BS 6349 – Maritime Works

Essential Update for the Ports and Maritime Community

Standards in Practice – Session 2

Is there a difference between choosing return periods and factors of safety?

Return Period and Safety Factors

Chris Boysons

BS 6349

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8th February 2016

Introduction

The project promoter says "design me a quay wall for a container terminal, and protecting breakwater"

So you ask

- how long do you want to use it for?
  = design working life
- what do you want to use it for?
  = actions

What you don't generally ask

- how much risk will **you** take of "failure" within the design working life = return period
- are you ok with normal factors of safety in design standards or do you want to be more conservative?
- what would be the consequence of "failure"

Design working life

BS EN 1990:2002+A1:2005, Clause **1.5.2.8**

"assumed period for which a structure or part of it is to be used for its intended purpose with anticipated maintenance but without major repair being necessary"

BS 6349 1-1 Section 17

"NOTE 1 Indicative design working life categories for maritime works are provided in Table 1, although it is emphasized that actual working life values need to be carefully considered by project promoters according to the particular requirements and circumstances applying."

Design Working Life

Return Period and Safety Factors

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BS 6349-1-1:2013 Table 1

Table 1 Indicative design working life categories for maritime works

Design working life category	Indicative design working life (years)	Examples
1	10	Temporary structures [A)]
2	10 to 25	Structural parts designed to be replaceable within a structure or facility of longer design working life
3	15 to 30	Structures dedicated to non-renewable natural resources, petrochemicals or similar industrial or commercial applications (such as open-piled jetties, mooring and berthing dolphins, Ro-Ro linkspans)
4	50	Common port infrastructure for commercial and industrial ports including reclamation, shore protection, breakwaters, quay walls
5	100	Common port infrastructure including breakwaters for ports of nationally-significant strategic or economic value. Infrastructure for regional flood defence or coastal management infrastructure

[A)] Structures or parts of structures that can be dismantled with a view to being re-used should not be considered as temporary.

Design working life

After discussions with the project promoter the following are chosen:

Container terminal quay wall	30 years
Breakwater	100 years

Reference period

BS EN 1990 Clause1.5.3.15

"reference period

chosen period of time that is used as a basis for assessing statistically variable actions, and possibly for accidental actions"

"NOTE In so far as a characteristic value can be fixed on statistical bases, it is chosen so as to correspond to a prescribed probability of not being exceeded on the unfavourable side during a "reference period" taking into account the design working life of the structure and the duration of the design situation."

Characteristic values of actions

BS EN 1990 Clause 4.1.2

"(7)P For variable actions, the characteristic value (Qk) shall correspond to either :

*– an upper value with an **intended probability** of not being exceeded or a lower value with an **intended probability** of being achieved, during some specific reference period;*

– a nominal value, which may be specified in cases where a statistical distribution is not known."

What is "an intended probability"?

Characteristic values of actions

BS EN 1990 Clause 4.1.2

*"NOTE 2 **The characteristic value of climatic actions** is based upon the probability of 0,02 of its time varying part being exceeded for a reference period of one year. This is equivalent to a **mean return period of 50 years** for the time-varying part. However in some cases the character of the action and/or the selected design situation makes another fractile and/or return period more appropriate."*

The nominal return period in BS EN 1990 is therefore 50 years and this is the basis for all structural design to the Eurocodes unless you choose something else!

BS 6349-1-2:2016

"6.2 Design situations

6.2.1 Persistent design situations

Persistent design situations should be as defined in BS EN 1990:2002+A1.

Conditions of normal use for a marine facility appropriate to assessment of actions and combinations of actions in a persistent design situation should include both normal and extreme operating conditions as defined in BS 6349-1-1:2013."

“NOTE Examples of persistent design situations are:

a. environmental actions having a return period equal to the reference period for the structure (but generally not less than 50 years);

- water levels having a return period equal to the reference period for the structure;

Item a) above is included in the list of persistent design situations since design methods in the codes of practice for wind, wave and current actions are based on the analysis of extreme situations, and the partial factors chosen are appropriate to that situation.”

Return Periods for Design Situations - Persistent

Return periods for persistent actions

Structure	Design Life	Return Period
Quay wall	30 years	50 years
Breakwater	100 years	100 years

BS 6349-1-2:2016

"6.2.3 Accidental design situations

Accidental design situations should be as defined in BS EN 1990:2002+A1.

