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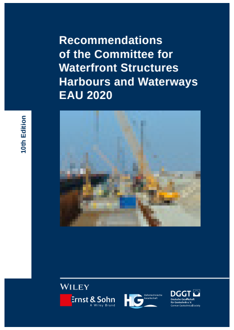

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ABOUT THE BOOK

The recommendations have been completely restructured in this 12th (2020) edition of the EAU (10th English edition), the aim being to provide readers with a better, clearer arrangement of the chapters. In addition, the information published in the annual technical reports of the Waterfront Structures Committee since the publication of the 11th German edition have been incorporated in this new edition. The recommendations also take into account the new generation of standards consisting of Eurocode 7, the associated National Application Documents and supplementary national publications (DIN 1054:2010). In isolated instances, partial safety factors differing from those in the codes are specified on the basis of practical experience. Safety standards for ports, harbours and marine structures are therefore upheld.

The recommendations satisfy the need for international acceptance in the planning, design, tendering, award of contract, construction, site supervision, acceptance and settlement of accounts for port, harbour and waterway facilities based on uniform approaches.

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Preface

Eight years have passed since the publication of the 11th edition (9th English edition) of the *Recommendations of the Committee for Waterfront Structures* (known as the “EAU” in professional circles). Over those years, new developments have been described in the committee’s annual, in some cases six-monthly, technical reports. This 10th English edition (the translation of the 12th German edition) represents a completely updated version of the recommendations of the “Waterfront Structures Committee”, a body organised jointly by the German Port Technology Association (HTG) and the German Geotechnical Society (DGGT). I am certain that, once again, this edition will become a standard work of reference for every engineer concerned with ports, harbours and inland waterways.

The numbered recommendations grew over many years to become the main means of orientation in the EAU. In this new EAU 2020 edition, the content has been given a facelift and the recommendations restructured to provide the reader with a better, clearer arrangement of the chapters. The numbered recommendations are, therefore, no longer included in this new edition of the EAU. The new technical developments described in the committee’s annual reports for the years 2013–2019 have been incorporated. Those developments concern topics such as vertical load-bearing capacity, line pull, offshore energy support bases and vessel sizes. There are also recommendations covering jetties and RoRo berths.

The “Waterfront Structures Committee” adheres to the principles for constituting committees laid down by the German Institute for Standardisation (DIN), i.e. appropriate representation of all groups with an interest and the provision of the necessary expertise. Therefore, the committee is made up of members from all relevant disciplines, who are drawn from universities, the building departments of large seaports, inland ports and national inland waterways, the construction industry, the steel industry and consulting engineers.

The following current and former members of the committee were involved in the preparation of EAU 2020:

- Univ.-Prof. Dr.-Ing. Jürgen Grabe, Hamburg (Chair since 2009)
- Ir. Tom van Autgaerden, Antwerp
- Dr.-Ing. Karsten Beckhaus, Schrobenhausen
- Ir. Erik J. Broos, Rotterdam
- Dipl.-Ing. Frank Feindt, Hamburg
- Dipl.-Ing. Francois Gaasch, Esch-sur-Alzette
- Ir. Leon A. M. Groenewegen, The Hague

- Dr.-Ing. Michael Heibaum, Karlsruhe
- Prof. Dr.-Ing. Stefan Heimann, Berlin
- Dipl.-Ing., M.Eng.Sc. Sebastian Höhmann, Hamburg
- Prof. Ir. Aad van der Horst, Delft
- Dipl.-Ing. Robert Howe, Bremerhaven
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- Dipl.-Ing. Torsten Retzlaff, Rostock
- Dr.-Ing. Peter Ruland, Hamburg
- Dr.-Ing. Hartmut Tworuschka, Hamburg

In a similar way to the work of the DIN when preparing a standard, new recommendations are presented for public discussion in the form of provisional recommendations in the annual technical reports. After considering any objections, the recommendations are published in their final form in the subsequent annual technical report. The status of the *Recommendations of the Committee for Waterfront Structures – Harbours and Waterways* is, therefore, equivalent to that of a standard. However, from the point of view of its relevance to practice and also the dissemination of experience, the information provided goes beyond that of a standard; this publication can be seen more as a “code of practice”.

