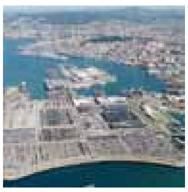
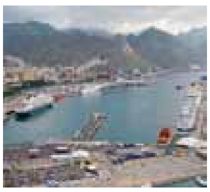
SERIES 2 Inner harbor structures

TRANSLATED VERSION OF THE ORIGINAL SPANISH TEXT

RECOMMENDATIONS FOR MARITIME WORKS

ROM 2.0-11

[Volume I]

Recommendations for the design and construction of Berthing and Mooring Structures

Puertos del Estado

GOBIERNO DE ESPAÑA

MINISTERIO DE FOMENTO

ROM 2.0-11
[Volume I]

Recommendations for the design and construction of Berthing and Mooring Structures

1st Edition
May 2019

EDITOR:
PUERTOS DEL ESTADO

PROJECT DEVELOPMENT:
José Llorca
PUERTOS DEL ESTADO

José Manuel González Herrero
ACCIONA INGENIERÍA

Sergi Ametller
SENER

DESIGN AND COORDINATION:
PUERTOS DEL ESTADO

PRINTER:
V.A. Impresores S.A.

LEGAL DEPOSIT:
M-30714-2015

Foreword

The ROM Program, the Recommendations for Maritime Structures, began 25 years ago and many changes have occurred in the field of Spanish Port Engineering since then; these changes have accompanied the process of modernization wrought by the Sistema Portuario de Interés General (The General Interest Port System) in its organization, management and financing.

During this long time period, numerous methodological challenges have been confronted in the development of the Port, and the steps taken to resolve these deserve to be acknowledged here.

First of all, a probabilistic approach has been progressively applied to the evaluation of the risks associated with the design, construction and subsequent usage of port and harbour structures. The empirical conceptual design of maritime structures, while useful, does not preclude its being framed as part of a regulated procedure to characterize the risk associated with the predominant modes of stoppage and failure in port and harbour structures.

In most cases, we have sufficient information to conceptualize the uncertainty relating to the main variables which determine the actions on each infrastructure, both for those derived from the surrounding physical environment (waves, currents, winds, etc.) and for those related to the particular installations, equipment and rolling stock, which the infrastructure services and/or supports.

We also have at our disposal other equally effective and efficient tools and techniques, designed to resolve each type of probabilistic model at each step in the process of design, calibration and use, for every type of probabilistic model irrespective of how sophisticated those models may be.

Consequently, today there are no longer any impediments, neither from a dearth of available information nor due to scientific and technological deficiencies, to analyzing the reliability and operational capacity of our port and maritime structures using the most complete and advanced probabilistic methods, and this is a theme which echoes throughout these recommendations.

Secondly, the ROM general methodology is fully compliant with those processes which are currently used to plan port infrastructure projects: those criteria used to evaluate each risk are based on the economic relevance of possible stoppages or failures of whichever particular infrastructure element and also on its potential socio-economic impacts.

Accordingly, it is necessary that a clear distinction is made between construction and service/operational periods, associated with their corresponding useful lifetimes, with a view oriented towards the ultimate objective of meeting the expected demand requirements of each period.

The ROM therefore becomes a technological asset, designed to delineate as far as possible the full decision-making process relating to port development, in accordance with the objective of making profitable infrastructure investments, both at the initial planning and design stages as well as during its subsequent maintenance and service periods.

It is worth highlight here, the inherent value of this new ROM for berthing and mooring structures, the with its innovative approach to the consideration of issues relating to port exploitation.

Beginning with this publication, specific connections are made between various civil engineering field related to infrastructure, traditionally of public origin and mainly focused on structural reliability, and other fields of port operations and services, more closely related to the ports business aspects, the vast majority of which are managed by private companies with a license or authorization from the Port Authority.

Both fields should be jointly evaluated in order to achieve an optimum integral economic objective, both for the infrastructure developer as the corresponding operators. It is no longer conceivable to plan the design of berthing and mooring structures (under the charge of a developer such as the Port Authority or a terminal operator) from any perspective other than one with some minimum guaranteed operational capacity levels to the served ships (under the purview of ship owners and shipping companies) or in the installations and equipment expected to provide support (under the purview of stowage companies and the providers of other port services).

Consequently, the indispensable procedures for the evaluation and verification of the structural reliability, must be formulated within a methodology based on port exploitation, in accordance with the ultimate socio-economic objectives that any maritime and harbour structure must now facilitate.

Together with the idea of operational capacity, it is worth mentioning, due to its relevance when planning future port infrastructure projects, inclusion in these new Recommendations of the concept of berthing line capacity, and, by extension, to the rest of the operational subsystems comprising the different port terminals.

The estimation of the maximum volume of traffic of ships, tonnage and passengers that in the most likely conditions a port terminal is capable of serving, provide a reference for the verification of actual service levels as well as for the establishment future targets to be reached.

Capacity is a good measure of the offer of any port infrastructure, which, being based on traffic units, can be directly linked to the demand, measured in the same units, and in this way obtain an estimate of its degree of utilization.

A barometer is therefore available to measure port infrastructure efficiency in the short and long term, linked to the actual traffic loads experienced at the port.

Moreover, the concept of capacity as developed in this document includes a full set of variables relating to efficiency, performance and productivity, whose utilization is extremely useful to the maritime infrastructure developer, whether this is a private company or the corresponding Port Authority, for the optimization of their operations.

With this objective it is desirable to gather information pertaining to those variables, to ensure that they represent a faithful mirror of the best practices for all matters relating to port operations.

I would like to thank all the members of the extended Technical Commission, who have contributed to the development of these Recommendations, and, particularly, those members that, together with me, have throughout the years contributed their efforts to building the technical bases of this document. It would have been impossible to achieve so many methodological advances without them.

No less than the linking of two types of reliability, structural and functional, into a more complete method of risk assessment has been achieved; this paves the way for Port Authorities and/or private companies to offer maritime and harbour infrastructure fully customized to the specific real needs of the actual demand and, at the same time, firmly committed to fulfilling all that our Society expects of them.

José Llorca Ortega

PRESIDENT
PUERTOS DEL ESTADO

Table of Contents

VOLUME I

VOLUME II

CHAPTER IV. DEFINITION OF THE STATES AND CONDITIONS OF THE PROJECT

Figures (Volume I)

CHAPTER II. TYPES AND FUNCTIONS OF THE BERTHING AND MOORING STRUCTURES

CHAPTER III. PLAN AND ELEVATION LAYOUT, DESIGN REQUIREMENTS AND GENERAL PROJECT CRITERIA

Tables (Volume I)

CHAPTER II. TYPES AND FUNCTIONS OF THE BERTHING AND MOORING STRUCTURES

CHAPTER III. PLAN AND ELEVATION LAYOUT, DESIGN REQUIREMENTS AND GENERAL PROJECT CRITERIA

Chapter I
General

Index Chapter I

CHAPTER I. GENERAL

1.1 SCOPE OF APPLICATION

ROM 2.0-11, *Recommendations for the design and construction of Berthing and Mooring Structures. General criteria and project factors*, is applicable to the planning, design, construction, exploitation, maintenance, repair and dismantling of berthing and mooring structures, whatever their use, physical configuration and structural typology may be, as well as whatever the materials used, ships and vessels expected at berth, and equipment and means used for their construction, operation, maintenance, repair and dismantling may be.

Likewise, this Recommendation is complementarily applicable to the rest of the Recommendations of Series I. *Recommendations for the design and construction of coastal defense structures, for the design, construction, exploitation, conservation, repair and maintenance of coastal defense structures,* where the berthing and mooring of ships and vessels may be expected.

1.2 CONTENTS

ROM 2.0-11 is the first ROM Program approved document corresponding to this new Series 2, devoted to berthing and mooring structures, one of the most characteristic and relevant harbour infrastructures, as well as coastal defense structures, which together constitute a fundamental and specific part of port engineering. These infrastructures absorb a significant amount of the total annual investment, both public and private, that takes place in ports around the world, and the safety of ships and vessels during their stay at the port, as well as the safety and efficiency of the port operations, rely on their adequate planning, design, construction and operation.

This first Recommendation of the Series is devoted to the general criteria and to the definition of the factors necessary for the planning, design and construction of berthing and mooring structures; though it is also applicable for the estimation of the capacity of port terminals and to aid in their efficient exploitation. In this sense, this ROM 2.0-11 can be considered as a Recommendation, aimed not only at berthing and mooring structures that are part of the loading and unloading subsystem of ships, but also at the design and operation of all the operational subsystems that comprise a port terminal, considering a port terminal to be the interchanger within the maritime mode or between the terminal and the land transport modes (road, railway, and even river transportation), equipped with the infrastructures, equipment and organization necessary to ensure that the continuity of the flow of goods between the different modes, is realized in an effective, efficient and secure way.

The original idea supporting this ROM 2.0-11 is the impossibility of designing a proper berthing and mooring structure and, consequently, a port terminal, without taking into consideration the ships, conditions, equipment and criteria that are going to be used for its operation, and the operational levels associated with them, in the climatic, physical, morphological and environmental conditions of the site. For this reason, several sections of this ROM 2.0-11 can also be used as Recommendations for the field of port exploitation.

The Recommendation facilitates a practical and seamless adoption of methodological processes based on the evaluation and verification of the appropriate safety and operational levels of the berthing and mooring structures at each service phase, by means of both deterministic-probabilistic formulations and probabilistic ones, as well as on the derived consequences for the economic optimization of the works and operational optimization of the terminals, in keeping with what has been established in the procedure and calculation bases of the design of maritime and harbour structures included in the second generation of Recommendations of the ROM program, from the publication of the ROM 0.0.

This Recommendation also updates certain contents of some of the previously published Recommendations, some of which are now outdated or superseded by the accumulated experience and technological advances of the last 20 years in general knowledge and in particular that of ships, goods handling and passenger boarding and disembarking equipment, as well as in the criteria and practices of port exploitation. It is especially worth mentioning that this ROM 2.0-11 represents a complete updating of the two previous recommendations, ROM 0.2-90, Actions in the design of maritime and harbour structures, and ROM 2.0-08, a pre-definitive and partial version of the actual Recommendation 2.0, both now classified as being “no longer in force”.

ROM 2.0-11 is structured in four chapters, with the following contents:

- ***Chapter I. General***
  This chapter includes general and organizational aspects related to the scope of application of the ROM 2.0-11 and its contents, and also to the developmental process of this Recommendation.

- ***Chapter II. Types and functions of the berthing and mooring structures***
  In this chapter the different types of berthing and mooring structures are defined and classified by their physical and functional configuration as well as by their structural typology, establishing the criteria for the selection of the most suitable physical configuration and structural typology as a function of its intended use, modes of operation and other existing site conditions. This chapter includes the conception and pre-dimensioning of each of the parts and elements that comprise a berthing structure for each structural typology considered.

- ***Chapter III. Plan and elevation layout***
  This Chapter defines the criteria and factors to be taken into account for the plan and elevation layout of berthing and mooring structures, as well as for those areas where the main operational sub-systems of the port terminals (operation area, storage and depot areas and land accesses) are located. As an element of that layout, this chapter includes the dimensioning of the heels and ramps necessary for berthing installations where total or partial rolling loading (roll-on) and unloading (roll-off) of ships takes place.

  The contents of this chapter may be used in reverse order to determine the capacity of mooring lines and the different operational sub-systems constituting port terminals, thereby becoming a very useful tool for both port planning and exploitation, as it allows for the quantification of the impact of different operational factors on the improvement of terminal efficiency and productivity, and consequently, on the infrastructural needs that are required to meet the anticipated demand.

