Content list

Notes from brain storming in HRW	V1_0
Working document + some review of existing documentation : SDY	V1_1
S. Cork / W. Allsop / J. Simm / A Brompton / D Wimpenny / G. Robertshaw / J Perrier (CNR) / JL Person (PA Marseille) / G Leconte (DDE80)	V1_2
W. Allsop / J. Simm / G. Robertshaw / David Slater / Jeffrey Melby	V1_3

Content list

HOW TO READ THE PRESENT DOCUMENT:

The present document is a extended table of content of the concrete manual. It is a collection of :

- Notes,
- Comments,
- Remarks for the project team identified between < >. These are not for specific consideration by the PSG.

PRELIMS

Acknowledgement

Content list

Glossary

<A glossary can be presented in prelims or in appendix>

1 INTRODUCTION <HRW>

A brief historical introduction on the use of concrete in maritime structures would set the scene. Ideally it could go back to Greece and Rome with appropriate references. <Several sources including The Roman Maritime Concrete Study (ROMACONS) project and the *International Journal of Nautical Archaeology*>

More recently ICE Historical Concrete sets out when reinforced concrete piers and jetties were first introduced.

1.1 Use of concrete in maritime structures

- This intro section should be punchy <not to waste page length> and sufficiently illustrated to set nicely the set the scene.
- It should show that we address the needs of EA and of the various funders of the project.
- It should give some focussed response to ***Why do we use concrete in maritime environment?***
- It should also give some focussed response to ***How am I sure that I use the appropriate material in the right place ?***, including LCI / availability / workmanship & skills / durability and maintenance / aesthetic / whole life cost / sustainability considerations < this is a major EA concern> <this may be done by producing a simplified SWOT analysis concluding to use of alternative design or adapted design to address difficulties ; an illustrative range of materials that are reasonable alternatives to concrete may be presented (eg. sheetpile wall instead of diaphragm wall) or for which concrete is a reasonable alternative (concrete units instead of natural armourstone) ; alternative materials could include: natural stone blocks, natural armourstone, steel tubular and sheet piles, timber, composites, and asphalt mix ; could be presented in a table where materials are ticked when they are used for the same type of structure>
- A brief overview of structures covered should be given with some classification < the classification should be explanatory and not redundant with Chapter 3. It could be a functional classification eg. vessel and facilities sheltering / vessel mooring / (un)-loading / access / protection against erosion and wave action. On the opposite the approach in Chapter 3 should be a typology: eg. built under water / in tidal zone / above water OR sloping impermeable / sloping permeable / vertical / piled / mixed>
- A list typical structures that are not covered should be given, ie. some typical port structures such as building, bridge, concrete slab for cranes, pavements, cryogenic structures, design for fire

1.2 Use of this manual

- This section should present the **key standard legal documents** : ISO 21650 <see also Torum 2006 in Coast Eng > ; Euro-codes and Performance based approach ; Existing national approaches (including British/French/Dutch/America/Japanese/Australian and PD documents
- It should also **present other key references** on the use of concrete in maritime environment Allen / French guidance etc… PIANC / FIP / NavFac

This manual is **not** a substitute for ISO, EN or national standards but :

- it provides guidance on **how** to use them
- it provides **missing** and **specialist information** in regards to maritime structures

- it provides information on new developments and new technologies that are not yet included in standard
- it provides a generalised model specification with explanations why the clauses are included

1.3 Structure of the manual

- Briefly present the project itself – funding and key partners < it can also be in the acknowledgement>
- Who is this manual for ? Present the target audience
- a section should present how the manual is organised, etc… < eg. Figure 1.1>

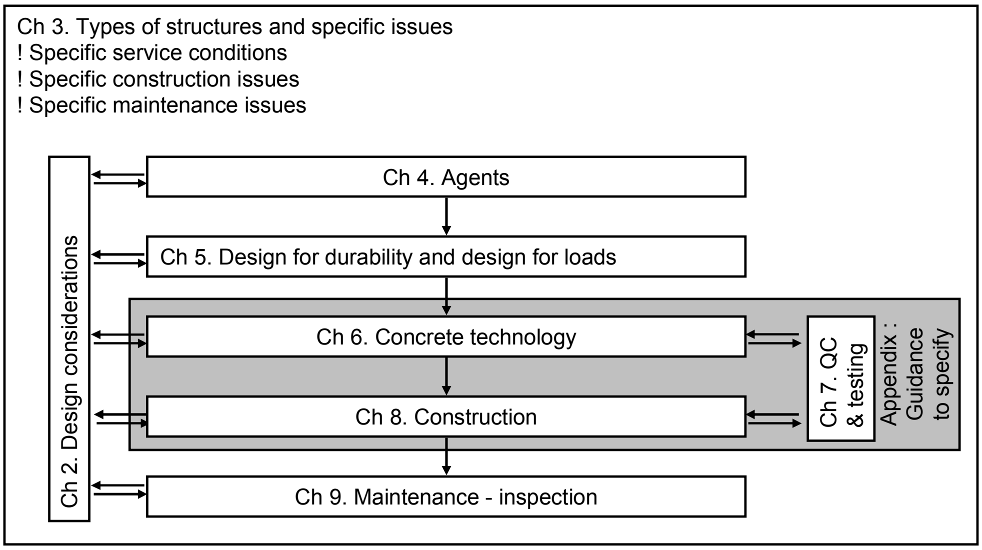

Figure 1.1 structure of the manual <this is only an overview and does not show detailed interaction between the different chapters>

2 DESIGN CONSIDERATIONS<HRW + HALCROW>

- The chapter should introduce all the section of the rest of the manual into a logical design approach. This lists of the key factors and decisions at concept stage which will then feed into the next subsections. Each of the sections below then gives a brief description of factors and decisions which can then be expanded upon later on.
- Differentiation between marine works and other concrete construction and service conditions is essential here
- Structure or asset management frameworks can be used as a general approach to the concrete structure (eg BS PAS 55 + EA environment asset management)