Accidental design situations for marine facilities should include the accidental operating condition as defined in BS 6349-1-1:2013. Credible accidental design situations and consistent environmental conditions should be ***established by risk assessment*** *as described in BS 6349-1-1:2013, Clause 22."*

Design Situations - Accidental

NOTE 2 For some structures it is necessary to take into account the effect of very extreme environmental or operating loads to achieve a level of performance to avoid progressive or disproportionate failure. ***In such situations it might be necessary to treat environmental actions from events of return period 500 to 1 000 years as accidental design situations.*** *A credible ship impact scenario with a structure supporting safety or production critical facilities might also be treated an accidental design situation.*

Return Periods for Design Situations - Accidental

Return periods for persistent actions

Structure	Design Life	Return Period
Quay wall	30 years	50 years
Breakwater	100 years	100 years

Return periods for accidental actions

Structure	Design Life	Return Period
Quay wall	30 years	500 years
Breakwater	100 years	1000 years

What's the risk

What is the risk of the action occurring within the return period?

BS 6349-1-2:2016 Clause 15.1 Note 2

"For an event with a return period of 100 years, there is a 1% probability of occurrence in any one year, even the year following a previous occurrence, and approximately an 18% chance of occurrence in a 20-year period. ***For an event with a return period of T_R, there is a 63% probability of occurrence within T_R years.*** *In this way it is possible to establish an acceptable level of risk of the design event occurring within a given number of years (the design working life or preferred maintenance interval).* ***For example, an owner or operator might establish that over a 20-year period it is acceptable to tolerate a 10% probability of occurrence of an event that leads to significant disruption to facilities operations****, then the necessary return period from Figure 1 is 200 years"*

So we do need to ask the project promoter what he is prepared to tolerate!

What's the risk

Is a 63% probability of occurrence of an action within the design working life a tolerable risk or should the probability be less?

As a reminder BS 6349-1-2:2016 says for persistent actions

- *environmental actions having a return period equal to the reference period for the structure (but generally not less than 50 years);*
- *water levels having a return period equal to the reference period for the structure;*

But BS EN 1990 Clause 4.1.2 says

- *"However in some cases the character of the action and/or the selected design situation makes another fractile and/or return period more appropriate."*

What's the risk

It interesting to look at another extreme/accidental risk

Seismic design has two levels of risk, L1 and L2.

The L1 seismic level is for "damage limitation", i.e. broadly similar to a persistent design situation.

The L2 condition is for "no collapse", i.e. much the same as an accidental design situation.

What's the risk

For a reference period of 50 years the return periods and probability of occurrence are:

Event	Return Period	Occurrence
L1	95 years	41%
L2 (Normal)	475 years	10%
L2 (Low e.g.UK)	2,500 years	2%

Most project promoters would tolerate the low risk of a seismic event.

What's the risk

Structure	Design Life	Return Period	Occurrence
Persistent			
Quay wall Breakwater	30 years 100 years	50 years 100 years	45.5% 63.4%
Accidental			
Quay wall Breakwater	30 years 100 years	500 years 1000 years	5.8% 9.5%
Seismic L1			
Quay wall Breakwater	30 years 100 years	95 years* 190 years*	27.2% 41.0%
Seismic L2			
Quay wall Breakwater	30 years 100 years	475 years* 950 years*	6.13% 10.0%

What's the risk

What would the project promoter want?

Should we use longer return periods?

Should he/we consider the consequence of failure?
or maintenance?

What do you think?

Partial Factors

The Eurocode and BS 6349 are limit state standards where partial factors are applied to individual actions and materials

The characteristic value is multiplied by the partial factors to give the design value

Numerical values for partial factors and other reliability parameters are recommended by the drafting CEN committees as *“**basic values** that provide an acceptable level of reliability”*

The partial factors provide against the normal uncertainty in the calculation of the characteristic value of the actions and materials and the uncertainty in the design process

Partial Factors

But as BS EN 1990 states

The general assumptions of EN 1990 are :

"- the choice of the structural system and the design of the structure is made by appropriately qualified and experienced personnel

– execution is carried out by personnel having the appropriate skill and experience"

So does the availability of the Eurocodes recommended basic values mean that the designer does'nt have to think about their relevance to the design?