- ***Chapter IV. Definition of the states or conditions of the Project***
  This Chapter develops the criteria and different methods for the verification of the safety and operational capacity of berthing and mooring structures, systematically defining the states or conditions of the Project to be considered in the verification process of those structures at specific sites, depending on the method adopted for the formulation and resolution of the verification equations of the various failure and operational stoppage modes. In this sense, all the project factors influencing the verification process of berthing and mooring structures (geometric parameters, construction material properties, physical environmental properties and agents and their actions) are defined, to facilitate the adoption of both deterministic-probabilistic and probabilistic methods to formulate and resolve the verification equations.

1.3 SYSTEM OF UNITS

The system of units used in these Recommendations corresponds to the mandatory Legal Measuring System in Spain, called the International System of Units (SI).

The International System units most commonly used in this Recommendation are the following:

- Length: in Meters (m).
- Mass: in Kilograms (kg), or its multiple, the Ton (t), where 1 t = 1,000 kg.
- Time: in Seconds (s).
- Temperature: in Degrees Celsius (°C).
- Force: in Newtons (N), or its multiple, the Kilo-Newton (kN), where 1 kN = 1,000 N.
- Frequency: in Hertz (Hz).

The above is established despite the fact that some units outside the International System of Units, with a great tradition in nautical and maritime transport fields (i.e., the knot, GT (Gross Tonnage) units, TRB units, RT units, etc...), will also be used.

The relation between the knot and the derived speed units in the International System (m/s and km/s) is:

- 1 knot = 0.5145 m/s = 1.85 km/h

1.4 RECOMMENDATIONS AND COMPLEMENTARY STANDARDS/ REGULATIONS

For the correct application of this ROM 2.0-11, the following ROM Program Recommendations in force should be complementarily considered, whenever no contradiction arises with the present Recommendations:

- **ROM 0.0**. General procedure and requirements in the Design of Harbor and Maritime Structures.
- **ROM 0.3-91**. Environmental Actions I: Waves. Annex I Wave climate on the Spanish Coast.
- **ROM 4.1-94**. Guidelines for the Design and Construction of Port Pavements.
- **ROM 0.4-95**. Environmental Actions II: Winds.
- **ROM 3.1-99**. Design of the Maritime Configuration of Ports, Approach channels and Harbour basins.
- **ROM 0.5-05**. Geotechnical recommendations for the Design of Maritime and Harbour works.
- **ROM 5.1-05**. Quality of coastal waters in port areas.
- **ROM 1.0-09**. Recommendations for the project Design and Construction of Breakwaters (Part I: Calculation and Project Factors. Climate Agents).

Similarly, the official civil engineering Codes and Standards, both Spanish and European Union, whose scope of application includes berthing and mooring structures, will be taken into account.

1.5 ELABORATION PROCESS OF THE ROM 2.0-11

The ROM 2.0-11. *Recommendations for the design and construction of Berthing and Mooring Structures. General criteria and project factors*, has been composed under the mandate of the Organismo Público Puertos del Estado, a subdivision of the Ministry of Public Works., within an extended Technical Commission specifically created for this purpose and comprised of experts from different institutional, business and academic sectors in the engineering and port operation fields. Agreements within the Technical Commission were adopted by consensus, on the basis of a debate of a Presentation Paper.

Throughout all the developmental phases, the Technical Commission was comprised of the following members:

- ***President of the Commission and ROM Program Director:***
  José Llorca, *Puertos del Estado*

- ***ROM 2.0-11 Presentation Paper Authors:***
  Sergi Ametller, *SENER*
  José Manuel González Herrero, *ACCIONA INGENIERÍA*
  José Llorca, *Puertos del Estado*

- ***Members of the Technical Commission of Experts:***
  Manuel Arana, *Puertos del Estado*
  José María Berenguer, *BERENGUER INGENIEROS*
  Alfredo Carrasco, *Autoridad Portuaria Bahía de Algeciras*
  Juan Carlos Carretero, *Puertos del Estado*
  Beatriz Colunga, *Autoridad Portuaria de Vigo*
  Jesús Corral, *Universidad Politécnica de Cataluña*

Julio de la Cueva, *Autoridad Portuaria de Gijón*
Mario de Miguel, *Autoridad Portuaria de Gijón*
Javier Escartín, *PROINTEC*
Francisco Esteban, *FCC*
Enrique de Faragó, *PROES*
Jorge Flores, *KV CONSULTORES*
Xavier Gesé, *Puertos del Estado*
Gonzalo Gómez Barquín, *Puertos del Estado*
Miguel Ángel Gómez Caldito, *ALATEC*
Marta Gómez Lahoz, *Puertos del Estado*
Gregorio Gómez Pina, *D.G. Costas. Ministerio del Medio Ambiente*
Noelia González Patiño, *DRAGADOS ACS*
Juan Ignacio Grau, *Puertos del Estado*
Gregorio Iglesias, *Universidad de Santiago de Compostela*
José Ramón Iribarren, *SIPORT XXI*
Ana de Lope, *Puertos del Estado*
Luis López González, *SIPORT XXI*
Cristina López Arias, *Autoridad Portuaria de Bilbao*
Miguel Ángel Losada, *Universidad de Granada*
Enrique Maciñeira, *Autoridad Portuaria de Coruña*
María Luisa Magallanes, *EGENOR*
María Jesús Martín Soldevilla, *Centro de Estudios Puertos y Costas*
David Martínez Lorente, *SENER*
Josep Ramón Medina Folgado, *Universidad Politécnica de Valencia*
José María Medina Villaverde, *NAUTILUS INGENIERÍA MARÍTIMA*
Rafael Molina, *TIPSA*
Pablo Molinero, *DRAGADOS ACS*
José Luis Monsó de Prat, *Instituto de Hidrodinámica Aplicada INHA*
Javier Mora, *Autoridad Portuaria de Tenerife*
José Moyano, *Autoridad Portuaria de Gijón*
Vicente Negro, *Universidad Politécnica de Madrid*
Begoña Pérez Gómez, *Puertos del Estado*
Carlos Pérez Quintero, *Puertos de Andalucía*
Eloy Pita Olalla, *INCREA*
Ignacio Rodríguez Sánchez-Arévalo, *Puertos del Estado*
Antonio Marcos Ruiz Vega, *Autoridad Portuaria Bahía de Cádiz*
Olga Sánchez Luzón, *Autoridad Portuaria de Sevilla*
Carlos Sanchidrián, *PROES*
Francisco Javier de los Santos, *Autoridad Portuaria Bahía Algeciras*
Obdulio Serrano, *Puertos del Estado*
Antonio Soriano, *INGENIERÍA DEL SUELO*
Juan Carlos Suñé, *Autoridad Portuaria Bahía de Algeciras*
Javier Uzcanga, *Autoridad Portuaria de Barcelona*
José María Valdés, *EPTISA*
César Vidal, *Universidad de Cantabria*
José Luis Zatarain, *Autoridad Portuaria de Santander*

- ***General Coordinator of the ROM Program:***
  Francisco José González Portal, *Puertos del Estado*

1.6 COMMENTS

Any clarifications, comments, application experiences, suggestions and other contributions to be offered to the present ROM 2.0-11, will be welcomed for consideration in future revision processes.

They may be submitted at any time to the General Coordination of the ROM Program at the following e-mail address: *programarom@puertos.es*

Chapter II
Types and functions of the berthing and mooring structures

Index Chapter II

CHAPTER II. TYPES AND FUNCTIONS OF THE BERTHING AND MOORING STRUCTURES

2.1 GENERAL CLASSIFICATION

The primary function of a berthing and mooring structure is to provide ships with adequate and safe conditions while in port and to allow the necessary operations of loading, stowage, unloading and transfer activities, as well as to facilitate the boarding and disembarking of passengers, vehicles and goods, to permit their transfer between vessels and/or between vessels and or other means of transport.

Berthing and mooring structures can be classified into:

- Docks.
- Jetties.
- Dolphins.
- Buoys, Buoy fields and Mono-buoys.
- Mixed solutions.
- Floating Transfer Stations.

General schemes of the above physical configurations are included in figure 2.1.1.

Docks are defined as those fixed berthing and mooring structures that form a continuous berthing line, which generally exceeds in length the moored vessel, and which are totally or partially connected to the shore by means of fillings along their backside, resulting in the creation of attached rear esplanades.

Jetties are defined as those fixed or floating berthing and mooring structures that form continuous or discontinuous berthing lines, accessible from one or both sides. The main element differing from that of docks is that they do not have adjacent fillings and therefore do not create esplanades. They may or may not be connected to the shore. In the first case, the connection is normally made by an extension of the structure or by gangways or bridges.

In general, the jetties that form discontinuous berthing lines usually consist of mixed solutions, as they may include several berthing dolphins and/or auxiliary platforms, rather than berthing and mooring buoys.

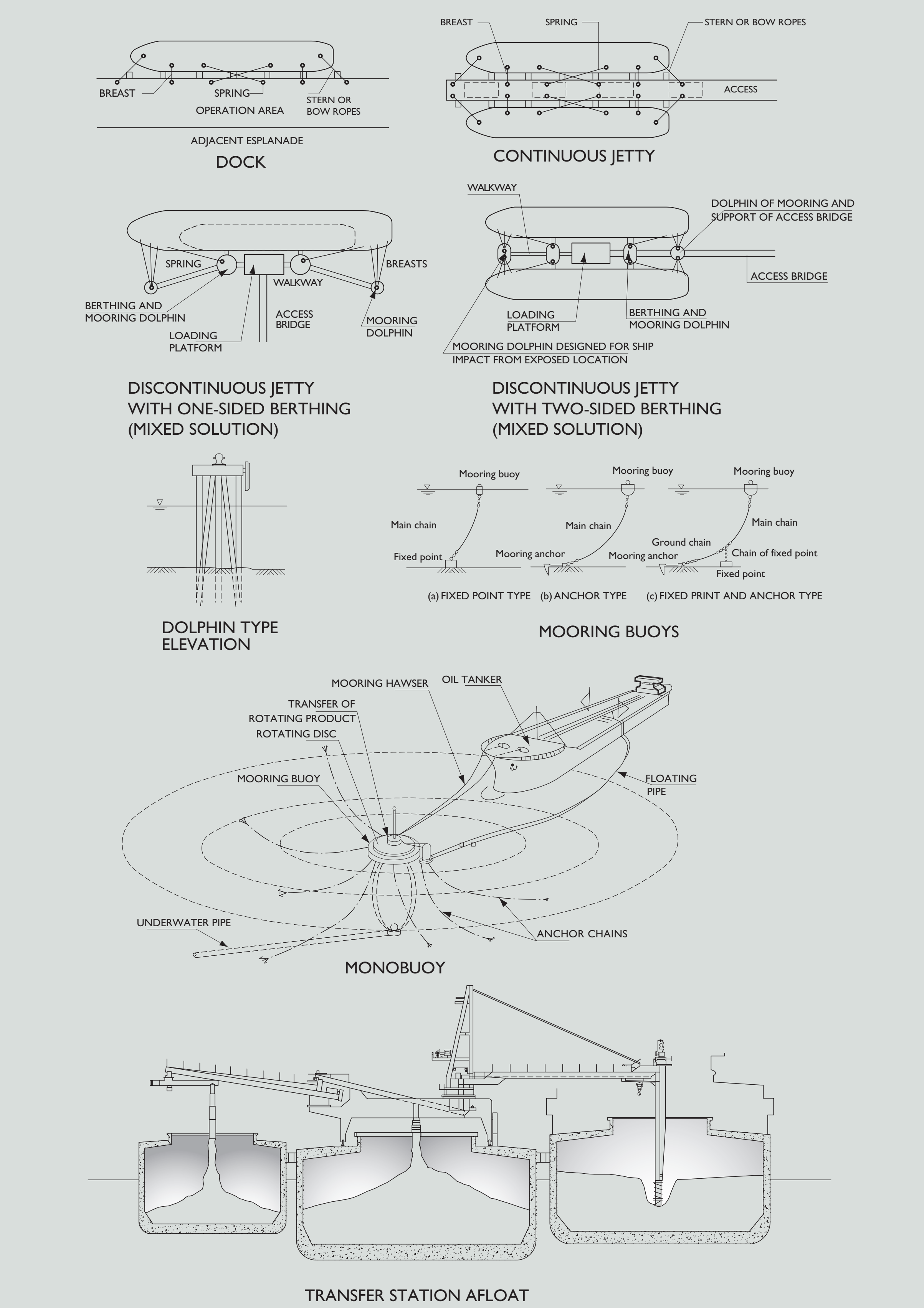
Dolphins are isolated offshore structures used as berthing or mooring points, or as auxiliary points to aid berthing manoeuvres or several of these three functions simultaneously. They may be isolated or be part of discontinuous mixed solution jetties, either in front of or complementing the auxiliary non-berthing platforms, or forming a single berthing and mooring line.

