into account as necessary when evaluating the action of waves.

4.2.5 Wave crest elevation and wave kinematics

4.2.5.1 Wave crest elevation

The height of a wave crest above the still water level is larger than one half of the wave height owing to the non-linear nature of water waves. Non-linear wave theories and/or reliable laboratory test data should be referred to when estimating the crest elevation of design waves. The theory and/or laboratory data of monochromatic waves may be applied to the highest individual wave of random waves for estimation of highest wave crest elevation.

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4.2.5.2 Wave kinematics

The wave kinematics, or the orbital velocities and accelerations of water particles under the action of waves, should be evaluated by means of non-linear wave theories of high accuracy, because the linear wave theory underestimates the orbital velocities especially around the wave crest.

When waves are expected to break at a location at which the action of waves are to be evaluated, special consideration should be taken when evaluating the kinematics and the form of the waves because they can be quite different to those of non-breaking waves. Use of hydraulic model tests and/or advanced numerical models is recommended for the evaluation.

4.2.5.3 Wave and current kinematics

When currents of appreciable strength coexist with waves, the vector sum of the current velocity and the orbital velocities of particles by waves may be employed in evaluating the kinematics of water particles.

4.3 Currents

4.3.1 General

Currents may have an effect on structures, directly and indirectly. Directly they exercise the drag and lift forces on the structure. Indirectly they interfere with the waves and modify the wave kinematics and thus affect the actions from waves and currents. Thus the current-wave interactions should be considered when evaluating the action of waves and currents unless the currents are weak.

Currents in coastal waters may be divided into tidal currents, wind-driven currents, density-driven currents and wave-induced currents.

Currents in coastal waters may be affected by the current in the adjacent ocean. The current velocities are in general stronger in coastal waters than in the deeper oceans.

4.3.2 Current velocity

The current velocity should be expressed in vector form, with the absolute magnitude (speed) and the direction, or with the velocity components in a coordinate system.

Current velocities at a design site should preferably be investigated by field measurements for a sufficiently long duration time. Where tidal currents are not negligible, measurements should be made at several elevations in the water, because current velocities vary vertically.

When field measurements are not feasible, numerical computations may be carried out for gaining information on currents. However, calibration of the computations model should have been made with the field measurement data at several sites in the region of the same coastal waters.

5 Wave and current action on structures

5.1 Wave action on mound breakwaters

5.1.1 Definitions

Mound breakwaters are characterized by a seaward sloping front and a porous structure. The rear side might be a slope, a vertical face structure or reclaimed land. While the core is most often made of relatively small size wide-graded stone material, the slope surfaces are generally armoured with larger well-sorted rocks or concrete blocks of various shapes. Core and armour layers are separated by filter layers. A monolithic concrete crown wall, sometimes fully or partly sheltered by armour blocks, is used for the crest when access roads are needed or by some other reason.