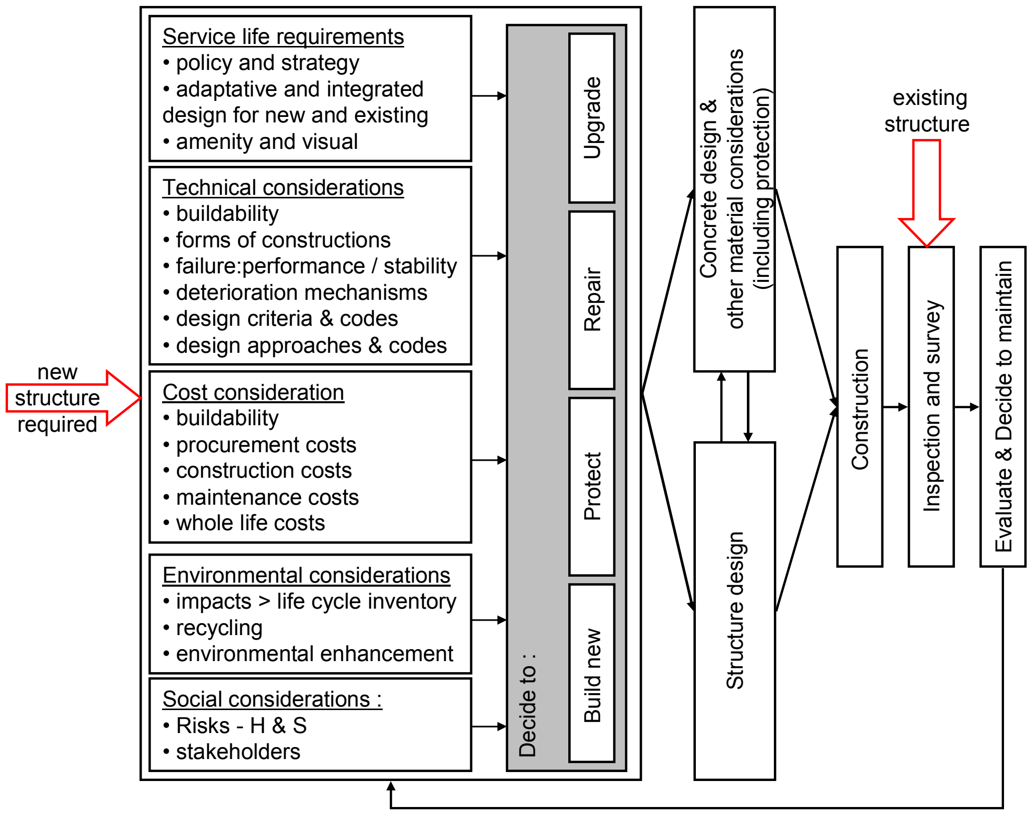

Figure 2.1 Design considerations for a concrete structure in maritime environment and cross referencing with the asset life

2.1 Service life requirements

This section should present the various service life requirements. The way these are addressed in the detail is dealt with in Chapter 5. This includes:

- Functional and performance requirements. It should be stated here that both hydraulic performance and stability should be considered, although their relative importance varies with the situation considered <eg for coast defence, overtopping is essential for normal service conditions ; damage is critical or essential for exceptional or overload situations>

- Standard Framework could be introduced here to set the scene (including Euro-codes and Performance based approach). X-ref should be made to Section 5.1 for further details <note the 2+2 limit states introduced in ISO 21650 and discussed also in Torum 2006 in Coast Eng : service – reparability – ultimate - collapse limit state >
- Policy and strategy, including approaches to assets
- New or existing structures should be addressed = adaptive design – system state and upgrading
- Visual and amenity issues
- Criticality and maintenance - when appraising structures it is important to put reasonable service life criteria on elements by assessing the "criticality" and the difficulty of "maintenance" of the element. i.e. if an element is critical to the operation then an increased service life criteria should be considered < DSR : Classification by Spanish Maritime Works Recommendation as reported by PIANC provides logical basis for selection against required security level >.

2.2 Technical considerations

<Useful comment from Jeffrey Melby (USACE) that we could use to set the scene or give an illustrative case study of what we mean here : "Reinforced concrete is a different beast than unreinforced concrete. Projects that are reinforced are going to be designed with a different perspective than unreinforced projects. For reinforced concrete in the marine environment, focus is on the composite strength and compressive concrete strength whereas for unreinforced concrete, focus is on the flexural strength of the concrete. Construction monitoring and testing are different (cylinders or cubes vs flexural beams). Actual construction is different for the two. Also, conventionally reinforced concrete differs greatly in design philosophy from fiber-reinforced or other types. You might consider separating reinforced concrete from unreinforced concrete ; As we have seen recently, a batch of dirty aggregate or a heat problem in one batch can destroy the profit margin for a contractor constructing unreinforced armor units and can jeopardize the integrity of the breakwater. However, if the units are properly reinforced, these issues may not be as critical. Small plastic shrinkage cracks or other cracks may not be important for reinforced concrete but they may be critical for unreinforced concrete">

This is a very complex subject. Consequently, we should only emphasise on concrete-related aspects :

- **Buildability is a key impact on construction quality**
- **Forms of construction (see BS6349)** and when to use (or not) them : Precast, in situ, reinforced, mass concrete, fibre reinforced concrete (steel and synthetic), underwater / tidal / in the dry work & **temporary works,** eg coffer dams, bunds & **facility requirements** (eg quays, dry docks…)
- **Structural failure modes** with reference to not achieving stability or expected performance : < This can only work for revetments and seawalls as a hierarchy of increasing consequence. Durability failures and structural failures for other types of structure are complex and not easily plotted onto a graph but could be described generically> < structure specific failure modes to be described in Chapter 3>
- **Deterioration mechanism and connection to durability failure modes** – introduce **durability assessment** < structure specific durability failure modes to be described in Chapter 3>
- **Design methodology (1) approaches** (deterministic – sensitivity analysis – semi prob…) **(2) progress** (Concept design - Feasibility design - Detailed design "working" design[1]) **(3) Design aspects** (Design of initial cross-sections / Transitions / Detailing and joints etc

[1] as alternative from contractor or adopting initial design to face unknown – materials ; ground conditions

- **Introduce design criteria** for loads and deterioration < details will be given in the Sections on design of structure for durability OR for loads and design of concrete>

2.3 Cost considerations

This Section should only set out the generalities of what needs to be considered since the build up of construction costs is highly site specific and method-related.

- This can be introduced presented X-ref to **Whole life costing** existing guidance
- **Introduce conventional cost item** : fixed, variables and give examples (eg setting casting yard + concreting and placing units OR hiring a dry dock and floating a caisson)
- **Procurement of concrete** (depending on the type of mixing facility + transport + special concrete eg colloidal) and cement (depending on cement type, location…) etc
- **Construction cost**, including tidal/underwater concreting, options for prefab or precast, etc
- **Maintenance costs**
- **Workmanship** for in situ concrete in maritime conditions : either precast construction is favoured or concrete mixes need to be easy to place and resist damage before setting, which may require high range water reducing admixtures and/or anti-washout admixtures, which makes them more expensive than average.