Buoys are floating mooring structures, whose range of motion is restricted by a chain linked to an anchor, a dead weight, or both, assuming a fixed point relative to the sea floor. A mooring buoy is called a mono-buoy when additionally, it allows for the loading and unloading of bulk materials when it is linked to shore by an underwater pipe. In this case the buoy is usually moored by several chains in order to minimize its horizontal motion.

Buoy fields are those layouts allowing for the simultaneous mooring of a vessel to several buoys, in order to restrict the motion of the moored vessel.

Transfer stations consist of a ship silo provided with unloading means, allowing for berthing to both sides of the same vessel, such as feeder ships, barges or ocean liners. This type of installation is a cheap alternative to onshore transfer facilities, since it can be used in poorly sheltered areas.

Figure 2.1.1. ***General classification of the berthing and mooring structures***



2.2 FUNCTIONAL CLASSIFICATION

Berthing and mooring structures allow for the loading and unloading of goods and for the boarding and disembarking of passengers, and are classified according to the type of goods or passengers boarded, disembarked or handled on them, as:

- Commercial use.
- Fishing use.
- Nautical/Sporting use.
- Industrial use (including construction and/or repair of vessels).
- Military use.
- Commercial use berths may be subdivided, depending on the type of goods and the form of presentation of the load into:
- Bulk liquids.
- Bulk solids.
- General goods (Conventional loads, Containers, Ro-Ro, Ferries and Multipurpose).
- Passenger (Cruise ships and Ferries).

2.3 PHYSICAL BERTH LAYOUT SELECTION CRITERIA

The most convenient physical configuration depends mainly on the volume and types of traffic (goods or passengers) to be handled, as well as on the operational requirements of the facility. The factors which need to be taken into consideration include:

- The size, composition and arriving frequency of the ship fleet.
- The surface area needs and the requisite loading and unloading equipment and installations at the berthing line.
- The need for storage areas in close proximity to the berthing line, and equipment and transport installations between these and the esplanades.
- Ground transport connection requirements.

The selection from among the different possible physical configurations meeting the operational requirements and desired capabilities of the berthing line and esplanade, should be made using economic optimization criteria, taking into account both the construction and maintenance costs (to include possible renovation and/or dismantling), as well as those extra costs occasioned by operational stoppages, and the social and environmental risks of the operations. As a general rule, the typology resulting in the lowest overall cost per unit of handled goods (or boarded and disembarked passengers, where applicable), should be selected.

The dock tends to be the berthing configuration that best adapts to all types of traffic because of its great operational flexibility, but, since it typically has higher construction costs than the other configurations, it is not always the most suitable, in economic terms, for specific berths. Excepting those local conditions of significant influence, and after considering all the factors, the physical berthing configurations for each goods type that usually results in the lowest overall cost per handled ton are the following:

2.3.1 Berthing Structures for Commercial Use

2.3.1.1 For Bulk Liquids

Bulk liquids are handled by means of very rigid special installations, where the goods transport system is continuous between the ship and the storage tanks or vice versa. At the same time, the dangerous character of many bulk liquids implies important limitations to their coexistence with other traffic (minimum distances, specific operational procedures, etc.). This favors special infrastructure, away from the most congested areas of the port. These circumstances can be avoided for only a few bulk liquids (wines, oils, some types of fertilizers, water, etc...)

whose lower volatility and the fact that they do not require special storage installations means that they can be handled by discontinuous systems at non-specific berthing structures.

a) Oil and chemical products

The berthing structure physical configurations that tend to be more suitable for the handling of petroleum and bulk chemical liquids (ammonia, sulfuric acid etc..) at specific berths are:

- Mono-buoys [1].
- Buoy fields [2].
- Mixed solutions of discontinuous jetties.

as only a single point is needed for the loading and unloading of the products, which are usually pumped by pipe from a central area of the moored ship, and the storage tanks are not obliged to be near the berthing line.

The selection from among the proposed solutions will depend primarily on local environmental, morphological and operational conditions: wind and wave regimes, depths, availability of towing, etc., some of which may affect the berthing line capacity and the quality of the service. However, when there is a significant amount of traffic the most recommended solution tends to be discontinuous jetties, since they facilitate the concurrent supply of other services to the ship, such as provisioning, waste collection, etc.

b) Liquefied Gases

The most suitable configuration for liquefied gases, both natural gas (LNG) and liquefied oil gases (LPG: propane, butane, ...) is, in most cases, the discontinuous jetty, because the required handling systems consist of articulated arms for loading and unloading, which must be placed between the discharge valves of the ship. Additionally, it is essential, for natural gas, that storage tanks be located close to the berthing line, due to the high cost of cryogenic piping, so the jetty should not be far from the esplanade housing the tanks. This requirement also rules out buoy and buoy field configurations.

c) Others: Oils, Water, ...

Except for extraordinary volumes, these products are usually handled by discontinuous systems (flexible hose with connections to land transport modes) and consequently, mono-buoys and buoy field configurations are incompatible. For specific terminals, the most appropriate configuration will be the discontinuous jetty, although the handling of these goods in multipurpose docks should not be ruled out.

2.3.1.2 For Bulk Solids

In the case of bulk solids, loading and unloading is done through a series of hatches distributed along the vessel, so that it is convenient to employ a continuous berthing line, longer than the length of the ship, regardless of the handling system used.

a) With special installations

Certain bulk solids can be handled by means of special installations, either pneumatic or mechanical, where the transport system of the product is continuous between the ship and the silos, esplanades, or storage sheds, or vice versa. In these cases, where close proximity of the silos, esplanades or sheds to the berthing line is not essential, usually the most suitable physical configuration is the continuous jetty.

(1) The English acronym SBM (Single Buoy Mooring System) is generally used.
(2) The English acronym MBM (Multi Buoy Mooring System) is generally used.

Nevertheless, in some cases, mixed solutions discontinuous jetties can be used, with auxiliary platforms adjacent to the berthing line, with a length similar to that of the ship.

For the loading and unloading elements, ship elements such as pumping systems or, means external to the ship, such as pneumatic loading/unloading arms, etc., may be used. Pipes, conveyor belts, endless screws, etc., may be used as transport elements.

In the case of very powdery bulk (alumina, concrete, etc...) or if annual global traffic volumes supports a significant initial investment to build a specialized terminal with compatible handling systems, then special installations are particularly recommended.

b) Without special installations

In cases where discontinuous loading/unloading systems (ship cranes, fixed and mobile cranes equipped with buckets) are used without direct transfer between the ship and land transport modes, the most recommendable solution will be the dock, as provisional storage areas (covered or uncovered) close to the berthing line are required.

In cases where the products are directly transferred between the ship and land transport modes, the most convenient configuration will generally be the continuous jetty.

2.3.1.3 For General Goods

a) Conventional loading

The most convenient physical configuration for conventional loading is the dock, because loading and unloading should ideally be carried out along the full length of the ship, and although the direct transfer from the ship to other transport modes is possible, it is still convenient to have an esplanade adjacent to the berthing line to provisionally store goods for subsequent land or marine transport, since the distance from the esplanade to the berthing line has a direct effect on its performance.

b) Containers

Similar to conventional loading, the most convenient physical berthing configuration is the dock, because the loading and unloading operations should ideally be performed along the full length of the ship. It is essential in this case to have an esplanade adjacent to the berthing line, because transport to and from the storage area is very costly.

c) Ro-Ro

Loading and unloading operations in Ro-Ro (Roll On/Roll Off) berths are carried out using rolling axle assemblies (wheels, casters, etc.), provided/supplied either by the cargo itself or the berth, and is typically done from one to three precisely defined points of the ship, called gangways, usually located close to or at the stern, bow and/or at the sides. Since ramps are required, these are usually placed at fixed locations (Ro-Ro heels) and because the transit area is not necessarily linked to the berthing line, the physical configuration of the berth that tends to be most convenient is the discontinuous jetty with auxiliary berthing and mooring structures, such as dolphins, etc.

In some cases, however, ships are not entirely Ro-Ro, loading or unloading partly by lifting (Ro-Lo). Whenever such fleets are expected in port, in order to provide the maximum operational flexibility to the berth, it is convenient to adopt the dock configuration.

In some cases, with high volumes of homogeneous rolling loads (e.g. automobiles as goods), the need to achieve increased output in the loading-unloading processes necessitates the reduction of the distance between the berthing line and the provisional storage esplanade. In such cases the dock configuration may also be preferable.

d) Ferries

Ferries are capable of carrying both passengers and automobiles as goods, whose loading and unloading is done primarily using rolling means, although in some cases this can also be partially accomplished by lifting.

For this type of traffic, the criteria previously defined for Ro-Ro traffic are also applicable, complemented with the requirements attendant to passenger boarding and disembarking operations, which are usually carried out at doors located on the side of the ship, using fixed or mobile platforms, which also serve to separate the pedestrians from the rolling traffic. For these reasons it is essential that the berthing length is of the same order as that of the ship, and consequently the most convenient berthing configurations tend to be:

- Continuous jetties.
- Docks.

Choosing between both solutions depends mainly on whether or not the proportion of goods to be handled by lifting is considered to be significant, and the operational flexibility that the berth requires in order to cope with all eventualities. In the latter case (a significant proportion), the most suitable configuration would be the dock.

e) Multipurpose

Multipurpose berthing structures are usually considered when the volume of traffic or other local limitations, either of space availability or operational restrictions, do not allow for the assigning of specific berths to each individual type of goods.

Although it is advisable from an operational point of view that multipurpose berths be considered only for different types of general goods (Ro-Ro, Containers and Conventional), in some cases it is not inconceivable that they also handle bulk solids. Multipurpose berthing works require maximum operational flexibility, and consequently the dock is the most suitable configuration.

2.3.1.4 For Passengers

a) Ferries

The recommendations outlined in 2.3.1.3. d) should be followed for this traffic.

b) Cruise Ships and other Passenger Vessels

These ships only transport passengers, with boarding and disembarking operations routed through the gangways located all along the side of the ship. For these cases, where provisioning operations and the need to control the movements of a ship with a large surface area exposed to wind are also of importance, it is convenient to employ a berthing with a length similar to that of the ship, althought an adjacent esplanade is not strictly needed, as that does not affect the quality of service.