The incorporation of the European standardisation concept has now been completed, and so this latest edition of the EAU complies with the notification requirements of the European Commission. It is registered with the European Commission under notification number 2019/655/D.

The fundamental revisions in EAU 2020 called for in-depth discussions with colleagues outside the committee, even the establishment of temporary working groups to deal with specific topics. The committee acknowledges the assistance of all colleagues who in this way made a significant contribution to developing the content of EAU 2020.

In addition, considerable input from experts plus recommendations from other committees and international engineering science bodies have found their way into these recommendations.

These additions and the results of the revision work mean that EAU 2020 corresponds to modern international standards. Specialists working in this field now have at their disposal an updated edition adapted to the European standards, which will continue to provide valuable help for issues in design, tendering, award of contract, engineering tasks, economic and environmentally compatible construction, site supervision, contractual procedures, operation, maintenance and repairs. It will, therefore, be possible to design and build waterfront structures that are in line with the state of the art and are based on consistent specifications.

The committee would like to thank all those who contributed to and made suggestions for this edition. It is hoped that EAU 2020 will attract the same resonance as previous editions.

I would also like to thank Ms Anne Hagemann, M.Sc., who has worked with the committee for quite some time.

4

Loads on waterfront structures

4.1 Vessel berthing velocities and pressures

4.1.1 Guide values

When vessels approach a berth transversely, it is necessary to determine the berthing velocities that must be assumed for the design of the fenders.

Guide values for sea-going ships that can berth without the help of tugs can be found in ROM (1990).

ROM (1990) also specifies guide values for berthing velocities for vessels that require tug assistance. However, compared with the figures given in PIANC (2002), these velocities are relatively high, which new studies have confirmed; see Hein (2014). Therefore, the recommendation is to apply the PIANC (2002) figures when calculating berthing velocities for vessels that require tug assistance.

The berthing velocities given in Figure 4.1, which are taken from DIN EN 14504:2019-09, can be assumed for inland waterway vessels approaching a berth transversely.

During preliminary design, no exceptional accident impacts need to be taken into consideration, just the typical berthing forces. The magnitude of these berthing forces depends on each ship's dimensions, the berthing speed, the fenders and the deformation of the ship's side and the structure.

In order to provide quays with adequate loading capacity to resist typical berthing forces, but at the same time avoiding unnecessarily large dimensions, it is recommended to design the structural components affected by berthing manoeuvres in such a way that a single compression load equal to the critical line pull force can be applied at any point. For quay walls in seaports, the load should be as per Section 4.9.1 and in inland ports as per Section 4.9.2, but the total load should not exceed the permissible limits.

The single load can be distributed according to the fendering; without fenders, distribution is permissible over an area measuring 0.50 × 0.50 m. In the case of sheet pile walls without heavyweight superstructures, only walings and waling bolts need to be designed for this compression load.

Berthing forces on dolphins are dealt with in Chapter 12.

If the failure of the waterfront structure as a result of a collision (e. g. ship impact) poses particular risks, e. g. for another facility situated immediately behind it, further delibera-

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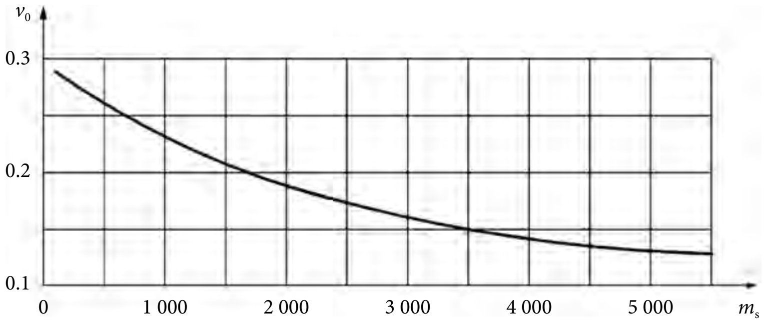


Figure 4.1 Berthing velocities of inland waterway vessels as a function of the vessel mass according to DIN EN 14504:2019-09.

tions may be necessary, and the measures to be taken then agreed upon between designer, client and the authorities.