NOTE

The partial factors given in BS 6349-2:2010 have been updated within BS 6349-1-2:2016

They have changed – some have increased

If you do nothing else when BS 6349-1-2 is published read these

Combination Factors

Perhaps the most important factors are the combination factors

Not all variable actions will have their maximum values at the same time, so

Eurocode allows for the principle of leading variables and accompanying variables

The leading variable and accompanying variables have to act simultaneously, and

They have to be independent of each other

This effectively gives a joint probability analysis of the variable actions

Combination Factors

Table 3 – ψ factors for load combinations in maritime structures

Action		ψ_0 Factor for the combination value of a variable action[A)]	ψ_1 Factor for the frequent value of a variable action[A)]	ψ_2 Factor for the quasi-permanent value of a variable action[A)]
Vehicular traffic loads	Road vehicles (gr1a)[B)]	0.75	0.75	0
	Road vehicles (gr1b)	0	0.75	0
	Pedestrian loads (gr1a)[B)]	0.40	0.40	0
	Horizontal forces (gr2)[B)]	0	0	0
	Pedestrian loads (gr3)[B)]	0	0.40	0
	Port vehicles	0.75	0.75	0
Pedestrian-only traffic loads [C)]	gr1	0.40	0.40	0
	Q_{fwk}	0	0	0
	gr2	0	0	0
Crane loads	Gantry crane	0.75	0.75	0[D)]
	Mobile harbour crane	0.75	0.75	0[E)]
	Construction crane	0[F)]	0	0
	Buffer	0	0	0
Cargo loads[G)]	Containers	0.90	0.60	0.30
	General cargo	0.70	0.50	0.30
	Bulk cargo	0.70	0.70	0.50
	Liquid products	1.0	1.0	1.0
Environmental loads	Wind	0.50	0.20	0
	Operational wind	1.0	0	0
	Thermal actions	0.60	0.60	0.50
	Snow	0.80	—	—
	Ice	0.80	0.80	0
	Water currents	0.6	0.2	0
	Operational water currents [H)]	0.6	0.2	0
	Wave	0.6	0.2	0
	Operational wave	0.6	0.2	0
	Tidal lag [I)]	0.6	0.2	0
Operational loads	Berthing	0.75	0.75	0
	Mooring	0.50	0.20	0[I]
	Ship ramps	0.70	0.50	0
	Ships propulsion	0.75	0.75	0
Construction and installation loads		1.0	0	1.0

Return Period and Safety Factors

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Combination Factors ψ_0 Container Quay Actions

Crane loads	Gantry crane	0.75
	Mobile harbour crane	0.75
	Construction crane	0[F)]
	Buffer	0
Cargo loads[G)]	Containers	0.90 ?
	General cargo	0.70
	Bulk cargo	0.70
	Liquid products	1.00
Environmental loads	Wind	0.50
	Operational wind	1.00
	Thermal actions	0.60
	Snow	0.80
	Ice	0.80
	Water currents	0.60
	Operational water currents [H)]	0.60
	Wave	0.60
	Operational wave	0.60
	Tidal lag [I)]	0.60
Operational loads	Berthing	0.75 ?
	Mooring	0.50 ?
	Ship ramps	0.70
	Ships propulsion	0.75

Operational and non-operational wind actions on gantry cranes can be derived for different return periods

Container actions, tidal lag, berthing actions and mooring actions could all be measured and a statistical approach could be used

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BS 6349

Essential Update for the Ports and Maritime Community

8th February 2016

Combination Factors ψ_0 Container Quay Extreme Actions

Crane loads	Gantry crane	0.75	
	Mobile harbour crane	0.75	
	Construction crane	0[F)]	
	Buffer	0	
Cargo loads[G)]	Containers	0.90	
	General cargo	0.70	
	Bulk cargo	0.70	
	Liquid products	1.00	
Environmental loads	Wind	0.50	
	Operational wind	1.00	
	Thermal actions	0.60	
	Snow	0.80	
	Ice	0.80	
	Water currents	0.60	0.2
	Operational water currents [H)]	0.60	0.2
	Wave	0.60	0.2
	Operational wave	0.60	0.2
	Tidal lag [I)]	0.60	0.2
Operational loads	Berthing	0.75	
	Mooring	0.50 ?	
	Ship ramps	0.70	
	Ships propulsion	0.75	

Mooring actions might apply if the ship cannot leave the berth

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Combination Factors ψ_0 Container Quay Operational Actions

Crane loads	Gantry crane	0.75	
	Mobile harbour crane	0.75	
	Construction crane	0 F)	
	Buffer	0	
Cargo loads G)	Containers	0.90	
	General cargo	0.70	
	Bulk cargo	0.70	
	Liquid products	1.00	
Environmental loads	Wind	0.50	
	Operational wind	1.00	
	Thermal actions	0.60	
	Snow	0.80	
	Ice	0.80	
	Water currents	0.60	0.2
	Operational water currents H)	0.60	0.2
	Wave	0.60	0.2
	Operational wave	0.60	0.2
	Tidal lag I)	0.60	0.2
Operational loads	Berthing	0.75	
	Mooring	0.50	
	Ship ramps	0.70	
	Ships propulsion	0.75	

