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Design of Vertical Gravity Sea and Quay Walls

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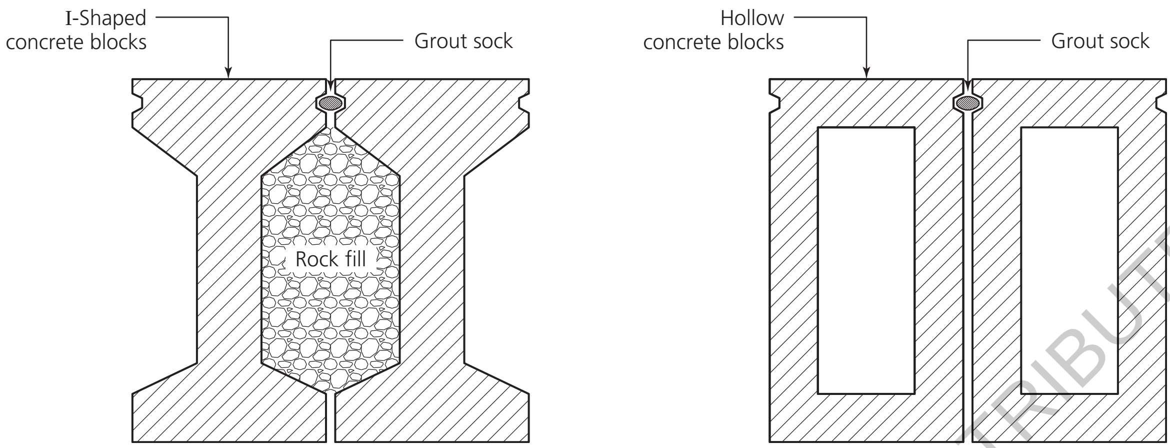
Figure 2.2 Plan view of I-shaped and hollow blocks



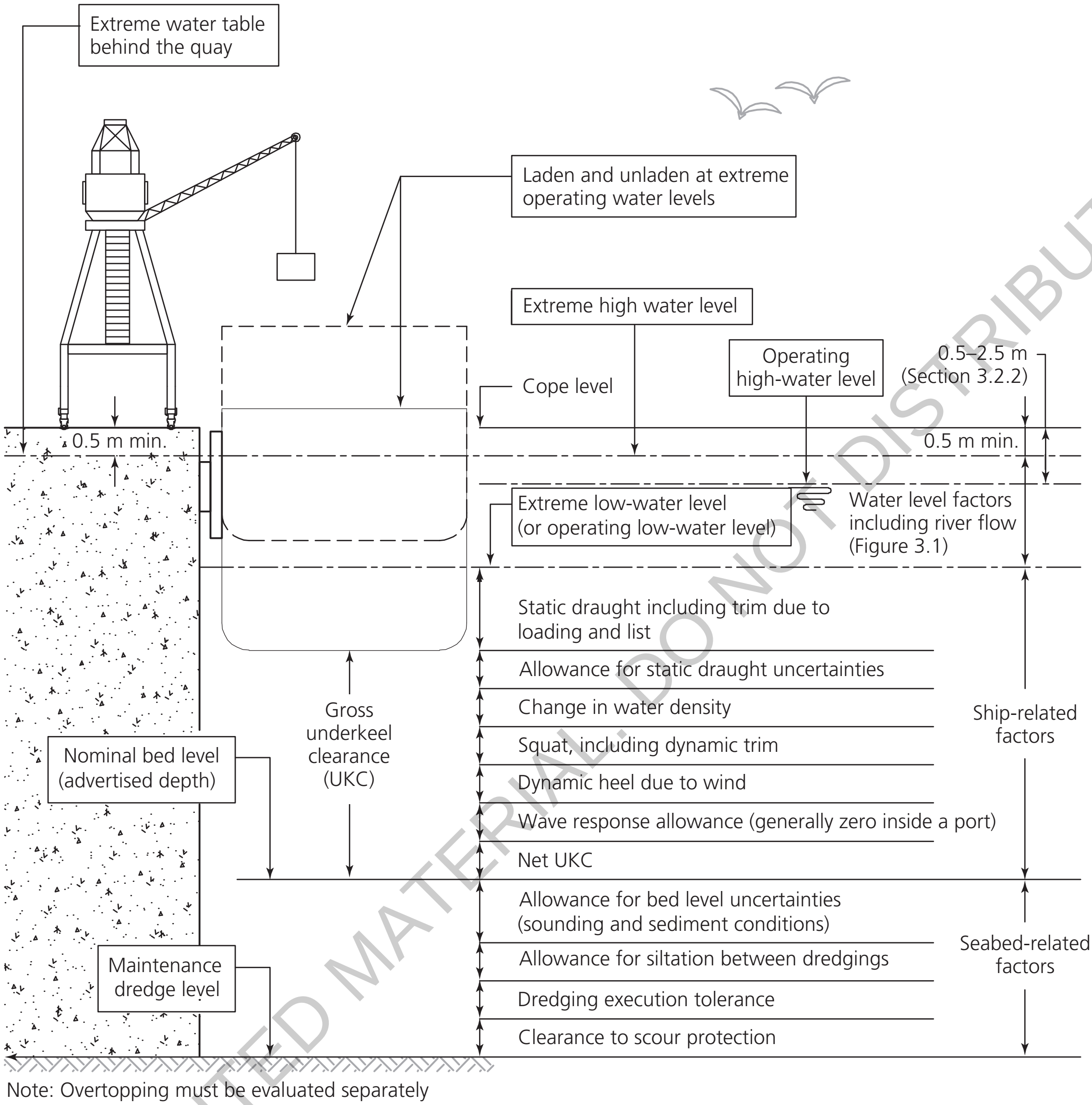
These units are ideal in a corrosive environment, as no or very little steel reinforcement is required compared with the other structure types.