2.4 Environmental considerations

- **Impacts and Life Cycle Inventory** : Details of the carbon footprint of a cubic metre of concrete would be very useful ; we should not make comparisons with other materials.
- **Environmental enhancement** : recycled concrete or recycling through concrete aggregates and cement
- Other environmental enhancement aspects

2.5 Social considerations

- Health and safety + risk assessment < refer to CIRIA guide SP 125 ; Cruikshank and Cork ; CDM regs >
- Perception / acceptance of concrete and concrete structures by the public
- Example 1 : Patterned and/or pigmented concrete can be used to improve aesthetics and mimic traditional forms of construction in historic and sensitive locations. It is more durable, economic and often more readily available than dressed stone. <surface treatments ; Roughened, textured surface, colored concrete, rubber mould inserts, etc>
- Example 2 : a concrete seawall may be perceived as stronger by public than a beach renourishment program

3 TYPES OF STRUCTURES AND SPECIFIC ISSUES <HRW>

3.1 Types of structures

There are different approaches to sort the various structures within the scope of this manual : Geometry / type of concrete / exposure / technical difficulty / frequency … This first section presents a typology of structures that are then discussed later in this chapter.

- **Vertical** : block works ; in situ cast work; caisson ; retaining and diaphragm walls ; crown wall ; quay walls
- **Sloping and embankments** : revetments ;breakwaters; submerged ; low crested
- **Intermediate or mixed** : coast defences ; sea walls ; groynes
- **Piled:** Piers / jetties (mainly X-reference to Mc Connel et al.)
- **Other** : Slipways ; boat ramps ; access steps **;** tidal barriers/gates **- Floating** : breakwaters

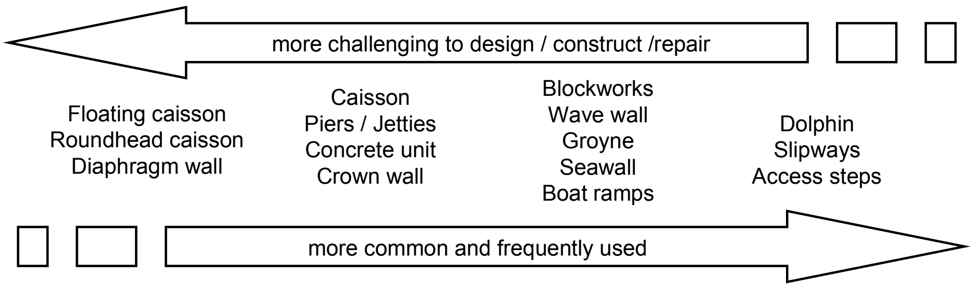

Figure 3.1 Overview of the types of structures covered in the manual viz. their frequency and difficulty to design / built / repair <please make sure we agree on this list>

3.2 Structure-specific aspects

<sections below need diagrams and photos>

3.2.1 Walls

3.2.1.1 Types and origins

- Examples of configurations : vertical / nearly vertical or batted / sloping / back beach-wall / crown wall (1) use existing wall shapes from overtopping manual (2) parameter map in PROVERBS (i.e. vertical face, low and high mound and crown wall)
- Typical walls
- Solid breakwater cap vs ribbed or porous cap <is it appropriate for this to be incorporated here ?>

3.2.1.2 Structure specific service conditions

- Hydraulic loads on vertical structures – Horizontal loads on structures (basic methods, with x-refs to other works). Uplift forces on nosed walls
- Effect of armourstone in front of crownwall
- Ship forces from collision with quay wall <Ship loading is dealt with by BS6349 ; Effects of collisions are greatly affected by the properties of the ship itself ; make sure we say something meaningful without going into details about types of vessels>
- Attrition < is it useful to define attrition, abrasion and wear in the glossary? > to seawalls
- Geotechnical and hydrostatic actions when retaining
- Scour

3.2.1.3 Structure specific construction issues

- Identify key buildability issues for this type of structures
- Various concrete technologies : mass or reinforced ; in situ or pre-cast elements (or block work – see dedicated section); slip form or conventional casting – effects of process on construction quality and risk of defects

3.2.1.4 Structure specific maintenance and repair issues

- Difficult since often in tidal zone
- Use of sprayed concrete
- Cathodic protection of reinforced concrete

3.2.2 Coastal works

<Mers les Bains (F) makes a nice case study combining various approaches>

3.2.2.1 Types and origins

- Primary function is coast defence
- Seawalls : (partly covered under walls and revetments) ; plan cross-section > smooth, dentated <add to glossary if required>, serrated, stepped, curved or nosed - Key role of overtopping control (Torum)
- Groynes : in situ or prefabricated ; top slab resistance and used as access to sea
- Combination with other types of defence (eg beach renourishment...)
- “chasing toe concept” example from NWHa <see also Seawall design form Thomas and Hall>

3.2.2.2 Structure specific service conditions

- Designing for severe exposure to attrition ; examples of site aggressiveness: sand / gravel / pebble beach in front ; use of timber cap on groynes / use of rock facing of concrete seawalls ; reference to it here, but refer to section 4.5
- Example of other requirement for use including public access and safety, including choice of defence shape, provision of access ramps/steps and surface treatments/textures to reduce risk of slippage.

3.2.2.3 Structure specific construction issues

- Identify key buildability for this type of structures
- in situ or prefabricated

- concrete mix design for placing conditions
- tidal work in general – length of construction front required for sequential construction in tidal zone versus programme duration
- transporting concrete on beaches

3.2.2.4 Structure specific maintenance and repair issues

- Examples of site aggressiveness? – environmental exposure conditions – underwater, currents, waves, inter-tidal, effects of climate on aggressivity of chlorides causing corrosion of reinforcement

3.2.3 Concrete block works

3.2.3.1 Types and origins

- Older Structures
- Commonly constructed in Middle East < blockwork quay walls are a standard design and are being built in the Middle East where **foundation conditions are good**. In UK, ground conditions are often poor and open piled structures are usually the only form of construction that is feasible>
- Examples

3.2.3.2 Structure specific service conditions

- Hydraulic stability : effect of inter-block friction / overall permeability / level of phreatic surface (cf. overtopping and infiltration) – see Blockwork Coastal Structures Network (1997), Bruce (ICCE2000), Bezuijen (2000). Also see, Failure Mechanism for Blockwork Breakwaters (ICE 2005) Bezuijen et al.
- Cohesion by friction or interlocking bits

3.2.3.3 Structure specific construction issues

- Identify key buildability for this type of structures
- Precast concrete elements for walls and breakwaters: size of elements related to wave height during construction?
- Keying the various blocs together (sloping faces, 'lego' shape keys…)
- Foundation design and placement underwater
- Scour protection
- Avoid excessive temperatures of hydration in massive blocks and Delayed Ettringite Formation and early thermal cracking problems

3.2.3.4 Structure specific maintenance and repair issues

- Low maintenance of blocks
- Careful detailing of in situ capping blocks with service galleries, cable ducts, mooring bollards etc to ensure durability

3.2.4 Concrete armour units

3.2.4.1 Types and origins

- Types and origin (see Rock Manual) – explain motivation for developments = eg hollow as a variation of cubes to limit concrete need and thermal cracking