For the above reasons, the most convenient berthing configuration is usually the continuous jetty.

2.3.2 Berthing Structures for Fishing Use

Berthing structures for fishing use should meet both the unloading requirements of fresh fish and its transfer to the market or land transport modes, as well as cater to those ships with more protracted stays in port and their provisioning needs (ice, fuel, etc...). An additional feature of this traffic is that it usually consists of large fleets with few homogeneous characteristics arriving to berth in a concentrated manner in a short space of time.

For these reasons, continuous berthing solutions are the most convenient, either in jetty or dock configurations, though the jetty solution is generally the most suitable for stays, provisioning and unloading of fish, due to lower investment costs, better exploitation of the available space and because it is not essential to the quality of service to have an esplanade adjacent to the mooring line.

However, when the transfer of loads to a fish market or to cold storage is required, the dock is the most convenient solution, as operational criteria mandates the shortest distance between the fish market and the unloading point.

2.3.3 Berthing Structures for Nautical and Sporting use

Berthing structures for nautical and sporting use, yachts and mega yachts, should primarily guarantee the safe stay of ships in the port, while facilitating accessibility to their users. The main consideration is that the physical berthing configuration should allow optimal use of the available space for fleets with few homogenous characteristics.

For these reasons, the most suitable configurations are continuous jetties for berthed vessels or buoy fields in anchorage areas.

2.3.4 Berthing Structures for Industrial Use

In general, berthing structures for specific industrial use and especially those devoted to the construction and repair of ships and other elements (e.g. offshore platforms) should allow maximum operational flexibility, with ample space adjacent to the mooring line for the storage of parts, equipment and products and to allow the development of floating works or their preparation overland. Consequently, the dock is the most suitable configuration for these purposes.

On the other hand, when the function of the berthing structure for industrial use is based on the reception and/or consignment of materials needed for industrial processes or manufactured products, the most convenient configurations will coincide with those established for the equivalent commercial use.

2.3.5 Berthing Structures for Military Use

Berthing structures for military use should usually allow for a wide variety of functions, both for the boarding and disembarking of passengers and vehicles, in addition to those associated with provisioning, munitioning and repairs, all of which must be able to be carried out along the full length of the ship.

For these reasons, continuous berthing configurations such as jetties and docks are generally suitable, although in cases where it is not essential to have an esplanade adjacent to the mooring line, a jetty may be an adequate solution.

Table 2.3.1 summarizes the most typically suitable physical berthing configurations, according to the type of traffic handled, after considering the most relevant criteria for each case.

Table 2.3.1. The usually most convenient physical berth configurations as a function of traffic type

Type of goods			Handling system	Physical berth layout
COMMERCIAL USE	BULK LIQUIDS	Oil & chemical products	Pipe pumping	MONO BUOY
				BUOY FIELDS
				DISCONTINUOUS JETTY
		Liquified gases	Articulated arms for loading + unloading piping	DISCONTINUOUS JETTY
	BULK SOLIDS	With special installation	Continuous systems	CONTINUOUS OR DISCONTINUOUS JETTY
		Without special installation	Discontinuous systems	DOCK
	GENERAL GOODS	Conventional loading	Lifting discontinuous system	DOCK
		Containers	Lifting discontinuous system	DOCK
		Ro-ro	Rolling means	CONTINUOUS JETTY
			Rolling means and lifting	DOCK
		Ferries	Rolling means	DISCONTINUOUS JETTY
			Rolling means and lifting	DOCK
		Multipurpose	Rolling means and lifting	DOCK
	PASSENGERS	Ferries	Rolling means	CONTINUOUS JETTY
			Rolling means and lifting	DOCK
		Cruises and other passenger vessels		CONTINUOUS JETTY
FISHING USING	FISHING		Lifting discontinuous system	CONTINUOUS JETTY
				DOCK
NAUTICAL-SPORTS USE				CONTINUOUS JETTY
INDUSTRIAL USE				DOCK
MILITARY USE				CONTINUOUS JETTY

2.4 DESIGN AND GENERAL DIMENSIONING

2.4.1 Elements of Berthing and Mooring Structures

Berthing and mooring structures can be divided into elements or parts in order to systematize their typological classification and make comparisons between typologies, as well as to facilitate the processes of the dimensioning and verification of their safety, functionality and operational capacity. In general, the following components may be defined:

- **Foundation**: The element of the structure commissioned to transfer the structural loads to the ground.
- **Structure**: The element or set of elements whose fundamental purpose is to preserve its own form, confronting the active forces and transferring them to the foundation.
- **Superstructure**: The element intended, in this case, to connect the top to the whole substructure and to provide a continuous berthing line, as well as to allow the transfer and distribution of the operational forces acting upon the resisting structure. Additionally, it also allows for the correction of construction misalignment and height differences between structural subsets.

- **Fill**: The material placed in the backfill of the structure in order to create an adjacent esplanade.

- **Elements of use and exploitation**: the auxiliary elements whose function is to enable the use and exploitation of a berthing and mooring structure, in accordance with the stated operational requirements. The most important elements are the following:

  - Rail Beams: those structural elements on which restricted mobility handling equipment is borne, whenever they are not directly included in the structure or superstructure of the berthing work.

  - Fenders: flexible elements normally placed on the superstructure, partially or totally absorbing by deformation, the kinetic energy developed during berthing, thus limiting the forces transferred to the structure as well as to the ship's hull. At the same time, the fender system, in combination with the mooring system under tension, can be used to reduce the motion of the berthed ship.

  - Mooring Points: elements placed on the superstructure (bollards, bitts and hooks) allowing for the configuration of the mooring system of the berthed ship, whose main function is to limit the ship's motion produced by environmental agents and any other operational agents while the vessel is berthed, transferring the forces created to the resisting structure

  - Ro-Ro Ramp: a sloping surface, fixed or movable, whose main function is to allow the loading and unloading of ships by rolling means, limiting the slopes between the ship and the pier to allowable values.

  - Galleries/gutters: Open/closed ducts placed in the superstructure to house the technical networks: Water supply, electricity, lighting, firefighting, communication etc...

  - Pavement: The top layer of the surface or load bearing structure laid on the esplanade to support the traffic of vehicles and goods handling equipment.

2.4.2 Classification of Berthing and Mooring Structures According to the Structural Typology of their elements

Figures 2.4.1 to 2.4.9 briefly depict some of the most important typical sections of berthing and mooring structures. They differ from one another mainly by the characteristics of each part into which they are divided and, related to this, by the way they resist stresses, and transmit the created forces to the ground. The berthing and mooring works are classified, depending on the structural typology of their parts or elements, as follows:

A. CLOSED FIXED STRUCTURES

A.1. Gravity Structures
- Blockwork
- Underwater Concrete
- Caissons
- Other types of Gravity Structures: L-shaped, frameworks, etc...

A.2. Diaphragm Wall Structures
- Diaphragm Wall without Upper Platform
- Diaphragm Wall with Upper Platform

A.3. Sheet Pile Cellular Structures

B. OPEN FIXED STRUCTURES

B.1. Piled
B.2. With Columns
B.3. Others

C. FLOATING STRUCTURES
- C.1. Buoys
- C.2. Pontoons or Jetties
- C.3. Caissons
- C.4. Transfer Stations

2.4.2.1 Closed Fixed Structures

The massive or closed fixed structures are those whose structural part forms a continuous vertical or quasi-vertical face to the berthing line from the superstructure to the foundation. Even though they generally do not allow significant water flow through them, sometimes this face may have some holes to reduce the possibility of reflections caused by wave action.

They are divided as follows, depending on the way the structure resists actions and transmits them to the foundation area:

◆ **Gravity structures**

In gravity works, the structure resists those actions caused by use and exploitation loads and, in this case, from the filling of the backfill, where applicable, by its own weight, transmitting them down to the foundation through a rockfill foundation berm, quarry run or other granular material.

Because of its heavy duty operation, the conception of this structure typology requires significant weight and a large foundation surface to allow the generation of greater friction resistance at the structure-foundation contact points to increase the sliding resistance, and to reduce the contact pressures on the ground to increase the sinking resistance and to center the point of application of the resultant forces in order to increase the overturning resistance. Therefore, this structural typology requires foundation soils with a large load bearing capacity at accessible depths. These soils may be either natural, improved or replacement fill.

Gravity works are divided as follows, depending on their structural characteristics:

▪ ***Blockwork***

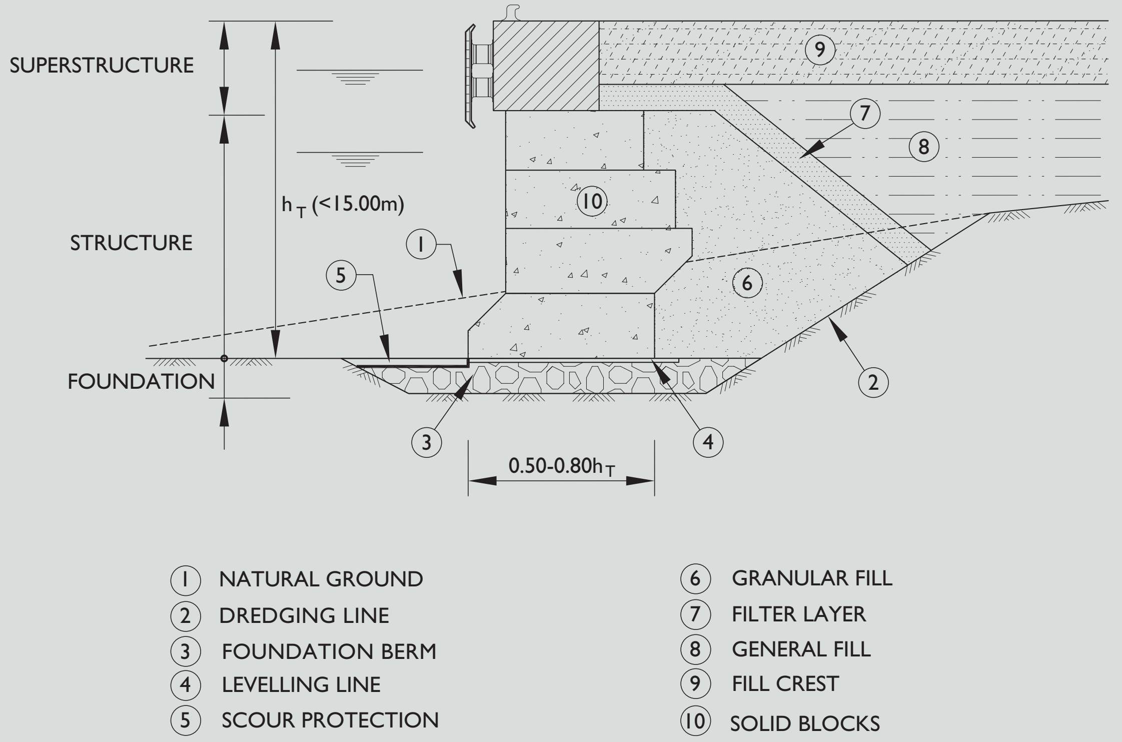
The supporting structure is made of blocks of stony materials or precast concrete. The blocks may be either solid or hollow, to be later filled with granular material or concrete. They are generally parallelepiped, but are sometimes built with sloped or chamfered interior and exterior faces, in order to reduce stresses or to center the resultant forces. Because of the requirements of the construction method, the weight of the precast blocks is usually the maximum allowed by the available means for on-site installation, but weights between 150 and 2,000 kN are typical.

The load bearing capacity is based on the mobilized friction between the blocks, which may or may not be linked to each other.