A fairly high volume of concrete is required for these units. The blocks can be modified from their rectangular shape to an I-shape or hollow blocks to reduce the volume of concrete required as well as the block weight, as indicated in Figure 2.2. The openings between the column stacks can be filled with rock or grout to increase the overall weight and to increase the resistance against sliding between the blocks. The base block of these modified block stacks is generally solid (or filled with tremie concrete after placement) and reinforced to increase the bearing area as well as to resist the bearing stresses. The almost completed construction of a bonded blockwork sea wall is shown in Figure 2.3.

Various block stack arrangements are used. Traditionally, the base block is the longest block, with the top block the shortest. Each block in between is then slightly shorter than the one below. This arrangement can be modified by increasing the top block length to provide a relieving platform effect by reducing the lateral pressures applied to the wall. Another optimisation can be to modify the geometry by using larger blocks on top (the blocks are heavier above water and can provide a relieving platform effect), smaller blocks in the middle and moving the base blocks forward (seaward) to ensure the overall wall centre of gravity is positioned to the rear, as shown in the lower image on the left of Figure 2.1. This arrangement can reduce the volume of concrete required as well as the bearing pressures at the base; however, the stability of the blocks at each level should be carefully assessed if they are not connected structurally,

Figure 2.3 Sea wall construction with bonded blockwork. (Photograph courtesy of Abdul Rahim)

Figure 3.6 Minimum cope level and berth depth requirements. (Adapted from PIANC (2014), https://www.pianc.org/publications/marcom/harbour-approach-channels-design-guidelines and ROM (Spanish Ministry of Public Works, 2012); permission to reproduce granted by the Spanish Ministry of Public Works)



The overall wall geometry can further be affected by the design vessel properties. For example

- The degree of list of a vessel berthed at the quay must be considered in determining underwater clearances to the face of the structure.
- Where the angle between the cope line and the longitudinal axis of a vessel with a bulbous bow is likely to exceed 7°, additional clearances must be allowed for.
- The risk of ships trapped under, or hung up on, a fender or protruding element during tidal movement must be avoided due to the extremely high forces that this can apply to the coping beam and wall structure. For this reason, angular projections must be avoided, and horizontal projections must be provided with a flare.
- Load effects from vessel berthing and mooring.
- Propeller wash affecting the scour or toe protection design.

The quay furniture required for berthing and mooring of the vessels affects the geometry of the coping beam. The spacing and geometry of fenders can affect the level and size of the coping beam that is required for fixing of the units, which can in turn affect the block sizes below. Similarly, bollards and mooring hooks can affect the coping level and geometry and indirectly affect the block unit sizes.

Table 3.5 provides vertical vessel motions on ships that can be used if site-specific information is not available. These are recommended maximum criteria for safe working conditions, and are useful in determining the minimum vertical (geometric) loading and offloading equipment limits.

In seismic design situations, Equation 5.85 applies (refer to Table 5.11 for the partial factor shown below)

$$F_d = \sum_{j \geq 1} G_{k,j} \text{ "+" } A_{Ed} \text{ "+" } \sum_{i \geq 1} \psi_{2,i} Q_{k,i} \tag{5.85}$$

A worked example is included below, to show how these formulae are used in obtaining the combined design action for various combinations and limit states.