4.1.2 Loads on waterfront structures due to fender reaction forces

The energy that can be absorbed by the fenders is determined using the deterministic calculation according to Section 7.4. See Section 4.1.1 for the guide values for berthing velocities that should be used in the calculations.

The maximum fender reaction force that can act on the waterfront structure or fender dolphin can be determined using the appropriate diagrams/tables of the manufacturer of the type of fender selected and the calculated energy to be absorbed. This reaction force is to be understood as a characteristic value.

Normally, the reaction force does not result in an additional load on the quay and only the local load derivation has to be investigated, unless special structures have been arranged for fenders, e. g. separate suspended fender panels.

4.2 Vertical imposed loads

In this section, all quantitative loads (actions) are characteristic values.

4.2.1 General

Vertical imposed loads (variable loads within the meaning of DIN EN 1991-2:2010-12 (Eurocode 1)) are essentially loads due to stored goods and means of transport. The changing positions of load influences due to mobile cranes (road or rail types) must be considered separately where these affect the waterfront structure. In the case of waterfront structures in inland ports, loads from mobile cranes generally only apply to those waterfront areas expressly intended for heavy-duty loading/unloading with mobile cranes. In seaports, in addition to rail-mounted quayside cranes, mobile cranes are being increasingly used for general cargo handling, i. e. not just for heavy loads.

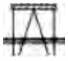
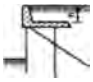
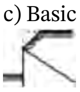
With respect to dynamic load influences, a distinction is made between three different basic situations (Table 4.1):

- In basic situation 1, the load-bearing members of the structures are directly loaded by the means of transport and/or stacked goods, e. g. jetties (Table 4.1, basic situation 1).
- In basic situation 2, the means of transport and stacked goods place a load on a layer of a certain thickness, which spreads and transmits the loads to the load-bearing members of the waterfront structure. This form of construction is used, for example, for structures built over embankments, which include a layer of material above the structure to spread the loads (Table 4.1, basic situation 2).
- In basic situation 3, the means of transport and stacked goods only place a load on the body of soil behind the waterfront structure, which, consequently, is only loaded indirectly via an active earth pressure resulting from the imposed loads. Typical examples of this are exclusively sheet pile walls or a partly sloping bank (Table 4.1, basic situation 3).

There are also intermediate cases between the three basic situations, e. g. a pile trestle supporting a short slab.

Provided that a complete and reliable basis for calculations is available, the magnitudes of the imposed loads should be assumed to be those expected in normal circumstances. The higher the proportion of dead loads and the better the distribution of loads within the structure, the easier it is to accommodate any increases in the imposed loads that may be necessary at a later date within the scope of the permissible limits. Structural systems complying with basic situation 2 and, in particular, basic situation 3 offer advantages in this respect.

Table 4.1 Vertical imposed loads (from EAU 2012).

Basic situation	**Traffic loads**[a]		
	Rail	**Road**	
		Vehicles	**Mobile cranes**
a) Basic situation 1 	Loading assumptions to German Federal Railways guideline RIL 804 and/or DIN EN 1991-2:2010-12 Dynamic coefficient: amounts > 1.0 can be reduced to half their value	Loading assumptions to DIN EN 1991-2: 2010–12	Forklift truck loads to DIN EN 1991-1-4: 2010–12; outrigger loads for mobile cranes to Sections 4.2.2 and 4.10
b) Basic situation 2 	As for basic situation 1 but a further reduction in the dynamic coefficient of up to 1.0 for a layer depth of 1.00 m. For a layer depth $h \geq 1.50$ m, use a uniformly distributed surface load of 20 kN/m^2		
c) Basic situation 3 	Loads as for basic situation 2 with a layer depth > 1.50 m		

a) Crane loads in accordance with Section 4.10.