A type section of this berthing structure is included in figure 2.4.1. Even though a wide variety of sectional geometry is possible, it generally assumes rectangular or trapezoidal shapes where the base is between 50 to 80% of the height. For intermediate blocks resting on lower ones, the base/height ratio is usually around 50% to enhance stability. The width at the crown depends on the superstructure's height and the auxiliary elements to be placed on it; the most common values range between 1 and 4 m.

The berthing face is usually vertical, although the presence of the fenders can extend the wall base between 0.5 and 1.0 m, slightly inclining the face or protruding the lower blocks. This layout improves the overturning and sinking resistance, by centering the point of application of the resultant forces on the base of the foundation.

Figure 2.4.1. ***Blocks berthing structure. Type section***



When a fill is included, the backfill face may be vertical, sloped or staggered. The reduced width terraces utilize the weight of the backfill on the steps, thereby reducing the volume of concrete. Sometimes, and principally for constructive reasons, the block of the second lower row is the same as that of the base placed back to front, as in figure 2.4.1, which helps take advantage of the backfill weight and the centering of the resultant force. This structural typology is usually more suitable to heights less than 15 m, measured from crown to foundation, or to short length works because it requires a lower initial investment.

- ***Underwater Concrete***

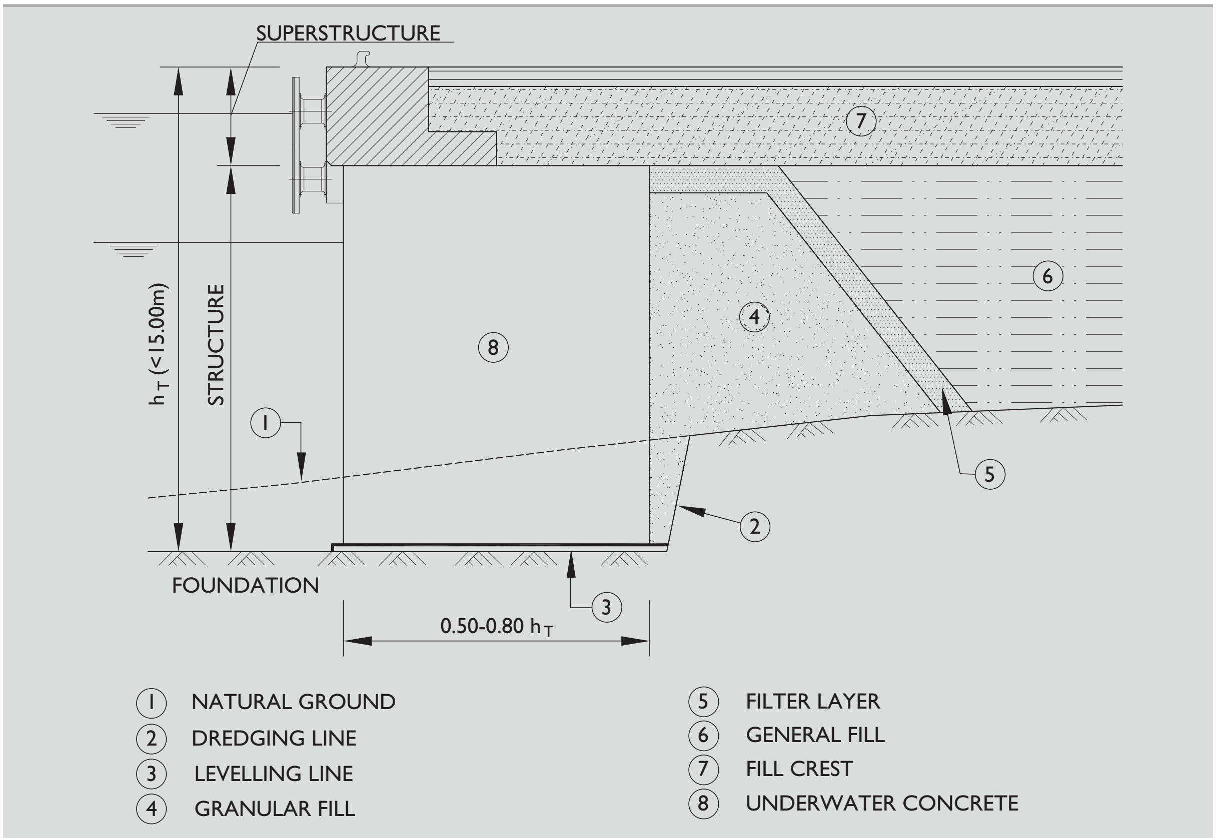
The construction of this type of dock is carried out almost entirely underwater, using tremie concrete methods, consisting of pumping concrete rich in cement with the end of the pipe kept immersed in concrete below the water level, in order to avoid as much as possible, the dilution of the concrete and fine aggregate during expansion.

This system was initially used in low height docks founded on tough terrain, but nowadays is also used on soils with poor load bearing capacity, on rockfill berms. This dock type is suitable when there is no room to precast blocks or to accommodate the means for their placement.

The difficulties posed by the formwork, usually necessitates the use of rectangular sections with small protrusions or steps (see figure 2.4.2). Concreting can be done in horizontal layers at least 1. 50 m high, or in full sections. In the first case, the formwork is bound to the side faces of each layer, resting on the base or on the layer below. Additionally, concrete blocks are often used as permanent formwork. These blocks have recesses to allow them to be filled with concrete, enabling them to form stronger bonds with the in situ solid concrete. The horizontal joints are made with keys to avoid sliding between layers. When concreting full sections, using modules, the formwork is U-shaped in plan, connecting each laying to the preceding module leaving a vertical key.

As in concrete blockwork structures, this structural typology is usually suitable to heights (from crown to foundation) of less than 15 m or to short-length works due to its lower initial investment costs. The base width/total height ratio also ranges between 0.50 and 0.80 m.

Figure 2.4.2. Submerged concrete dock. Type section



- ***Caissons***

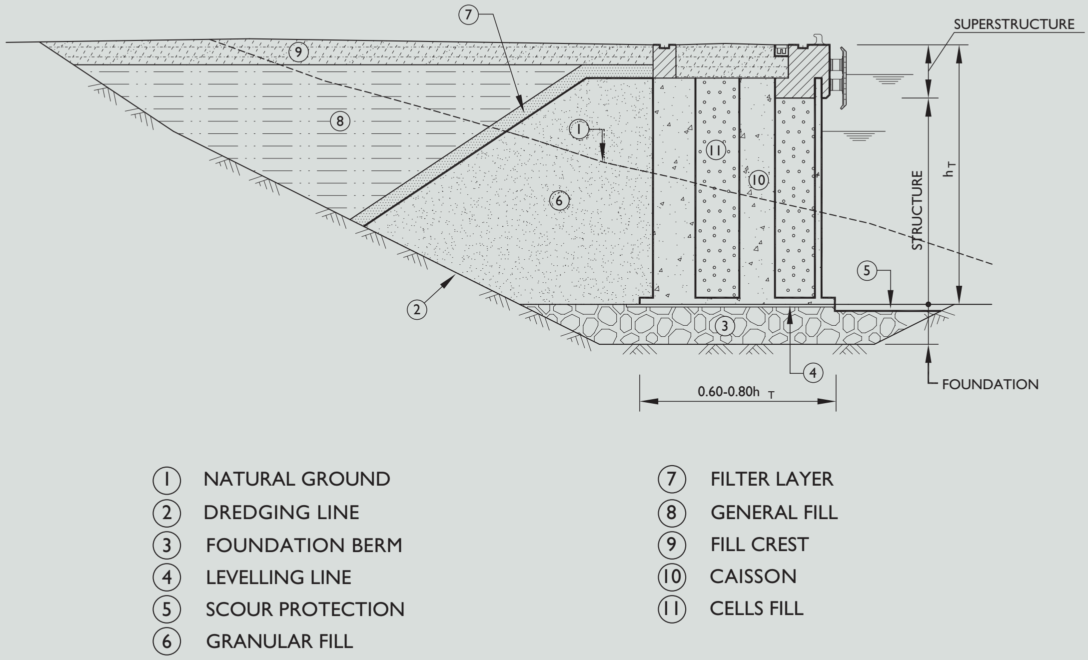
The supporting structure consists of prefabricated caissons, usually in reinforced concrete (or alternatively, prestressed concrete, metal caissons or mixed), followed by cells, constructed overland or in floating docks and subsequently towed, anchored and filled with water, granular material or lean concrete.

Floating caissons may have different shapes and sizes, both in plan and elevation, depending on conditions and the available local construction options. Rectangular plans and elevations are the most common patterns. In general, they are composed of a foundation slab, a hollow shaft with rectangular, square or circular cells all along its height, and footings or foundation slab areas cantilevered from the shaft.

A typical section of this berthing structure is included in figure 2.4.3.

The caisson shaft width or beam is mainly determined by the loading capacity and the required stability of the berthing work, but also by the naval stability of the caisson, or by operational conditions, as in the case of needing to incorporate the rear leg of a crane into the caisson. It is possible to reduce ground contact pressures by increasing the width or by filling the rear cells close to the backfill. For reasons of stability the dock width usually ranges from between 60% and 80% of the height, and less than 25 m, although there are caisson yards capable of constructing caissons with a beam greater than 32 m. The shaft's height corresponding to the design draught may be determined by conditions and construction possibilities and naval stability, taking into account a crown level affording suitable work conditions both for filling the cells and for superstructure construction. Heights up to 38 m have been reached in Spain. The caisson length also depends principally on the prevailing conditions and the available constructionoptions. The most typical dimensions range between 25 and 40 m. Lengths up to 66 m have been reached in Spain.

Figure 2.4.3. ***Caissons berthing structure. Type section***



Other typical section dimensions are:

- Foundation slab and footing thickness: 0.40-1.00 m.
- Cantilever footing: 0.50-1.50 m.
- Circular cell diameter: 2.50-3.50 m.
- Rectangular cell span: 3.50-4.50 m.
- Thickness of outer walls of circular cells: 0.20-0.40 m.
- Thickness of outer walls of rectangular cells: 0.25-0.50 m.
- Thickness of inner walls of circular cells at tangential point: 0.15-0.25 m.
- Thickness of inner walls of rectangular cells: 0.20-0.30 m.

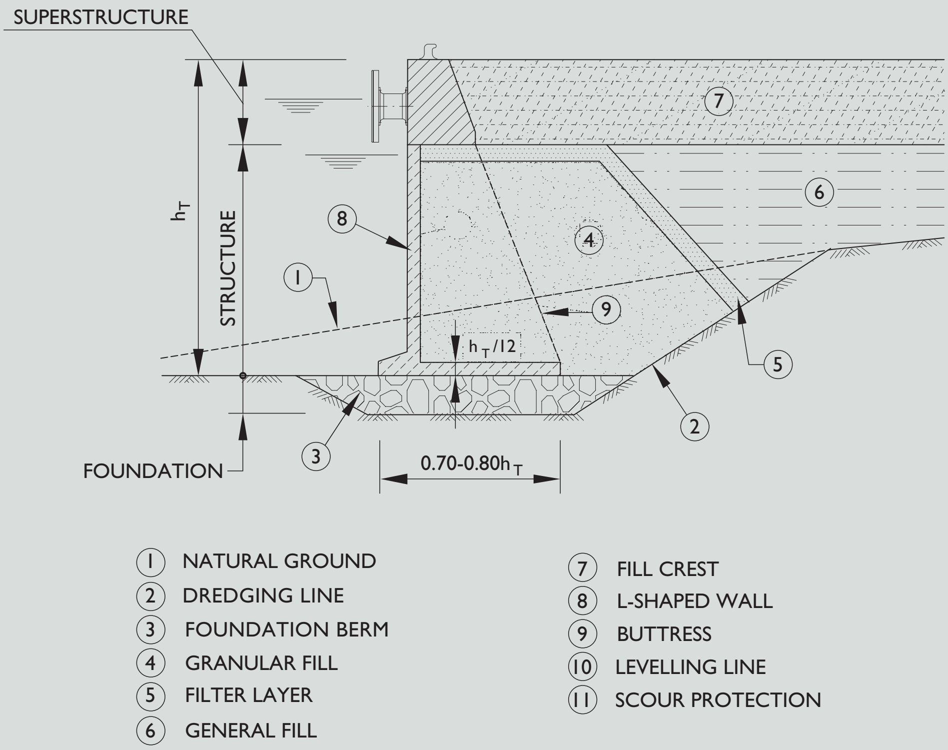
This structural typology has a wide range of application, and is especially indicated for draughts ranging from 10 m up to draughts much higher than 20 m.