- Development of various units with the following improvements: structural strength / hydraulic stability / hydraulic performance (run-up, reflection / …)
- Effect of shape of the CAU eg σ_t (Core-loc) = 2 σ_t(Dolos)
- Settlement of armour layer : introduction of fillets
- Give guidance from experience: example 1 : use same mould and higher density concrete for more exposed area or reinforced? better to use 30 t NRC units or 25 t RC units < Flexural strength and lack of built-in cracks from plastic settlement and early thermal effects important for strength. Consider fibre reinforced units instead of reinforcement>

3.2.4.2 Structure specific service conditions

- Design basis : hydraulics (see Rock Manual)
- In service loads (to be developed) — breakage rate (Burcharth work) – position of higher loads
- Abrasion when placed adjacent to shingle foreshore
- Scour at the toe : on sand foundation, the risk of scour is high and loss of support of toe leading to sliding of armour units and cracking due to displacements

3.2.4.3 Structure specific construction issues

- Identify key buildability for this type of structures
- Key aspects are : simplicity of fabrication / simplicity of placement / simplicity of repair
- cost effectiveness viz. concrete volume per m2 of sea defence or breakwater
- crane capacities
- Fabrication and casting of units and construction practice – delayed repeated vibration to eliminate plastic settlement cracking; mix design to minimise bleed
- Handling of units : lifting methods and stacking
- Placing of units : position, orientation
- Needs for physical modelling – how to deal with structural strength (see Timco)

3.2.4.4 Structure specific maintenance and repair issues

- Long term durability : heating of top surface of hollow blocks
- Types of repair : urgent replacement or concrete bags / replacement / compatibility of repair units with exiting ones

3.2.5 Concrete Revetment systems

- Brief presentation of types / Examples of revetments armour types
- Specific placement techniques
- Identify key buildability for this type of structures
- Mainly X-ref to K McConnell design manual for main types
- Mass/reinforced concrete, insitu/precast

3.2.6 Caissons (breakwaters etc)

3.2.6.1 Types and origins

- Vertical caisson / perforated caisson / slit caissons
- cellular caissons
- sloping (slit or not) caisson

- Examples of configurations : empty, filled, ballasted
- Exposed or composite caisson

3.2.6.2 Structure specific service conditions

- Hydraulic loads on caisson - specific issue of breakers at caissons – and on floating caissons
- Capacity of holes and slits
- Foundation : design for sliding – interface with mound (Trichet) & specific shapes for high friction (van Tol) ; in service loading (Hanzawa ; Martinelli)
- Structural design of dividing walls
- Transition with land (eg Monaco caisson) or the rest of the structure (eg roundhead caissons)
- Mooring of floating caissons
- Ship collision

3.2.6.3 Structure specific construction issues

- Identify key buildability for this type of structures
- Slipform <case study on surface cracking while the form is slowly moving up>
- Durability
- Deformations and cracking during construction under wave loading before stiffened by horizontal slab
- Actions on the base when built in the dry and during floating
- Transport by floating/barge
- Concreting of highly reinforced zones around holes and slits

3.2.6.4 Structure specific maintenance and repair issues

- Cathodic protection as a strategy for long term durability

3.2.7 Exposed port structures

- Retaining and diaphragm wall
- Piers / jetties (x-ref to McConnell)
- Examples of configurations
- Wave/water level: normal or accidental
- Normal (eg mooring) and accidental (eg collision) ship loads
- Durability of jetties platform exposed to water + salt

3.2.8 Dolphins

- Loading
- Types (with diagrams showing examples)
- Construction issues
- Casting, placing, Handling
- Loading
- Service Issues
- Durability

4 AGENTS IN THE MARITIME ENVIRONMENT <HRW>

This chapter presents data and site conditions that will then be used for the design <Eurocode terminology shall be explained here in particular agents (and agents ?)>.

An overview of environmental agents as well as ‘internal’ agents is presented in Figure 4.1. < maybe section

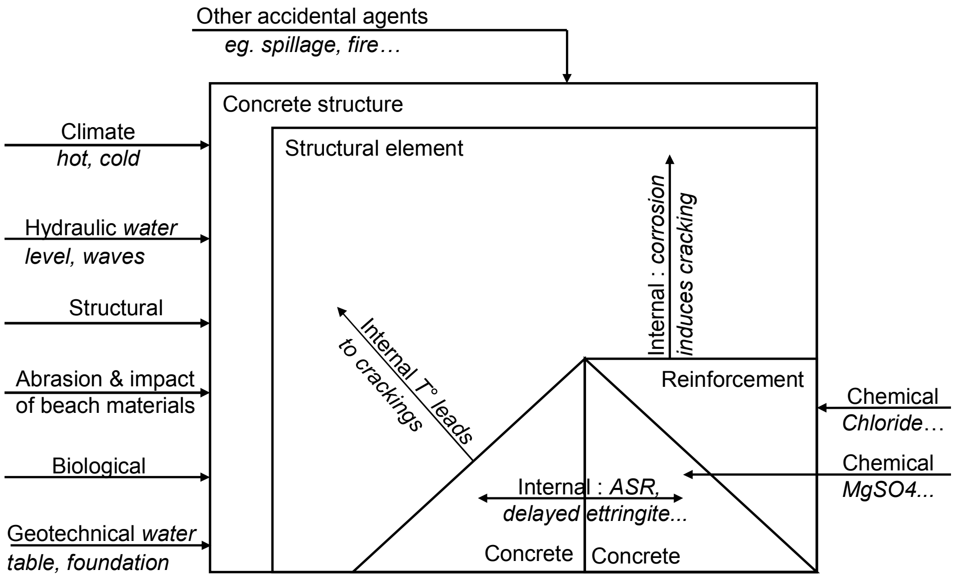

Figure 4.1 Schematic overview of the structure and concrete exposure to agents <illustrative - to be completed if useful and adapted to look like a real concrete structure rather than a conceptual presentation?>

4.1 Introduction

<This Section should describe all environmental agents and x-refer to the way they are addressed during the structure design / the concrete design / construction... See if a flow chart could help to visualize>

Environmental agents affects the concrete durability and its mechanical resistance / concrete workability / aesthetics. < Link to EA “deterioration and whole life costs projects” HRW and Royal Haskoning> < a schematic diagram to represent the areas of structures subject to the different deterioration mechanisms>

Agents convert into :

- **Loading** such as hydraulic agents (wave) mechanical (weight, mooring) internal (thermal stresses)
- **Deterioration** such as electrochemical (chloride), chemical (sulphate), climate, abrasive and biological agents

They are respectively dealt as follows:

- **Design for loadings** during structural design (x-ref to design for loads 5.2) and concrete strength selection …
- **Design for deterioration** during concrete mix design and deterioration modelling (x-ref to design for deterioration 5.1)