- The effect of the current.
- The use of air bubble systems.
- Heating or other thermal transfer systems.

In any given case where a precise stipulation of the ice loads is required, experts should be called in and, if necessary, model tests carried out.

When positioning port entrances and orienting harbour basins, particular consideration must be given to the wind direction, current and the shear zone formation of the ice when it comes to determining ice loads and ice formation processes.

If the ice loads on dolphins are substantially greater than the loads resulting from vessel impact or line pull, a check should be carried out to determine whether such dolphins should be designed for the higher ice loads or whether, for economic reasons, occasional overloads can be accepted.

The reader is referred to the explanatory notes in Hager (1996). Advice taken from other international regulations (of the United States, Canada, Russia, etc.) can be found in Hager (2002). Other methods for determining loads due to ice pressure can be found in Thoresen (2018). The values to be used for structures in the Port of Hamburg are specified in ZTV-TB (HPA) (2020).

4.11.2 Determining the compressive strength of ice

The mean compressive strength of ice σ_0 essentially depends on its temperature, salt content and specific rate of expansion, i. e. the ice drift speed. In addition, ice has noticeably anisotropic properties, i. e. the maximum compressive strength depends on the direction of pressure. If no detailed studies of the material properties of the ice are available, then the following assumptions apply for the north German coasts:

- Linear temperature distribution over the thickness of the ice, with a temperature on the underside of approx. –2.0 °C for the German North Sea coast and approximately –1.0 °C for the German Baltic Sea coast (varies according to the salt content of the water) and the top surface of the ice at air temperature.
- The salinity of the ice in the North Sea and the Baltic Sea in accordance with Table 4.13.
- A specific rate of expansion $\varepsilon = 0.001\ \mathrm{s}^{-1}$ (the compressive strength of the ice depends on the rate of expansion and attains the maximum value in the range between ductile and brittle failure at $\varepsilon \approx 0.001\ \mathrm{s}^{-1}$).

Based on the salt content and temperature of the ice, the porosity ϕ_B, i. e. the quantity of salt crystals and air pockets in the ice, according to Kovacs (1996) is as follows:

$$\varphi_B = 19.37 + 36.18 S_B^{0.91} \cdot |\vartheta_m|^{-0.69}$$

where

ϕ_B	porosity [%]
S_B	salinity [%]
ϑ_m	mean ice temperature, $(\vartheta_o + \vartheta_u)/2$ [°C]
ϑ_u	temperature on underside of ice ($\vartheta_u = -1$ °C in the German region of the Baltic Sea, $\vartheta_u = -2$ °C in the German region of the North Sea) [°C]
ϑ_o	temperature on top surface of ice (corresponds to air temperature) [°C]

Table 4.13 Guidance values for salt content (salinity S_B) of the seawater and sea ice along the German North Sea and Baltic Sea coasts according to Kovacs (1996).

North Sea	Salinity of water [%]	Salinity of ice [%]	Baltic Sea	Salinity of water [%]	Salinity of ice [%]
German	32–35	14–18	Belt Sea	15–20	10–12
Bight Estuaries	25–30	12–14	Bay of Kiel	15	8–10
			Bay of Mecklenburg	15	8–10
			Arkona Basin and Bornholm Sea	8–10	5–7
			Gotland Sea	5–7	[a]
			Gulf of Finland and Gulf of Bothnia	1–5	[a]

a) The compressive strength of ice for salinity < 5% is determined in accordance with Section 4.12.