- ***Other types***

This typology includes those caissons partly without foundation slabs, although they are not widely used. These improve the sliding resistance between the structure-foundation contact points, although they produce higher pressures on the foundation soil. In such cases they can be considered to be enclosures. For soils with low load bearing capacity at upper layers with moderate thickness above solid ground, this type of caisson may be sunk, thus avoiding the need for foundation berms and reducing the amount of dredging required (Indian caissons).

There are other types of gravity structures, not very common in Spain, where the load bearing structure is formed by L-shaped elements, frames and other constructive configurations. The resisting mechanism of L-shaped structures is similar to that of classic retaining walls. Their operation and general main dimensions are comparable to those of caisson works, but without rear walls. In such cases it is essential to assure maintenance of the base slab backfill for the stability of the whole structure. L-shaped elements are either dry-built in-situ or more commonly, precast, in short heights up to 7 m. Nevertheless, heights have been reached of up to 20 m with buttresses. Their lengths range from 3 to 12 m, depending on the local availability of construction equipment. A typical section of this berthing structure is depicted in figure 2.4.4.

Figure 2.4.4. ***Berthing structure in L-shaped elements. Type section***



◆ Diaphragm walls

In diaphragm wall structures, the structure transmits horizontal forces coming from the ground and all or part of the use and exploitation loads by means of its embedment or ground foundation, support and the anchoring set up in the backfill, in order to maintain the balance between the forces generated by the ground foundation and by the fill on both sides of the diaphragm wall, combined with the action (or reaction) of the anchorages.

The load bearing capacity of the structure is based mainly on its capacity to withstand the flexing and shearing forces generated along its height.

This typology is especially suitable to sandy and silty soils and may be used for soft cohesive soils, but is unsuitable for ground with hard rock which prevents the piles from being driven into it or in sandy ground with pebbles which make it difficult to reach the necessary embedding depth.

Depending on the inclusion of structural elements added to the diaphragm wall and directly transferring part of the use and exploitation loads to the ground foundation, diaphragm wall structures are divided into:

- ***Diaphragm walls without upper unloading platform***

  This supporting structure consists of a single vertical or slightly sloped diaphragm wall and one or several anchorages which help to increase its rigidity and augment its load bearing capacity.

  The diaphragm may be composed of driven metal sheet piles or in-situ reinforced concrete.

  Steel sheet pile diaphragms are usually made of simple "U" or "Z" profiles or composed of higher inertia elements (rolled H sections, metal pipes, ...) with sheet piles inserted in between. Anchorage action is usually transferred to a tie beam, normally of steel, to transfer the anchoring force to the individual sheet piles.

  The anchorage system is generally a passive one, usually composed of steel bars or cables securely attached to the diaphragm, and a rear anchorage structure consisting either of a shorter diaphragm, a concrete dead weight or a vertical, horizontal, or sloped plate. The dead weight or plate may be simply supported on the ground or cemented on piles to provide greater reaction capacity.

  A width equivalent to almost 150% of the sheet pile ground clearance is needed to develop the passive anchorage. This should be located above mean sea level and dimensioned to avoid bending due to soil settlement.

  Nevertheless, an active anchorage system is also possible. In this case it is normally composed of prestressed cables, steel bars or micropiles fitted into bore-holes and linked at the base to the seabed using bulbs injected with mortar or cement grout.

  The superstructure is made of an overhead concrete girder capable of distributing the horizontal use and exploitation actions, acting in the crown along a certain length of the structure. It does not usually have the capacity to withstand significant vertical actions, unless it includes elements to transfer superstructure loads to the sheet piles.

  This structural typology is generally suitable for ground clearances around 10 m, but simple sheet piles can reach up to 20 m and composite sheet piles up to 30 m.

  Reinforced concrete sheet pile diaphragms are usually made in rectangular or T-shaped sections, generally between 0.60 and 1.20 m thick. Tangent pile diaphragms may also be built. The anchorage system is usually an active one, because of its low deformability, but it may also be a passive one. It is similar to that described for sheet pile diaphragms.

  In many cases the crown of the concrete diaphragm has superstructure functions, even having the capacity to support significant vertical loads such as those produced by goods handling equipment.

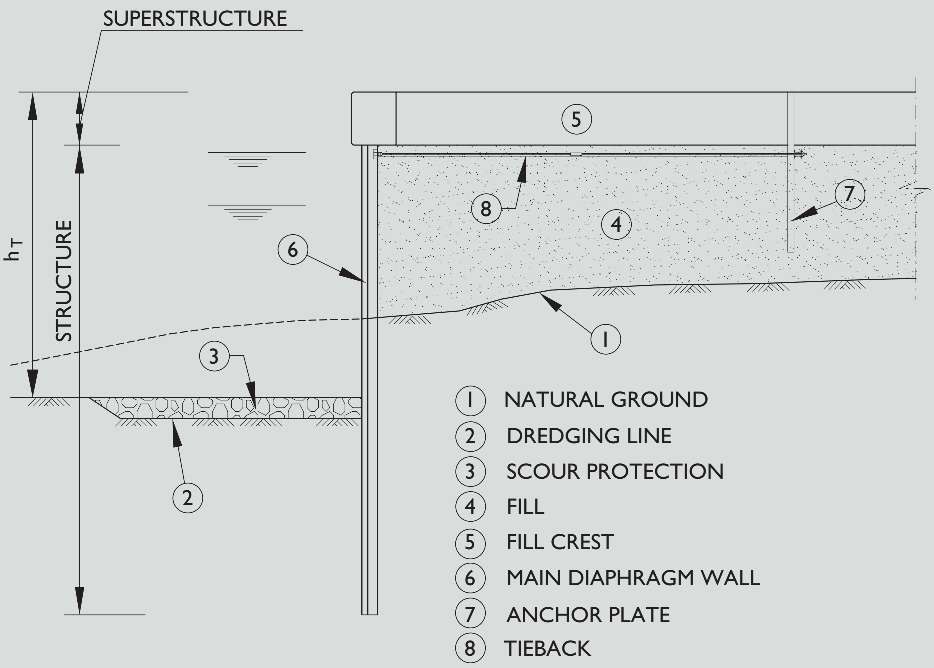
  This type of diaphragm may be precast (close driven piles, groove profiles,) or concreted in-situ by keeping the initial ground excavation stable using thixotropic products such as bentonite, and subsequent concreting, which must be done on dry ground, either natural or a temporary fill. Great care must be taken to achieve proper coverage along the full height of the diaphragm wall, particularly in soft soils. For this last constructive methodology, the soil must not be very permeable nor contain significant voids or cavities.

  Depending on the thickness of the resisting section adopted, this typology allows ground clearances higher than 20 m. A typical section of this berthing structure typology is depicted in figure 2.4.5.

- ***Diaphragm walls with upper unloading platform***

  This supporting structure is identical to that corresponding to those without upper platforms, but with the addition, on the top of the diaphragm and over the outer water level, of a reinforced concrete platform in the backfill, supported on the diaphragm itself and on several vertical and/or sloped piles.

Figure 2.4.5. ***Diaphragm wall berthing structure without upper unloading platform. Type section***



The main function of this platform is to reduce backfill pressures and to directly transfer the use and exploitation loads to the foundation without increasing the horizontal forces on the diaphragm. Consequently, it may be convenient to use this typology for diaphragms with a high ground clearance and/or for very significant vertical use and exploitation loads, or when the locally available sheet pile profiles are small and therefore unable to withstand high flexing forces, as well as when there is insufficient available width to develop the forces. For that purpose, a platform width reference may be enough to cut the backfill ground failure plane.

The horizontal use and exploitation forces are transferred to the ground by the diaphragm, piles and anchorages where appropriate.

This berthing structure typology, not yet used in Spain, is best suited for ground clearances ranging between 15 to 20 m. A typical section of this berthing structure typology is depicted in figure 2.4.6.

- **Sheet Pile Cellular Structures**

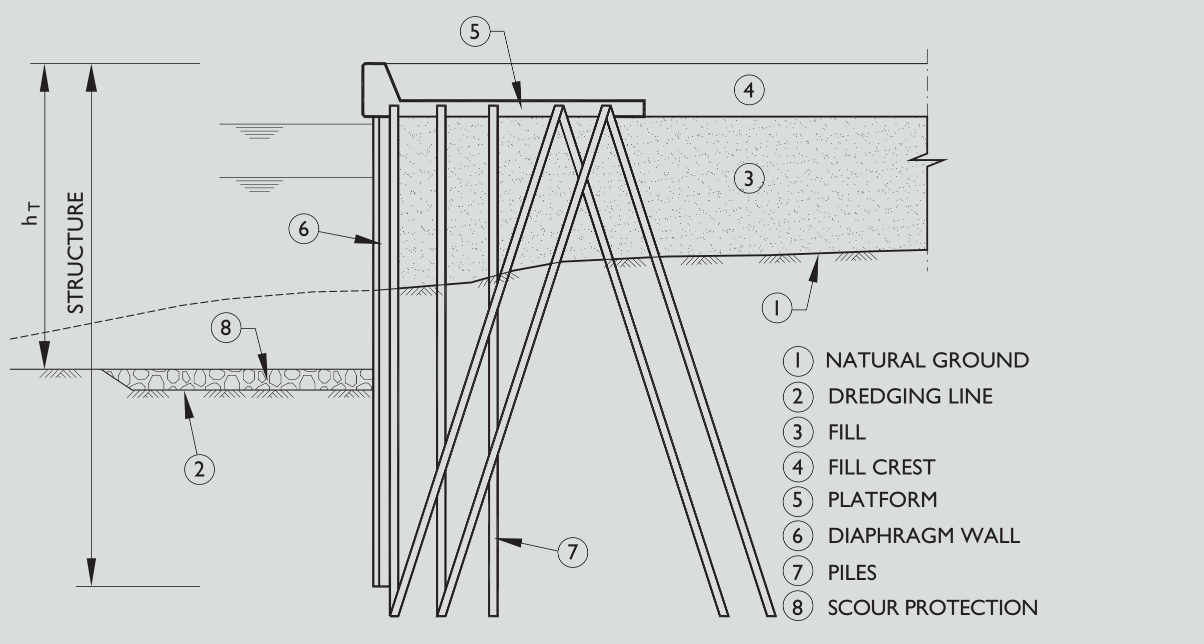
This supporting structure consists of a row of metal sheet pile cells, linked together, which can be constructed in various geometric configurations (see figure 2.4.7):

- Circular shaped cells, creating independent cells which are then joined together at the front (and, eventually at the rear by means of circular arcs built from flat sheet piling.
- Cells with diaphragms, with flat transverse walls and curved front faces.
- Two parallel sheet pile rows, braced together at different levels and with one or more cells specially braced to stiffen the structure.
- Other variants: four-leafed clovers tied along two axes, elliptical shapes, variable curved forms …

The above-mentioned cells are later filled with granular material.