Note that the operational combination factors for equipment are the same as the extreme case

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8th February 2016

Combination Factors ψ_0
Breakwater Extreme Actions

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8th February 2016

Crane loads	Gantry crane	0.75	
	Mobile harbour crane	0.75	
	Construction crane	0F)	
	Buffer	0	
Cargo loads G)	Containers	0.90	
	General cargo	0.70	
	Bulk cargo	0.70	
	Liquid products	1.00	
Environmental loads	Wind	0.50	
	Operational wind	1.00	
	Thermal actions	0.60	
	Snow	0.80	
	Ice	0.80	
	Water currents	0.60	0.2
	Operational water currents H)	0.60	0.2
	Wave	0.60	0.2
	Operational wave	0.60	0.2
	Tidal lag I)	0.60	0.2
Operational loads	Berthing	0.75	
	Mooring	0.50	
	Ship ramps	0.70	
	Ships propulsion	0.75	

Water levels are not included in the table as they don't in themselves apply an action to the breakwater

Combination factor for wind

What does a wind combination factor of 0.5 mean in terms of wind speed?

Combination factors are applied to the action not the wind speed, V.

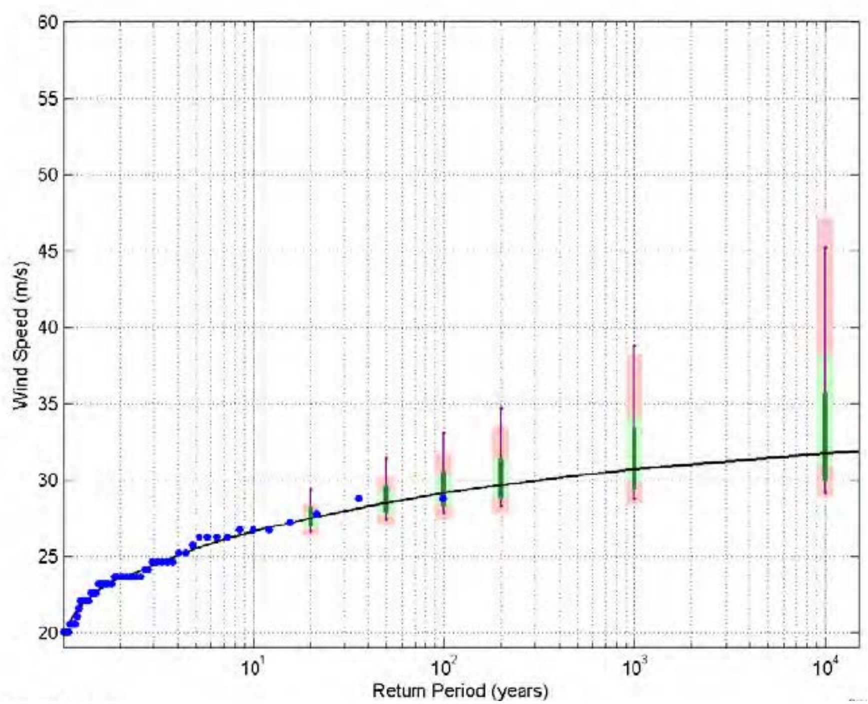
Wind actions are a function of V^2

Mooring actions are also function of V^2

Hence a combination factor of 0.5 can be translated to a wind speed factor of $0.5^{1/2} = 0.71$

“Real” wind data

Example wind speed extreme analysis



1:50 year wind speed = 28.5 ms^{-1}

Combination wind speed = 20.2 ms^{-1}

Combination return period = abt 1 year

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Combination factor for waves

What does a wave combination factor of 0.6 mean in terms of wave height?