- **Construction / mix design** to **limit defects** or **improve quality** < GRH : for example we can improve the compaction of the face by casting units with the exposed face down (by precasting)>: cracks, compaction, curing, low cover, repairs

4.2 Hydraulic agents <headings 4.2 to 4.8 may be grouped together 1 to 3 heading : external non chemical / external chemical / internal >

(x-ref to ch4.1 to 4.3 rock manual)

- Static ie phreatic surface in relation to infiltration and overtopping
- Pulsating vs impact and slamming : Location of the critical load on a caisson ; on a slope ; on a wall…
- Difficulties to scale strength of concrete units in hydraulic models (Timco 1982)
- Effect on stresses to formwork for in-situ casting

4.3 Geotechnical and structural agents

- Static loads : eg arching of concrete armour units in cover layer
- Mooring loads during transport or in-service for floating structures
- Geotechnics (x-ref to section 4.4 rock manual)
- Construction – self weight in casting yards and handling
- Impact dues to ship collision in service or accidental
- Fatigue

4.4 Abrasion and impact agents

- From sand / shingle / cobble beaches
- Assessing site aggressiveness (no method currently standard, therefore give case studies for this and propose methodology of carrying out testing, both insitu and laboratory)
- Concrete mix design (mix types, aggregate types and size, surface treatments)
- Design details (increased chamfers/bullnoses etc.)

4.5 Chemical agents

- Water : makes some reactions possible ; transports aggressive agents from surface or port waters ; leaching
- CO_2 = carbonatation >> corrosion
- Chlorides : $MgCl_2$ and $CaCl_2$ and corrosion
- Sulphates : $MgSO_4$ and $CaSO_4$
- Salt

< The above items are adequately treated in the relevant section 4.5.1 or 4.5.2>

4.5.1 Attack on reinforcement

<JEFFREY MELBY (USACE) : Rebar corrosion is always an argument against reinforcing but we have had armor units in place for 35 years with conventional reinforcement and there is not a problem.

However, all of our reinforced units are lightly reinforced with only flexural steel and no torsion hoops. So the benefit of reinforcing was only marginal>

4.5.2 Attack on cement and / or concrete

4.6 Internal agents

- Effects of construction processes that weaken the concrete and make it more vulnerable to deterioration processes
- Alkali-silica aggregate reaction
- Internal sulphate attack > late ettringite
- Rebars corrosion (induced by Cl or CO2) induced inflating and cracking of concrete <Carbonation-induced corrosion is not an issue in marine structures because conditions are usually too wet to allow ingress of CO2>
- Thermal cracking : De Rourck = 1% of heavy cubes affected / 10 to 15° sufficient to initiate thermal cracking (x-ref to concrete design : low hydration cements to construction : cooling of water and aggregates - curing and from removal (?) rapid (allow heat to go but increase thermal gradient between inside and air) or not (limit T gradient but not economical) – just after both T peak has passed and Rt is achieved)
- Conventional sulphate attack
- Thaumasite form of sulphate attack

< the above items are adequately treated in the relevant section 4.5.1 or 4.5.2>

4.6.1 Attack on reinforcement

4.6.2 Attack on cement and / or concrete

- Absolute max temperature limit set to limit formation of ettringite

4.7 Climate related agents

- Cold climate : recommended % air entrainment corresponds to % expansion of water upon freezing? So no air entrainment required if no freeze?
- Freeze and thaw >> surface spalling
- Ice : impact and abrasion fro minor and major ice (x-ref to section 4.5 of rock manual)
- Hot climate
- Hot/cold cycles inducing mechanical stresses and cracking
- electrochemical deterioration processes accelerated by temperature
- Hot and humid / high salinity climates

4.8 Other agents

- Biological agents : Some molluscs with affinity for clay minerals in aggregates ; < SDY to contact LARISA NAYLOR from NWHa> The incidence of marine boring molluscs which can damage concrete by their acid secretions seems to depend upon water quality as no examples have been seen in recent years in Middle East ports since pollution of the water started. It may become a problem in remote, non-industrial waters
- Structure use specific agents or accidental: Fire in LNG ports ; Chemical spillage <We may be able to give a reference document for further study. This has been a major issue on fertiliser shipment jetties in Jordan>

- <also examples of guano effect on concrete>

<marine-boring molluscs and guano – unlike hot & cold, may not be well documented in other manuals / guidance and so might be useful to cover>

4.9 Classes of exposure

<the above sections describe the phenomena that are in place while section deals with their intensity>
<GRH : this may be dealt within the relevant section up there>
< Review figure 6.2 p.104 of Conc in Coastal Structures (RTL Allen) shows details of exposure severity rating><Needs definition of climatic conditions as a separate table or diagram>

- Environmental agents zoning : vicinity / splash zone / tidal zone / underwater
- Table with standard classes of exposure (EN 206) : CO2 : XC classes / Corrosion but not chlorides : XD Classes / Chlorides : XS classes / Freeze and thaw XF classes
- other phenomenon or classes : Attrition other than classes XM / Climate classes <LCPC research >

5 DESIGN FOR MARITIME ENVIRONMENT<HRW + HALCROW>

5.1 Design methodology

5.1.1 DESIGN APPROACHES

Design for permanent and temporary loads & deterioration / buildability / easy maintenance and repair.

The question of designing to allow some deterioration and designing to limit/prevent other forms of deterioration needs to be addressed. It will depend upon structure type and sensitivity to the deterioration predicted. <Should be introduced in 5.1 and discussed in 5.2>

< refer below to Euro, ASTM, JCI ; GRH to check about ongoing project headed by C Boysons – feed back from GRH>

- **Design phases** : Concept > feasibility > detailed design : cf ISO 21650 – BS 6349
- **Design approaches** (ref to Kovarik ; Melby ; Burcharth): deterministic / semi-probabilistic (Kovarik, ROSA2000) / probabilistic (Oumeraci)
- **Design situation** : both construction and service situation should be presented <consider a sketch like Figure 5.29 of the rock manual> ; SLS and ULS ; comparable to exposure classes - refer to varying return period ;

<give a case study where the construction / placing phase is the critical moment (eg caisson built in the dry and floated or placement of CAU or ?>
<Possible case study from DSR In a site where caisson were being built, the temporary condition during slip-forming the caissons before they were stiffened by the deck slab, was critical as the exposed conditions before the breakwater was built allowed storm waves to hit the caisson and deformed the walls, causing widespread cracking. Hence the temporary loading condition needs to be addressed, not just ULS and SLS in the final structure. This is a contractors risk but when the cracks have appeared nobody will condemn the cracked caisson(s) and order their removal, so it becomes a client's long-term risk >