The load bearing capacity of the structure is provided mainly by the inner fill and the mutual interaction between the sheet pile cells and the natural ground.

Figure 2.4.6 ***Diaphragm wall berthing structure with upper unloading platform. Type section***



In general circular-shaped cells are the most commonly used. The advantage of this structural typology with respect to the other sheet pile forms is that it consists of individually freestanding cells and that the cells can be independently filled. For this reason, they are most suitable for rocky terrain. Diaphragm cells must be filled simultaneously inside an admissible interval and require a greater number of sheet-piles. The potential advantage of this configuration lies in lower forces on the sheet piles. The other variants are usually used for great depths.

A typical section of this berthing structure is depicted in figure 2.4.7.

For clearances less than 15 m, the diameter of the circular shaped cells normally ranges between 10 and 20 m, with minimum separation distances between 1.00 and 2.00 m. Metal sheet piles of 40 or 50 cm wide and 9 to 13 mm thick are used in these cases, with the radius of the connecting arcs ranging between 3.00 and 5.00 m respectively.

The superstructure rests not only on the sheet piles but also on the inner fill, so checks must be made to verify that no significant settling of the fill has occurred. If so, the structure must be founded by driving piles through the fill.

This structural typology is most suitable for heights (from crown to lower foundations) less than 15 m. The above, cells have been built with heights exceeding 20 m.

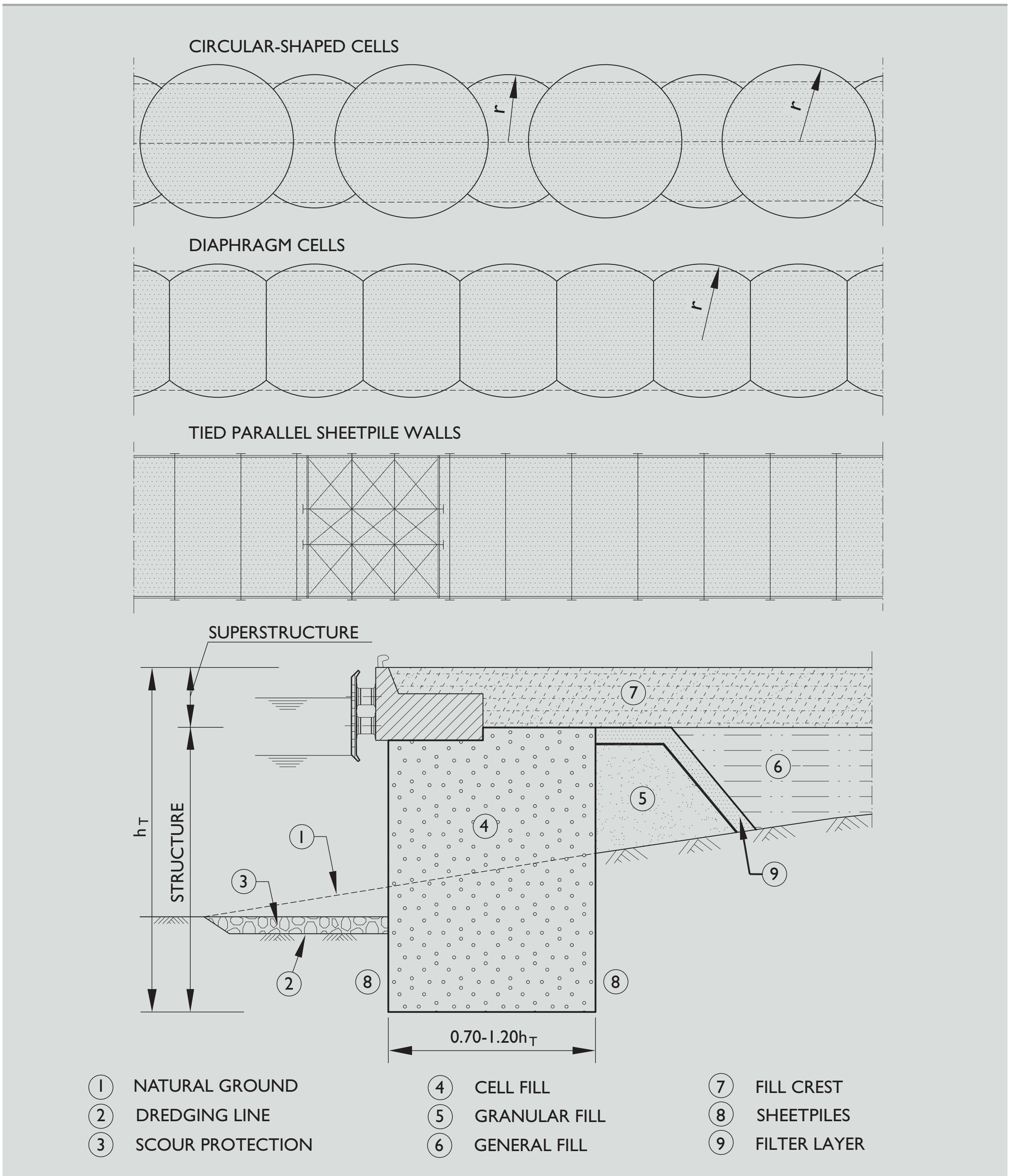
2.4.2.2 *Open Fixed Structures*

Open fixed structures are those whose structure is composed of a platform supported on piles or columns, with a non-continuous face (which forms the berthing line), thus allowing cross water flow.

When an adjacent fill is present, the platform is an extension of the crest of the fill along its slope up to the berthing line.

In this typology the structure may be considered as integrating the elements of the superstructure itself. Depending on the way the structure resists the actions and transfers them to the foundation area they are divided into:

Figure 2.4.7. ***Sheet pile cells berthing structure. Type section***



- **Piled Structures**

The resistant structure is made of a platform supported on vertical and/or sloped piles. In the presence of an adjacent fill, it may be supplemented by an earth retaining structure linked to the platform at the crest of the slope. To reinforce the resistant capacity of the structure against horizontal forces, there may be anchorages attached to the platform.

The structure transfers all of the use and exploitation forces acting on the platform to the ground foundation by means of the piles. If all the piles are vertical, they are under axial, shearing and flexing forces. In the presence of sloped piles or vertical and sloped ones, they are mainly under axial forces. Load bearing piles should be embedded into the ground at the necessary depth to safely transfer loads from the piles to the ground.

Piles may be made of cast "in situ" concrete or precast and subsequently driven: diaphragm wall units, metal profiles (pipes or H-shaped profiles), pre-stressed concrete or mixed (pipes filled with concrete). They can reach depths of up to 50 m. Plan dimensions and thus piles structural capacity should be in accordance with the ground resistance and the depth reached. The diameter of "in situ" concrete piles normally ranges between 0.6 and 2 m. A rectangular plan distribution net is normally used. Pile separation depends on the magnitude and direction of the operation forces acting on the platform seeking a balancing solution between the platform load bearing capacity and the piles. The separation between pile axes is usually less than 8 m. Their length depends on the soil type, as they need to reach a depth level which allows them to resist the transferred vertical forces from the tip and/or shaft and, where applicable, to mobilize the necessary horizontal reactions to partially or totally withstand the horizontal forces.

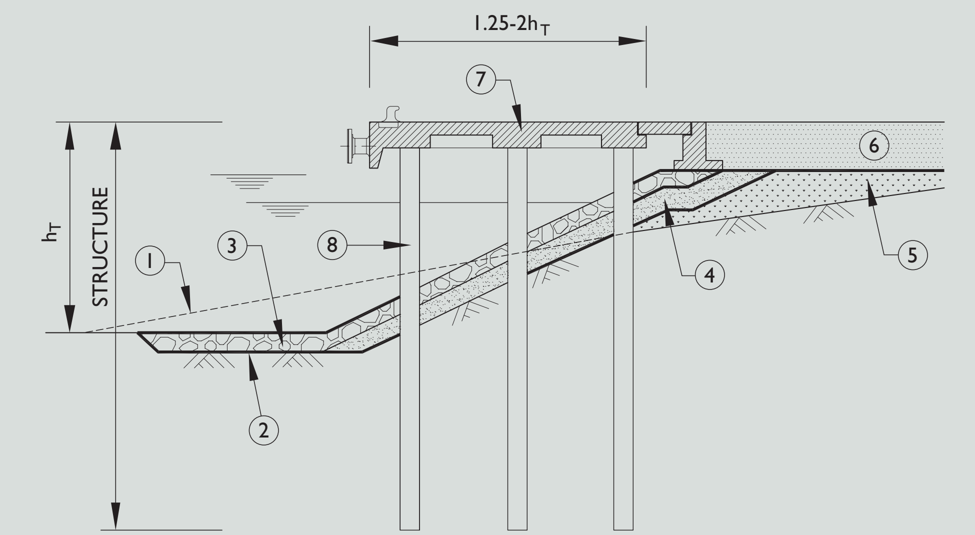
The platform is usually constructed of reinforced concrete and may be composed of precast and "in situ" concrete elements.

The fill retainer on the crest of the slope can be a gravity solution with precast or "in situ" concrete walls normally founded above the mean sea level or alternatively a sheet pile diaphragm solution can be used.

The possible differential settlement of the flexible backfill and the rigid platform is especially important. These settlements may hinder dock exploitation if it becomes necessary to heighten the backfill pavement. It is also possible to break the Piles by erroneous berthing manoeuvres, mainly from ship's bulbs, a circumstance to be borne in mind in the maintenance of this type of structure.

A type section of this typology is included in figure 2.4.8.

Figure 2.4.8. Piled berthing structure. Type section



This berthing and mooring structure typology may be built for any draught and virtually any type of soil. The difficulties that may arise when traversing some hard soil layers or embedding in rock may be solved by using perforated piles and concreting “in situ”.

Nevertheless, its employment is mandatory for soils where the load bearing layer is too deep with respect to the designed draught.

In any case, when the load bearing layer is very deep, piled structures may become overly flexible, generating movements that could be incompatible with required operating conditions. In such cases and also when horizontal loads are so high as to preclude reasonable structural dimensioning, it is advisable to use mixed solutions, such as disengaging the platform from the berthing and mooring points using dolphins or stiffening the structure using trestles of sloped piles.

The engineer should also take into account “negative friction” cases, where the backfill settlement is higher than that of the pile head. These cases imply higher pile compression forces than those caused by the loads transferred from the structure.

- **Made of columns**

This resistant structure differs from the piled ones in that the platform is supported on columns which are generally composed of gravity structures.

Vertical and horizontal use and exploitation loads are resisted and transferred to the foundation through the columns, by means of their own self-weight and the sliding resistance at the contact points between the structure and the foundation. In general, the platform is not dimensioned to withstand the huge horizontal forces directly applied to the columns from berthing and mooring.

The columns will conform to the characteristics corresponding to those of the gravity structures included in section 2.4.2.1 of this Recommendation. Columns should be adequately spaced according to the required load bearing resistance of the attached deck and it is recommended to place the soffit of the deck girders above sea level for all tidal conditions. On the other hand, in commercial harbors the column separation should be less than the maximum allowable between fenders or mooring points.

Since columns are generally gravity structures, this structural typology requires foundation soils of high load bearing capacity at accessible depths. These soils may be either natural or enhanced or replacement fills. Isostatic deck bearings are recommended on the columns, to better absorb differential settlements between them.