The horizontal uniaxial compressive strength of the ice σ_0 according to Germanische Lloyd (2005) and Kovacs (1996) is derived from the material properties specified above or, in an ideal situation, by means of the material properties determined in situ or through experiments:

$$\sigma_0 = 2700\dot{\varepsilon}^{1/3} \cdot \varphi_B^{-1}$$

where

σ_0	horizontal uniaxial compressive strength of the ice [MN/m^2]
$\dot{\varepsilon}$	specific rate of expansion ($\dot{\varepsilon} = 0.001$) [s^{-1}]
ϕ_B	porosity [%]

If more precise ice strength studies are not available, the flexural strength σ_B can be assumed to be roughly $1/3\sigma_0$ and the shear strength τ roughly $1/6\sigma_0$.

4.11.3 Ice loads on waterfront structures and other structures of greater extent

4.11.3.1 Mechanical ice pressure

The following design approaches can be used to determine the horizontal ice loads on vertical planar structures on the north German coasts for ice thicknesses d in the order of magnitude of $0.25\,\text{m} \leq d \leq 0.75\,\text{m}$ plus compressive strengths as per Section 4.11.2:

a) A horizontal mean line load p_0 acting at the most unfavourable height of the water levels under consideration. It is assumed here that the maximum load calculated from the uniaxial compressive strength of the ice σ_0 is only effective, on average, over one-third of the length of the structure (contact coefficient $k = 0.33$). The mean line load is:

$$p_0 = k \cdot h \cdot \sigma_0$$

where

p_0	mean line load [MN/m]
k	contact coefficient (0.33) [–]
h	thickness of ice [m]
σ_0	compressive strength of the ice [MN/m^2]

b) A local load per unit area p acting over the thickness of the ice must be taken into account in local analyses. This results in the following equation:

$$p = \sigma_0$$

where

p	local load per unit area [MN/m^2]
σ_0	uniaxial compressive strength of the ice [MN/m^2]

c) A reduced horizontal mean line load p_0' acting at the most unfavourable respective height of the water levels under consideration in the case of platforms and revetments in tidal areas when the layer of ice has broken as a result of fluctuating water levels. According to Hager (1996), this results in the following equation:

$$p_0' = 0{,}40 \cdot p_0$$

where

p_0'	reduced line load [MN/m]
p_0	mean line load [MN/m]

It is not necessary to consider the simultaneous effect of ice coupled with wave load and/or vessel impact.

If no maximum ice thickness values specific to the location are available, the maximum values specified in Table 4.14 can be assumed, which are based on ice observations conducted over many years.

4.11.3.2 Thermal ice pressure

Thermal ice pressure, as a further form of static loading on waterfront structures and other planar structures in the water, is caused by rapid changes in temperature and simultaneous restraint to expansion. In confined, iced-up port basins or similar configurations, considerable loads can occur as a result of thermal expansion. A precise determination of the thermal ice pressure on waterfront structures is complex, since the calculation approaches available frequently require numerous input parameters such as air temperature, wind speed, solar radiation, snow covering, etc., which can only be determined with a considerable degree of uncertainty.

With respect to the thermal ice pressure of sea ice as a function of the rate of temperature change (°C/h), ISO/FDIS 19 906 (2010) specifies the values given in Figure 4.21 for various ice temperatures and thicknesses.

Table 4.14 Measured maximum ice thicknesses as guidance values for design (BSH 2001).