For serviceability limit states, the combined design action is determined using Equation 5.86 for the characteristic combination (normally for irreversible limit states), Equation 5.87 for the frequent combination (normally used for reversible limit states) or Equation 5.88 for the quasi-permanent combination (normally used for long-term effects and the appearance of the structure)

$$F_d = \sum_{j \geq 1} G_{k,j} \text{ "+" } Q_{k,l} \text{ "+" } \sum_{i > 1} \psi_{0,i} Q_{k,i} \tag{5.86}$$

$$F_d = \sum_{j \geq 1} G_{k,j} \text{ "+" } \gamma_{1,1} Q_{k,1} \text{ "+" } \sum_{i > 1} \psi_{2,i} Q_{k,i} \tag{5.87}$$

$$F_d = \sum_{j \geq 1} G_{k,j} \text{ "+" } \sum_{i \geq 1} \psi_{2,i} Q_{k,i} \tag{5.88}$$

Refer to Table 5.11 for the partial factors shown above.

Ultimate limit states STR and GEO includes three design approaches, for which each EU country can specify which approach(es) should be followed within its jurisdiction. Design approach 1 includes two combinations – both of which must be checked. Design approaches are discussed further in Chapter 6; however, a brief description of each is provided below.

- Design approach 1A or DA1-1. Partial factors are applied to actions only, using set B or A1 in Table 5.10 (and M1 and R1 in Table 6.1).
- Design approach 1B or DA1-2. Partial factors are applied to ground strengths and variable actions only, using set C or A2 in Table 5.10 and M2 and R1 in Table 6.1. Note that for short-term (undrained) situations the partial factor is applied to the soil's undrained strength and for long-term (drained) situations the partial factor is applied to the soil's angle of shearing resistance and effective cohesion.
- Design approach 2 (DA2). Partial factors are applied to actions or action effects and to resistance simultaneously, while ground strengths are left unfactored, using set B or A1 in Table 5.10 and R2 and M1 in Table 6.1.
- Design approach 3 (DA3). Partial factors are applied to structural actions (using set B or A1 in Table 5.10) and material properties (M2 in Table 6.1), while geotechnical actions (set C or A2 in Table 5.10) and resistance (R3 in Table 6.1) are left unfactored.
  A geotechnical action is an action that is transmitted to the structure by the ground fill or water. A structural action is any other action. When checking slope stability analysis, the factors of set C or A2 in Table 5.10 are applied to all actions, not just geotechnical ones.

5.11.1 Worked example

The worked example provided as Figure 5.18 is based on a gravity soil retaining quay wall structure with storage space for general cargo behind the wall. Two horizontal mooring actions must be considered, one operational and the other accidental. Tidal lag is not of concern. This example demonstrates how the combined design actions F_d for three design combinations for limit states EQU are determined. A serviceability limits states characteristic combination is also provided. For simplicity, moments are not included.

The combinations are

- Combination 1: a transient and persistent design situation with cargo as the leading variable action and mooring as the accompanying action.
- Combination 2: an accidental design situation with the accidental mooring load as the leading action and the cargo load as the accompanying variable action.
- Combination 3: a seismic design situation with seismic action as the leading variable action and mooring and cargo actions as the accompanying actions.
- Combination 4: a characteristic serviceability limit states combination with cargo as the leading variable action and mooring as the accompanying action.

BIBLIOGRAPHY

Allsop NWH (2000) Wave forces on vertical and composite walls. In *Handbook of Coastal Engineering* (Herbich J (ed.)). McGraw-Hill, New York, NY, USA, ch. 4.

Allsop NWH, Vicinanza D and McKenna JE (1996) *Wave Forces on Vertical and Composite Breakwaters*. HR Wallingford, Wallingford, UK, Report SR443.

Anastasopoulos I, Loli M, Antoniou M *et al.* (2015) Centrifuge testing of multi-block quay walls. *Proceedings of the SECED 2015 Conference: Earthquake Risk and Engineering Towards a Resilient World, Cambridge, UK.*

ASCE (2018) ASCE/COPRI 61-14. Seismic design of piers and wharves. ASCE, Reston, VA, USA.

Bond A and Harris A (2008) *Decoding Eurocode 7*. Taylor and Francis, London, UK.