5.1.2 GEOMETRICAL DESIGN

This section does not give detailed information on how to design the plan layout, the cross-section or the details of the structure but highlight key issues for these that affect buildability and maintenance of concrete structure <The scope of the manual is clearly not to go too far on these. I suggest that we stress issues that will affect buildability and future maintenance while the engineer is holding the pencil to draw the layout, cross-sections and details. This should be principles and examples / case study ?>

- Plan layout
- Cross-Section : Overtopping analysis – Eurotop /Scour - ? / Reflectivity - ? / Construction - ?
- Construction issues <can be addressed through an example or case study>
- Maintenance issues <can be addressed through an example or case study>

5.2 Design for deterioration

5.2.1 Introduction

- Link to :

1. EA “deterioration and whole life costs projects” (HRW and Royal Haskoning)
2. AFGC guidelines 2004: ‘concrete for a given design life (?)’ <in english and french> ou ‘conception des bétons pour une durée de vie donnée des ouvrages’

- give definitions for :

1. design life
2. life time analysis
3. residual life
4. part life (measurements)

Numerical modeling of concrete: strength modeling, dynamic response, impact response, heat production, cracking

5.2.2 Durability by exposure class

- Extension of EN 206
- National guidance - BS6439 + Fr
- Best of international guidance to give concrete mix and cover <do not overlap with 5.2.5>

5.2.3 Performance based approach

- Brief description of durability modelling (main models and approaches)
- Refer to AFGC 2004 used in France
- Deterministic / probabilistic

5.2.4 Durability by protection

- Cathodic protection : principles / issues / examples (Tangier)
- Coating protection : principles / issues / examples
- Concrete skin improvement

< possible case studies from PA Marseille>

5.2.5 Detailing for durability

- Joint design
- Crack width and cover etc for varying design life (100y – 25 y) and materials (grades of steel, types of concrete)
- Reinforcement detailing < is this to be covered? eg shall we briefly discussed welded ends or tied ends of rebars ?>
- Examples of good and bad details

5.3 Design for structural and hydraulic loads

“Types of loading - static, cyclic, impact. How do you design for all 3? Eg, in Japan, they use low strength concrete for concrete armor because they feel that ductility is critical. However, in the U.S. we assume that impact strength increases with static strength so you always get some benefit from increased static strength" <from J Melby USACE>

5.3.1 Design for specific maritime environment loads

- Stability Assessment
- Overturning assessment
- Foundation Design / Geotechnical and in particular interaction with foundation (see Rock Manual – section 5.4)
- Response to wave and dynamic assessment (under impact loads) - PROVERBS
- Stability of concrete armour units – refer to rock manual/manufacturer guidance
- Response to collision (ship, missile broken stone or concrete armour units)
- Use of physical models for that <x-ref to Timco ?>
- Numerical modeling of concrete: strength modeling, dynamic response, impact response

5.3.2 Detailed design of mass concrete

- Mass concrete design for CAU
- wave walls) : give details
- Fibre reinforced concrete design : give details
- Design for :

1. flexural and shear stress situation
2. dynamic loading
3. impacts

5.3.3 Detailed design for early-age temperature

- Significance (1) Cracking (2) DEF <?> (3) Strength gain
- Standard Guidance
- Other methods

5.3.4 Detailing for structural and hydraulic loads

- End effects
- Transitions
- Joints in linear structures
- Relations to 'point structures'
- Steps
- Holes and slits
- Dentations and crenulations
- Wave walls details to avoid air trapping
- Post-overtopping detailing

5.4 Case Studies

- Case study for designing in an abrasive environment (Wyre BC?)
- Case study for choice of reinforcement and design details (e.g. choice of reinforcement, cover and crack width requirements) (GR to identify example)
- Mass concrete design – blockwork wall design (GR to identify example)
- Alternative reinforcement design - (Blackpool revetment)

- Design of crown wall with in situ slip form (Le Havre – SDY to check ?)
- Others?

6 CONCRETE TECHNOLOGY <HALCROW>

It is difficult to give reliable rule of thumb guidelines for all situations, but in general terms it should be possible to provide the reader with DEFAULT values <For example, high density concrete for armour units will require expensive heavy aggregates the same as used for radiation shielding applications>, eg :

- steel for reinforced concrete = 40-100kg of steel /m^3
- Density = 2.3 t/m^3 for NRC & 2.36 t/m^3 for RC / 2.6 t/m^3 for high density…

6.1 Concrete

6.1.1 Mix selection for maritime applications

This section should summarise:

- the various properties expected from concrete for maritime applications – this strongly refer to the design section 5.2 and 5.3
- how the concrete mix parameters may affect these properties and the general expectation for concrete in maritime apps (eg workability).

6.1.2 Concrete mixes for maritime applications

After reading Section 6.1.1, the reader has some idea of the ideal concrete he is looking for. Section 6.1.2 gives a list of concrete mixes used for maritime applications. He can use it to choose the right concrete mix or as a starting point for adaptation. It can be presented in a table format with concrete mix properties for the following types of concrete :

- Unreinforced
- Reinforced : prestressed / rebar / fibre reinforced (example Blackpool)
- High performance (or ulta high performance concrete) : more impermeable thus more resistant to chloride attack< This is not strictly correct as it is pore size distribution and cement chemistry that improves resistance to chloride ingress and increases electrical resistivity which makes a concrete more durable to chloride attack of embedded steel>
- Self compacting and auto placing : ideal for major repair of concrete structure < Self-consolidating (self-compacting) concrete may reduce problems with quality control in unreinforced armor (e.g. over-vibration, bleed water pooling, localized bleed water extraction). Preventing the scrap of one or two armor units might pay for the additional cost of using SCC>
- Normal / heavy : give typical values and rules of thumbs in term of aggregate type, quantity, density and achievable concrete density (hematite, barytine, baryum sulphate, iron ore, other high density recycled products with mass density from 3000 to 5000 kg/m^3)
- Colloidal concrete - colcrete: appropriate but expensive
- “Plumbs” or ‘Cyclopean’ concrete – concrete with large size aggregates (>60mm but low cement content – not accepted by ready mix plant – go for in situ fabrication) <Aggregate sizes greater than say 40mm are not normal and cannot be mixed as concrete. The techniques needed to produce engineered and controlled concrete with large rock “plumbs” added to save on concrete volume goes beyond normal concrete technology. The control of rock shape, size and grading and the introduction in layers into a previously poured wet concrete would require a site specific specification and rigorous site control to avoid formation of voids between rocks.>
- Sprayed concrete : excellent of concrete of sea defences – “gunite” ?
- Underwater concrete

- Pigmented concrete (example in Appledore) or patterned concrete
- Abrasion resistant concrete
- Precast

6.2 Materials

- Including constraints

6.2.1 Cement

- Cement classification EN 197-1 CEM I to CEM V and A to C variations, including special cements
- Benefits of blended cements for seawater exposure