North Sea	max h [cm]	Baltic Sea	max h [cm]
Helgoland	30–50	“Nord-Ostsee” Canal	60
Wilhelmshaven	40	Flensburg (outer fjord)	32
“Hohe Weg” lighthouse	60	Flensburg (inner fjord)	40
Büsum	45	Schleimünde	35
Meldorf (harbour)	60	Kappeln	50
Tönning	80	Eckernförde	50
Husum	37	Kiel (harbour)	55
Wittdün harbour	60	Bay of Lübeck	50
		Wismar harbour	50
		Bay of Wismar	60
		Rostock-Warnemünde	40
		Stralsund–Palmer Ort	65
		Saßnitz harbour	40
		Koserow–Usedom	50

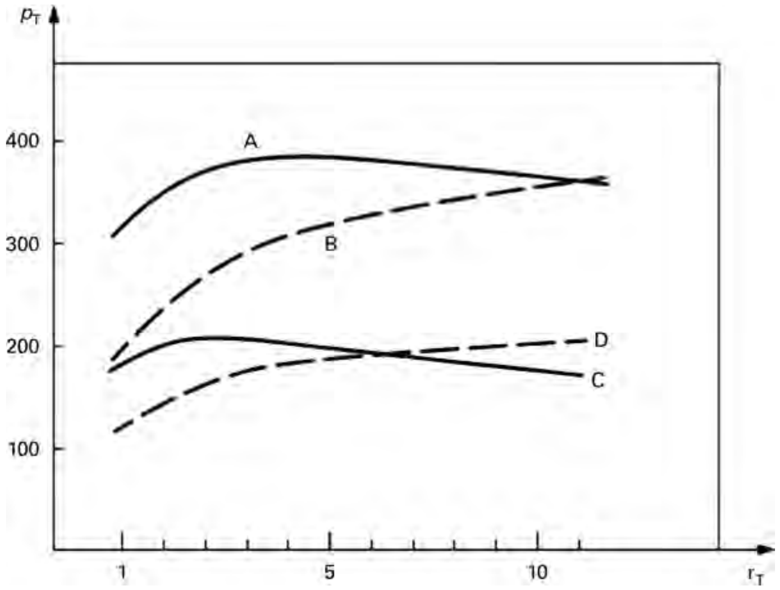


Figure 4.21 Thermal ice pressure as a function of ice temperature and thickness (according to ISO/FDIS 19906 2010). A: $\vartheta_m = -30$ °C, $h = 1.0$ m; B: $\vartheta_m = -30$ °C, $h = 0.5$ m; C: $\vartheta_m = -20$ °C, $h = 1.0$ m; D: $\vartheta_m = -20$ °C, $h = 0.5$ m; p_T: thermal ice pressure [kN/m]; r_T: temperature change rate [°C/h]; h: ice thickness; ϑ_m: mean ice temperature.

DIN 19704-1:2014-11 recommends considering a load of 0.25 MN/m^2 uniformly distributed over the ice thickness as a calculation parameter for German coasts and ice thicknesses $h \leq 0.8$ m. The reader should refer to (HTG 2010) for further information and calculation approaches.

7

Configuration of cross-sections and equipment for waterfront structures

7.1 Configuration of cross-sections

7.1.1 Standard cross-sectional dimensions for waterfront structures in seaports

7.1.1.1 Standard cross-sections

When building new cargo-handling facilities and extending existing installations, the standard cross-section of Figure 7.1 is recommended, which takes into account all relevant influences.

The distance of 1.75 m between crane rail and edge of quay should be understood as a minimum. In the case of new construction and watercourse deepening works, it is better to allow 2.50 m, as the outboard crane bogies can then be built as wide as required. (The crane bogies of modern port cranes are often approx. 0.60–1.20 m wide, see Figure 7.1.) In addition, it is easier to comply with the health and safety regulations for mooring operations and for embarkation/disembarkation via gangways.

A crane safety clearance must be maintained for railway operations. The centreline of the first track must be at least 3.00 m from the front crane rail. However, these days, railway tracks are only constructed on quay walls in exceptional circumstances.

7.1.1.2 Walkways (towpaths)

The walkway space (towpath) in front of the outboard crane rail is necessary to provide space for the installation of bollards and storing gangways, to serve as a path and working space for line handlers, to allow access to berths and to accommodate the outboard portion of the crane gantry. Consequently, this clearance is of special importance for port operations.