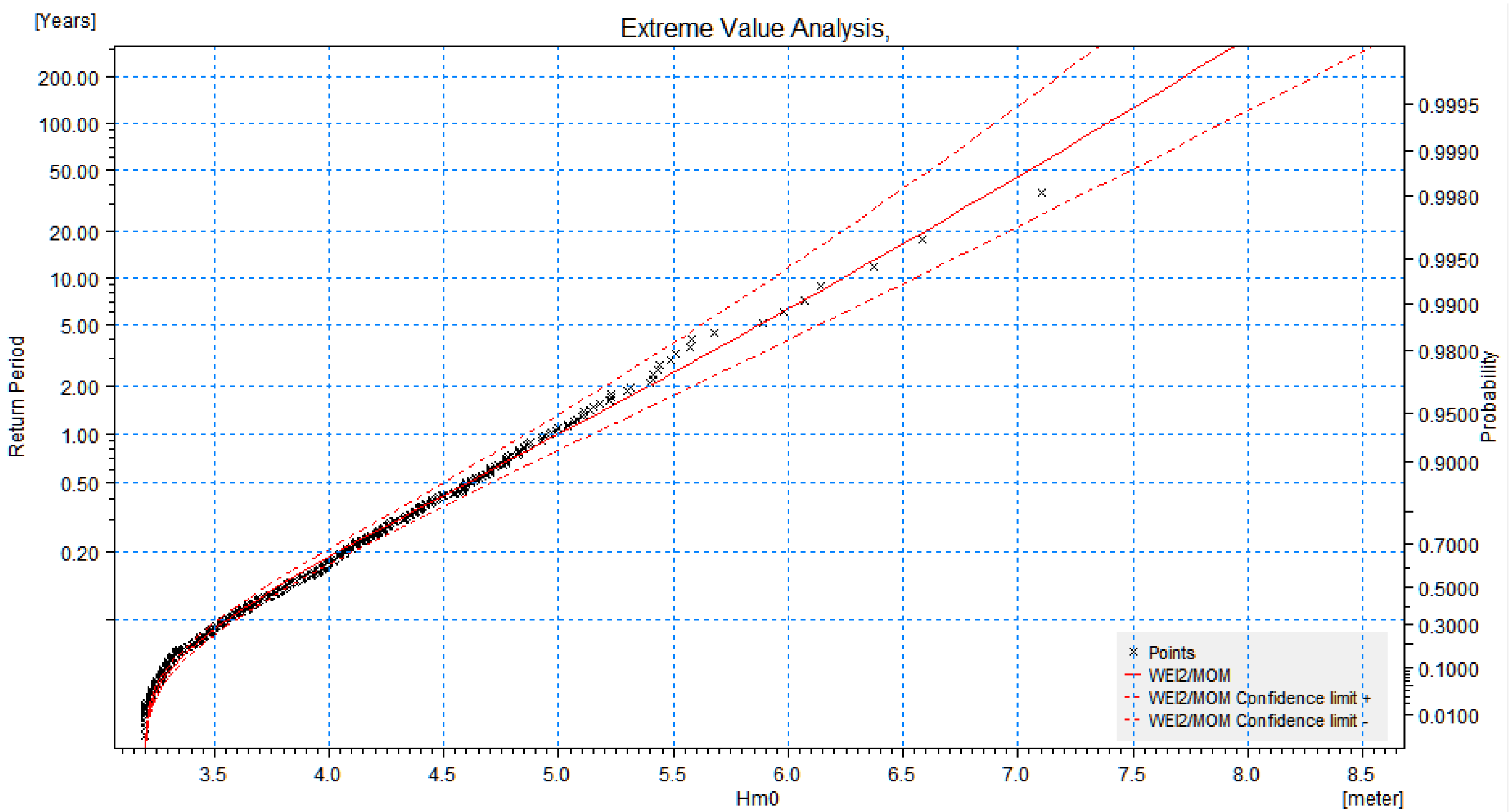
Wave actions that apply to structures vary according to the type of structure

For a quay wall the action is a function of the wave height, H

For a breakwater the action is a function of H^3

For a pile, Morison's equation makes life difficult as the inertia term is a function of H and the drag term H^2

Example wave extreme analysis from Wavewatch III



Wave Combination Factor v Return Period

Return Period (year)	Hs (m):
1	5.01
10	6.24
20	6.60
50	7.06
100	7.40
200	7.73

1:50 year characteristic wave height = 7.06m

Combination factor = 0.6 H - f(H) - for quay wall design

Equivalent combination wave height = 4.24 m

Combination Return Period = abt 0.2 years

Wave Combination Factor v Return Period

Return Period (year)	Hs (m):
1	5.01
10	6.24
20	6.60
50	7.06
100	7.40
200	7.73

1:50 year characteristic wave height = 7.06m

Combination factor = 0.6

For breakwater design $0.6^{1/3}$ – $f(H^3)$ = 0.84 H

Equivalent combination wave height = 5.93 m

Combination Return Period = abt 6 years

Wave Combination Factor v Return Period

For a pile design

V and/or V^2 ?

Answer = ?????

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Would it be better to use a probabilistic combination factor for instance a 1:1 year value as the “extreme” combination value?

And why is 1:1 year better than choosing any other return period?

Answers to chris.boysons@ch2m.com

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Thank you