1. maritime cements (NF P 15-317 in F)

2. for high sulphate concentration (XP P 15-319 in F)

- Alternative cements

1. calcium aluminates cement (EN 14647) – recommended since 30MPa in 6 hrs but expensive and caution for its use (P 15-316 in F)

2. natural cement (NF P 15-314 in F) – sulphate and maritime water resistant ; low initial resistance (less than 20MPa) increasing with time – poor availability in UK, expensive and no case histories to confirm track record <SWD to look for case study in France >

6.2.2 Aggregates

- EN 12620 and PD documents (XP P 18545 in F) – special discussion on alternative and heavy ones
- Types of aggregates crushed / semi-crushed / alternative / heavy < see aggregain project >
- Problems associated with aggregates: alkali-silica reaction + thaumasite risks? Salt contamination of dredged unwashed sand
- Effects of using local or man-made aggregate/sand. In Hawaii, they make the sand by crushing rock. This produces a unique concrete mix. <possible interesting case study from JEFFREY MELBY (USACE) – SDY also check with French Navy for the known case for nuclear test sites>
- High density aggregate - particular considerations for design/construction. Typically used for pipeline collars. Useful for concrete armor.

6.2.3 Water

- Quality of normal water for concrete (EN 1008)
- No use of seawater ? - Suitability of sea water for mixing structural concrete exposed to a marine environment Cement and Concrete Composites, Volume 17, Issue 3, 1995, Pages 177-185 S. K. Kaushik and S. Islam / Performance of seawater-mixed concrete in the tidal environment Cement and Concrete Research, Volume 34, Issue 4, April 2004, Pages 593-601 Tarek Uddin Mohammed, Hidenori Hamada and Toru Yamaji

<Seawater will increase the background chloride level and allow ingress of chlorides from the environment to cause corrosion sooner than if fresh water is used. It will also accelerate the setting. It is not recommended>

6.2.4 Additives acting on cement content

- Pore filling additives : fillers from siliceous or limestone products
- Reactive agents additives : fly ash, slag, silica fumes <Seawater will increase the background chloride level and allow ingress of chlorides from the environment to cause corrosion sooner than if fresh water is used. It will also accelerate the setting. It is not recommended>

6.2.5 Additives acting on concrete properties

- Setting admixtures (accelerating or retarding)
- Hardening agent
- Plasticiser (or water reduction agent) and super plasticiser
- Water retentive agent
- Mass water repellent
- Air entraining agent
- Anti-washout admixture
- Corrosion inhibitors (Studies on the performance of migratory corrosion inhibitors in protection of rebar concrete in Gulf seawater environment Cement and Concrete Composites, Volume 26, Issue 3, April 2004, Pages 235-242 Anees U. Malik, Ismail Andijani, Fahd Al-Moaili and Ghazi Ozair)
- AWA (?)
- Pigments

6.2.6 Reinforcement

- Make a distinction between 'pure integrity' reinforcement and 'skin strain reinforcement' to limit crack opening <example from NWHa>
- Avoid whenever possible – but plain concrete needs careful design and handling to avoid damaging cracking
- When used, what type, pros/cons
- Conventional steel rebars : CS, SS and SS clad
- Prestressed concrete
- Non ferrous rebars : non corrodible eg pultruded
- Steel fibre : CS and SS
- Plastic grids – macro-synthetic
- Synthetic Fibres
- Prefabricated reinforcement instead of conventional rebar <NWHa>

6.3 Concrete mix design

- Typical indicators for concrete mix design of maritime concrete : high cement content, low water/cement ratio, low temp hydration cement …
- Standard methods for mix design
- Non-standard mix design

1. eg Ras Laffan
2. Mix design for resistance to attrition
3. 300kg/m3 cement + 60mm aggregates for concrete units in marseille. <Seb to investigate more and possibly make a case study ?>

6.4 Concrete protection

While section 5.2.4 introduction, the possibility of designing for durability with protection and the key principles, this section should give practical useful on what product to use for that protection.

6.4.1 Cathodic protection

- brief description
- x-ref to key design guidance < cp design for rc is quite different from cp design for steel and specialist experience required. Also design tends to be sub-contracted to materials suppliers who may promote anodes with unproven durability/reliability – independent third party check required> <SDY to see with Brahim Benaissa CETMEF/DPMVN if he can work on that>

6.4.2 Surface coating and improvements

- brief description : by wood or hard rocks for attrition resistance / painting / surface improvement (? repellent…) controlled permeability formwork for vertical surfaces, vacuum dewatering for horizontal surfaces, water/cement ratio in surface zone most important, curing also important for early age protection
- x-ref to key design guidance

produits pénétrant = durcisseurs, hydrofuges

produits de surface = peintures, polymère (usure…) >> revêtement minces ou épais / problèmes d’application

7 QUALITY CONTROL AND TESTING <HRW>

7.1 Quality control

This section should contain a general flow chart with concrete construction process / QC points and tests / actions if non compliance – the key quality control subject with regard to maritime environment should be stressed

- Testing schedules and methodologies (recommendations for application of the current codes of practice)
- On concrete components <JEFFREY MELBY (USACE) : seems like we have certain areas of the world that are prone to poor QC>
- On concrete
- On concrete elements
- QC of mass concrete + placing + curing

Acceptance/rejection criteria for marine concrete. Specification.

<JEFFREY MELBY (USACE) Suggest a Chapter/Section on "what to look for in project lab tests/construction inspection/field inspection" with many photos of the types of problems. This could be a separate document (e-document) or appendix that refers back to the primary text.> <This is a nice idea but this is ambitious. Would nicely complement other projects such as PAMS>

7.2 Concrete testing

What are the objectives of these tests :

- confirm mix design <DSR : The time needed to carry out meaningful tests for mix selection is often/usually overlooked in the planning process and therefore the concrete quality starts at a disadvantage and can never be recovered. If there is no proven concrete mix with proper trials including placement and coring, then for high durability concrete it will be necessary to install cathodic protection from the outset. It is therefore very important to discuss testing and the difficulties of the available test methods. Standard tests are not sufficient for projects where long durability is required – for example major flood defence structures>
- verify durability
- verify surface finish
- verify mechanical resistance
- provide reference for QC or is a means to perform QC.

<The specific issues of testing concrete FOR the maritime environment or IN a maritime environment (eg sampling conditions….) should be addressed in here>.

7.2.1 Testing key properties of concrete

< we should not go down this route to far on testing materials for concrete : maybe testing the key property on cement and aggregate is far enough >

< we can simply x-ref to standard test and only detail those that are not standard yet or fill gaps>

<we should also give rules of thumbs for estimates when tests are not available: Rt ≅ 1/10 Rc ; Rt (dynamic) ≅ 1.4 Rt (static) >.