Health and safety regulations must also be considered when selecting the walkway width. Furthermore, account must be taken of the fact that ship superstructures often project beyond the hulls of moored vessels and that cargo-handling operations must still be possible on listing ships.

For the reasons outlined above, the walkway must be wide enough so that the outermost edges of the cargo-handling facilities are at least 1.65 m, but preferably 1.80 m, behind the front edge of the quay wall or face of timber fender, fender pile or fender system (Figure 7.1).

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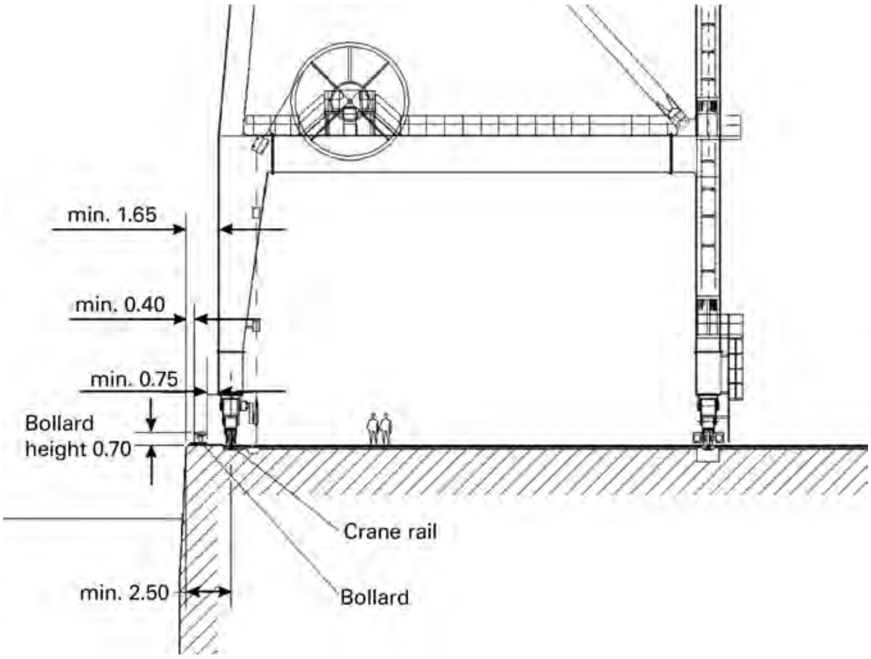

Figure 7.1 Standard cross-section for waterfront structures in seaports (service ducts not illustrated).

7.1.1.3 Railings, rubbing strips and edge protection

Railings are not required at the edges of quays for mooring and cargo-handling operations. However, the edges of such quays should be provided with adequate edge protection according to Section 7.2.13. The edges of quays with public access and those not used for mooring or cargo handling should be provided with railings.

7.1.1.4 Edge bollards

The front edge of an edge bollard must lie 0.15 m behind the front face of the quay wall, because otherwise it is difficult to attach and remove the hawsers of ships moored tight up against the quay wall. The width of the head of a bollard should be taken as 0.50 m.

7.1.1.5 Arrangement of tops of quay walls at container terminals

Owing to the safety requirements and high productivity demands at container terminals, a greater clearance between the front edge of the quay and the axis of the outboard crane rail is recommended, as shown in Figure 7.1. It should be possible to store gangways parallel to the ship between the front edge of the quay and the cranes, also to park service and delivery vehicles and, thus, separate the zones for cargo-handling and ship service traffic. It is accepted that container cranes will require longer jibs.

If containers are automatically transported between crane bridge and storage area, it is essential to separate ship service traffic and container-handling areas for safety reasons. In such cases, the distance of the front edge of the quay from the outboard crane rail should be such that all service vehicle lanes can be accommodated in this strip. Alternatively, one lane can be placed in this strip and another adjacent to the outboard rail beneath the portal of the crane, separated from the container-handling area by a fence.