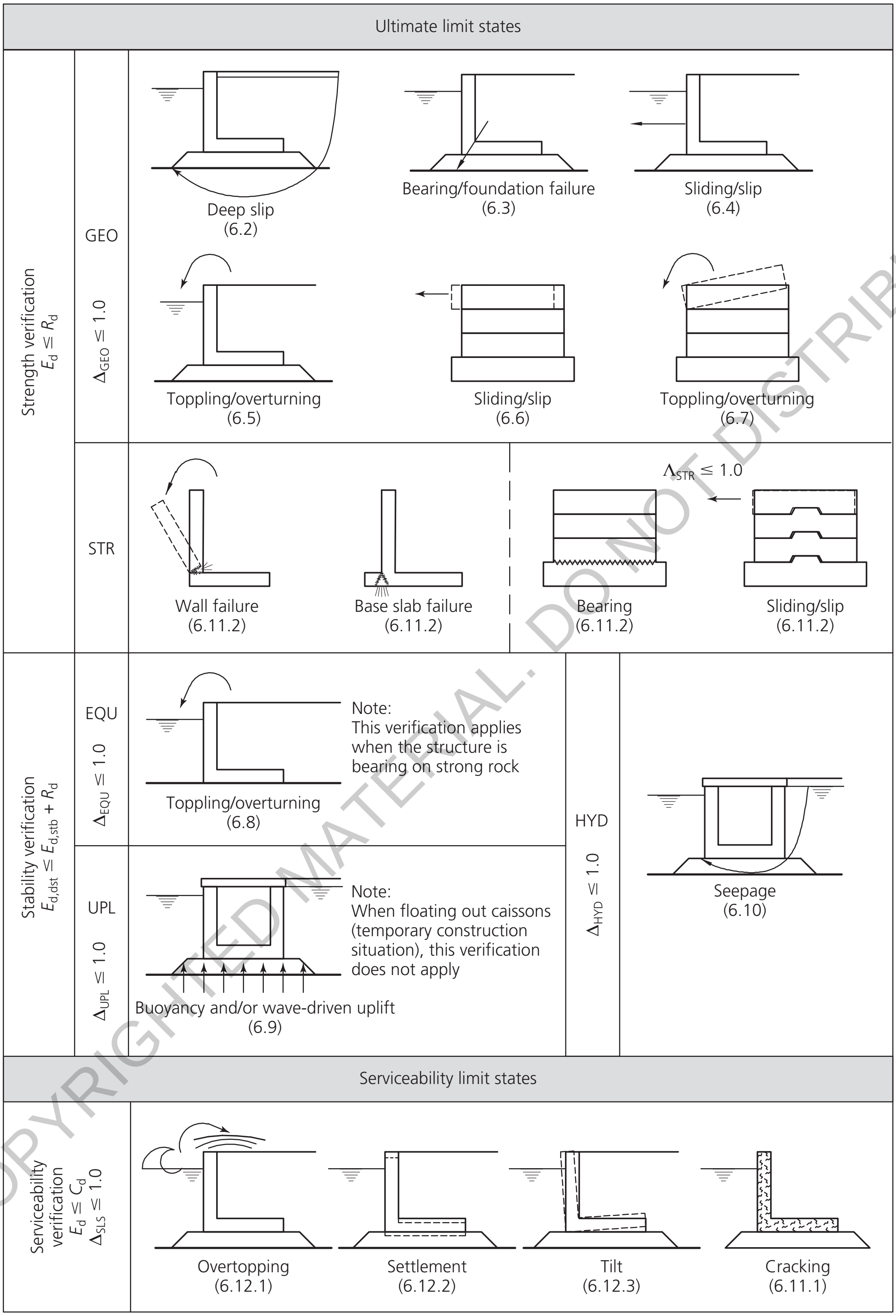
Bond A, Brooker O and Harris AJ (2011) *How to Design Concrete Structures Using Eurocode 2*. MPA The Concrete Centre, London, UK, ch. 9.

Bowles JE (1997) *Foundation Analysis and Design*, 5th edn. McGraw-Hill, Singapore.

Bruce T, Allsop W, Pullen T and Pearson J (2005) How far back from a seawall is safe? Spatial distributions of wave overtopping and wave loads on buildings. *Conference Proceedings: Coastlines, Structures and Breakwaters* (Allsop NWH (ed.)). ICE, London, UK, pp. 166–175.

Bruce T, Müller G, Allsop W and Kortenhaus (2009) Criteria for wave impacts at coastal structures. *Coastal Structures 2007: Proceedings of the 5th International Conference*. World Scientific, Singapore.

Figure 6.1 Gravity sea and quay wall failure mechanisms



( ) = section reference.
Note that scour protection design is not included, as it is seen as a preventative measure in reducing the risk of some of these limit states being exceeded. It is discussed in Section 6.13.1

joint a stone-filled joint. The migration of sand through the horizontal wall joints at the foundation level (at L-walls and counterfort walls) should also be prevented with a solution such as stone fill between the units, covered with a stone-filled grout sock and layers of geotextile. Where the backfill is rubble/rock, the backfill acts as a tidal drain, and is therefore not required. With sand-filled block walls, sometimes PVC pipes (about 50 mm diameter) are fixed to the lower unit before placing the upper unit, compressing the pipe and thereby providing a seal.

Figure 6.23 provides a few examples of wall joints and tidal drains. Reference can also be made to BS 6349-2 and BS 6349-7 for more examples.

Figure 6.23 Typical details of wall joints and tidal drains