The section should start with :

- Sampling (and test specimens for QC)
- Stocking reference concrete samples EN 12390-2

This section should be short and may be in a table format that summarizes all EU + GB/FR test required to determine key properties of concrete. More details for specific test – including non-standard ones – relevant for concrete in maritime environment are given in Section 7.2.2

- Consistence (previously known as workability)
- Hardening velocity or early age strength gain
- Mechanical strength (compression / tension) / dynamic strength for CAU and walls
- Environmental performance : abrasion (CNR test) / resistance to impacts
- Environmental durability : air content (+ 1% > -4-8% of Rc), penetration of Cl, penetration of CO2
- Durability : chloride barrier; alkali-silica reaction – internal sulphate
- Aesthetic properties: shade of colour, texture, etc…

7.2.2 Testing properties of concrete for maritime environment

- Flexural strength of mass concrete
- Dynamic tests
- Testing concrete for attrition < CNR test method >
- Testing for resistance to impacts < CNR test method >
- Testing concrete for workability properties
- Testing for heat of hydration and early temperature rise
- Testing concrete for durability properties
- Testing for stiffness of concrete for concrete armour units <?>

7.3 Testing of concrete elements

7.3.1 Non destructive testing of concrete elements

- For quality control purposes – influence of construction and curing etc.
- Sclerometer – only surface
- Temperature – 'maturation estimation' and resistance assessment
- Sonic velocity

Metre en avant les essais simples ! maturomètre pas par tout le monde

7.3.2 Full scale destructive testing of concrete units

- Full scale testing concrete units – <see HR report SR100>

8 CONSTRUCTION <HALCROW>

< experience seems to disappear, especially for local works, that tends to induce higher cost eg by using high tech concrete for underwater work instead of really knowing HOW to do it properly… This section is essential and should also address smaller works >

8.1 General organisation of the work

- Close to water / in the tidal zone / under-water
- Coordination between the various activities on site : Construction of concrete cap of BW after primary settlement / Lead time for construction of CAU
- Organisation of casting yard and stock for prefab elements
- Organisation when large prefab floated elements
- Transport to site : method / time

A general comment on the impact of these considerations on the contractor's method and the quality of the completed structure will be useful. The designer will often overlook the method of working yet it can have a massive influence on whether or not the final structure will be durable. The detailed consideration is beyond the scope of this report but full durability design planning needs to consider the temporary conditions since the concrete is at its most vulnerable when it is immature. <DSR>

1. Transport of large units and caissons

2. Specific innovative methods – Pre-cat Form Caisson (CEJ vol 44 –issue 3)
    - Health and safety : Risk assessment – H&S procedures / Underwater and tidal work / Handling of large prefab units

8.2 Concrete construction aspect

8.2.1 Mixing concrete

<The scope of the manual is clearly not to go too far on these. I suggest that we stress issues that will affect buildability and future maintenance while the engineer is holding the pencil to draw the layout, cross-sections and details. This should be principles. ??><Is this relevant/within scope.>

- Ready mix concrete plants do not accept very large aggregates / Inspection and quality certificate of permanent mixing plants
- Site mixing plants / Typical rate for the various technologies / pros and cons
- Importance of mixing technique for microsilica mixes to ensure dispersion and required durability properties

8.2.2 Formwork and casting

- Casting and casting yard for large elements or CAU
- Form-work types (timber, steel, liners),
- Slip form
- General – simplicity…
- Specificity for maritime environment : permeability, mechanical resistance, underwater form-works
- Keeping formwork and rebars clean in tidal work : High Pressure fresh water cleaning

8.2.3 Transport of concrete and pouring / compacting

- Permanent plant to casting yard
- Access to in situ pouring location
- Typical rate for the various technologies < This is application dependent and the means of delivery has to match the size and shape being poured to avoid cold joints>
- Transport of concrete eg. on beaches / Pumping
- Pouring : tremie pipes / pouring from hopper
- Specificities for underwater work
- Compacting techniques
- Vibration techniques / compacting - methods

8.2.4 Stripping and Curing / protection

- The best moment has to be found with reference to concrete temperature and tensile strength, which varies with the shape of the cast object
- There is controversy on specifying required in-form curing time.

8.2.5 Handling and placing of prefab or precast elements

- Lifting prefabricated elements : units / elements
- Placement

8.3 Concrete type specific issues

This section could nicely address the point by given case studies of each situation detailing or stressing a point from above.

8.3.1 Prefab concrete

< we believe it is interesting to introduce a distinction between prefabrication and pre-casting . Prefabrication consists of factory production of standard concrete elements in well controlled conditions. It produces good quality profiles but that may not be fully relevant to maritime application (cf. S Cork comment below). Precast concrete (eg concrete armour units) covers concrete elements that are casted on site in temporary installations to produce highly relevant elements but somehow.>

- Case study from S Cork ? : use of prefab elements is recommended but typical section for maritime application should be used, not the standard CECA profiles

8.3.2 Precast

8.3.3 In situ

8.3.4 Slip form

8.3.5 Underwater

8.4 Case Studies

- Constructing a major revetment and seawall (Blackpool, Wyre etc)
- Constructing with Concrete armour units (MCG/SDY to consider, preferably to include onsite casting and good placement plant – Le Havre SDY to check)

Content list

- Caisson construction (Tangier?)
- Repair and construction of seawall and groynes on pebble beach : ½ prefab ; top slab cast in situ (Mers les Bains – SDY to check)
- Others?

9 MAINTENANCE INSPECTION AND REPAIR

Clear definition of “maintenance” including the different aspects of it : inspection / logging / assessment of remaining life / maintenance or repair or upgrading

Address how fragility curves are backed-up by experimental work

9.1 Inspection and monitoring

9.1.1 Inspecting

9.1.2 Monitoring

- Corrosion sensors

9.1.3 Logging

9.2 Evaluation of structure condition / performance / remaining life

9.3 Repair and maintenance

9.3.1 Maintenance

- Coatings and joints
- Cathodic protection maintenance

9.3.2 Repair

- Patch and surface repair – use of sprayed concrete (cf Maritime concrete)
- Use of fibre + resins for repair (RGCU-IVOR)
- Underwater
- Fabric form
- Bag work
- Repair of reinforcement corrosion
- Movement joints
- Epoxy patches

10 APPENDIX A GUIDE TO SPECIFYING CONCRETE IN THE MARITIME ENVIRONMENT

It shall be noted that one exists already on the F guidance. This can be presented as standards clauses with commentary.

- General : standards and codes
- Spec for materials
- Spec for construction
- Spec for testing
- Spec for quality control and non-compliance

The model ‘guide to specification’ of the French guide includes :

- Description of the works
- Preparation and organisation of the construction site
- Procurement, quality and preparation of materials
- Construction