When the width of the structure of a dock of columns allows for the development of the slope under the straight or vaulted decks, the dock is of the so-called “skylight” type.

- **Others**

Another type of open fixed structure is that of metal structures braced horizontally by means of truss elements with soffits supported on driven piles. These are the so-called “space trusses” or “jackets”. They are commonly used in offshore platforms for research or oil extraction but also in berthing and mooring structures.

2.4.2.3 Floating Structures

Floating structures are those whose structural element is floating, with the possibility of vertical and/or horizontal motions. The positioning control systems are materialized through mooring mechanisms, anchored to natural ground or to fixed structures and selected based on the necessary operational requirements and local conditions, both environmental (waves, tides, currents, wind, ...) as well as on the location and available space. Depending on the characteristics of the resistant structure, berthing and mooring floating structures are divided into:

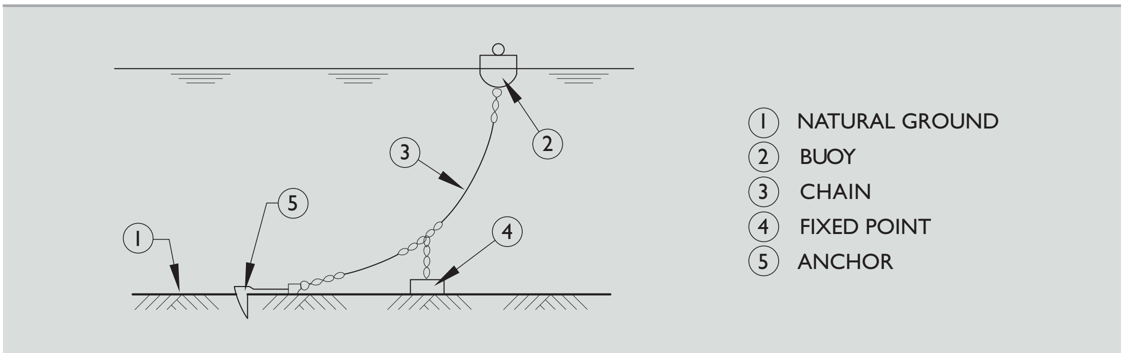
◆ Buoys

Buoys are mooring structures. They consist of a generally cylindrical solid structure of steel, fiberglass or plastic material, attached to a mooring system comprised of one or more mooring lines made of flexible elements such as chains, cables, elastic bands, etc., more or less pretensioned and fixed to the seabed by means of an anchor, dead weight or pile, depending on the magnitude of the tensions at the anchorage point.

Buoys withstand horizontal and vertical mooring actions by transmitting these to the mooring and anchoring system. Buoys should possess enough reserve buoyancy to remain afloat at all times even when the maximum pull is acting on the mooring line.

A typical section of this typology is included in Figure 2.4.9.

Figure 2.4.9. ***Floating berthing structure. Buoy. Type section***



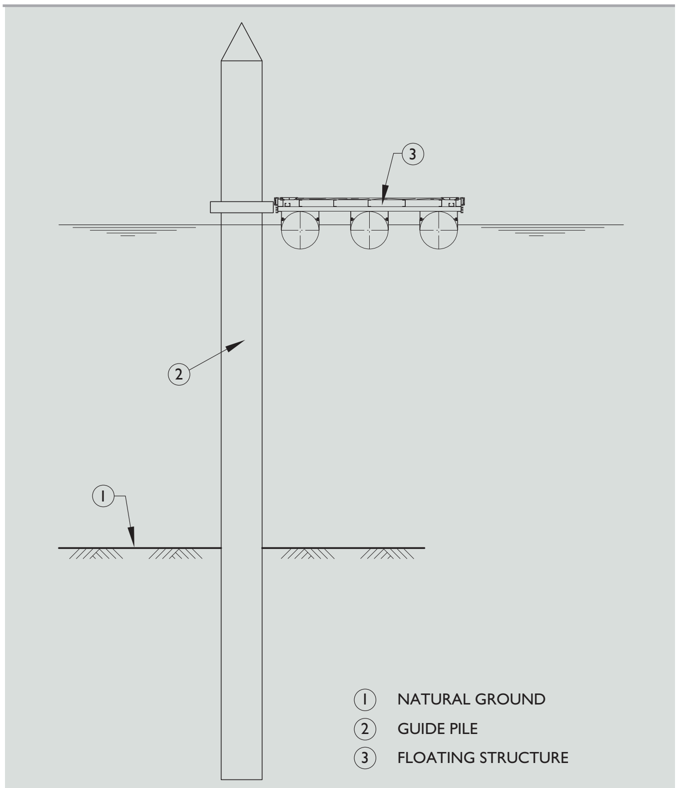
◆ Pontoons or Jetties

Pontoons are berthing and mooring structures for use and exploitation loads related to berthing and of sport, leisure or fishing ships, auxiliary platforms for loading and unloading vehicles or ro-ro traffic, etc.

They are made up of structures with very variable sections, generally in steel or aluminum, though fiberglass, plastic or concrete may also be used. Mooring is usually achieved by guiding from fixed structures such as piles or dolphins, because operational requirements demand the maximum possible limitation of motion. In some cases, the mooring device is replaced by mooring lines composed of chains, cables, etc.

In general, this type of structure supports horizontal use and operation forces by transferring them to

Figure 2.4.10. ***Floating berthing structure. Jetty. Type section***



the guiding elements and/or to the mooring systems. Vertical loads are resisted by the structure itself, whose naval stability must be verified.

- **Caissons**

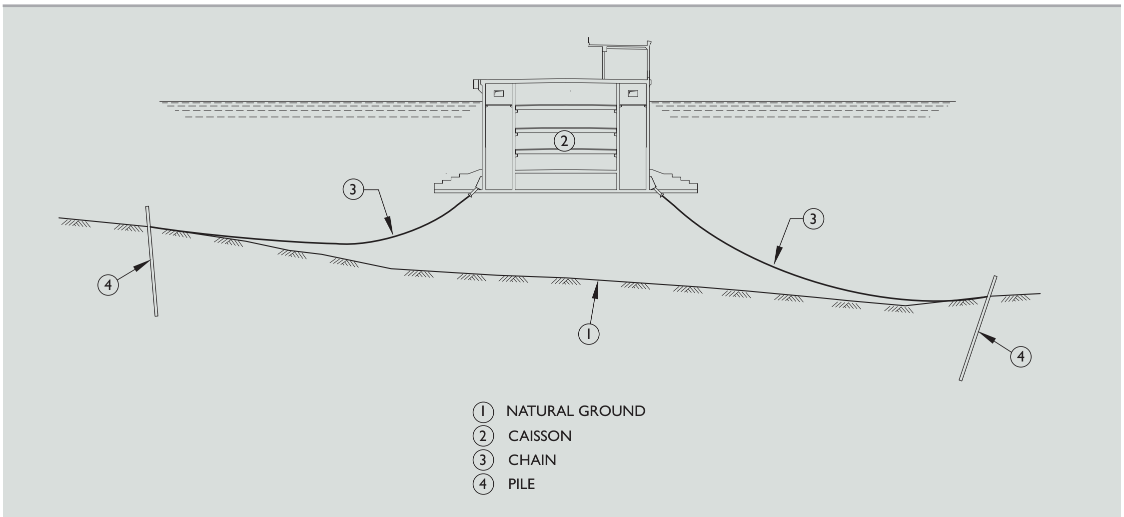
At present there is sufficient experience in the construction of berthing and mooring structures to manage significant horizontal use and exploitation loads, using steel, reinforced or prestressed concrete caissons. In addition to this main function, they fulfill some others like vehicle parking or storage of light craft.

The limitation of motion demanded in these structures by operational requirements can be achieved by means of mooring systems composed of several mooring lines formed by more or less prestressed flexible elements, anchored to the seabed, or by mixed mooring systems and ground support using special articulated mechanisms.

This type of structure resists horizontal actions by its dynamic interaction with the environment, according to its dimensions and by transferring the forces to the support and mooring system. The stability of this system must also be checked and validated in its particular location.

An example of this type of structure is the La Condamine floating dock in Monaco, depicted in figure 2.4.11.

Figure 2.4.11. ***Example of a floating caissons berthing and mooring structure. Breakwater-dock of La Condamine (Monaco)***



- **Transfer Stations**

These are vessels or other types of floating structures, in concrete or steel, permanently situated in a specific location, performing the functions of docking, storage and the transfer of goods, generally bulk solids and liquids

2.5 STRUCTURAL TYPOLOGY SELECTION CRITERIA

The selection of the most convenient structural typology for a berthing and mooring structure requires an analysis of the advantages and disadvantages and therefore the feasibility of each one facing the use and explotitation requirements and the geotechnical, morphological, climatic, seismic, environmental and construction conditioning factors as well as the locally available conservation and maintenance materials.

As a general criterion, the most economical structural typology should be selected from among the ones satisfying the use and exploitation requirements, while meeting the environmental and safety conditions, evaluating its suitability to the possible evolution of the use and exploitation requirements and the eventual possibility of enlarging the installation to meet the traffic demand evolution during the useful life of the structure. For this economic evaluation, the construction costs as well as the expected useful life maintenance and repair costs and, where appropriate, dismantling and environmental recovery costs, should be taken into consideration.

Due to the severe environmental and climate conditions berthing and mooring structures are exposed to, it is generally much more economical and dependable to adopt robust, simple and durable structural typologies, requiring minimum maintenance during their useful life and with easy construction, dismantling and environmental recovery processes., as appropriate.

The most important considerations to be taken into account for the selection of the structural typology are summarized as the following:

2.5.1 Use and Exploitation Considerations

The considerations relating to the use and exploitation of a berthing and mooring structure, mainly associated with the types of ships and goods and with space and handling equipment needs, as well as the required exploitational capacity levels, dependent primarily on its interaction with metocean agents, fundamentally determines the selection of the physical configuration of the berthing and mooring (see Section 2.3), even more than its structural typology.

Nevertheless, the process of selecting the structural typology can be directly influenced by the magnitude of the overloads and the goods handling equipment when transmitting important and, where appropriate channeled stresses, which may well require either the over-dimensioning of the resisting structure or the design and inclusion of supplementary structural elements such as floating girders or piles whenever the structure is not able to directly withstand these forces, or to limit deformations. These additional structural elements should be taken into account when comparing the different solutions.

Normally piled solutions are designed so that the crane rails coincide with a pile alignment, taking advantage of the structure itself. In gravity structures and diaphragm walls with unloading platforms, the crane rails should be directly situated on the structure, as far as is possible. On the other hand, in diaphragm solutions without unloading platforms or in narrow gravity structures it is usually essential to add the aforementioned additional structural elements.

The maximum permissible vertical and horizontal deformations of the resisting structure in service conditions, compatible with the handling equipment and port operations in safe conditions may also be a relevant factor in the selection of the structural typology. In general, fixed pile structures best meet the design requirements in this regard, then the gravity structures and finally floating structures. In docks with a backfill, the possibility of differential settlement between the structure and esplanade should be given due consideration.

For adaptability to different use and exploitation requirements, gravity structures typically have greater ability to deal with significant loads and therefore to possible increases or distribution changes in the use and exploitation loads, than either diaphragm walls, piled structures or floating structures. On the other hand, the latter ones are best suited to adapt to the need to increase berthing draughts to accommodate the evolution of ship characteristics.

2.5.2. Geotechnical Considerations

The quality and homogeneity of the foundation terrain is a fundamental factor in selecting the structural typology.

Gravity and open piled structures require firm foundation soils, with a high load bearing capacity, both in terms of stability and settlement, located at accessible depths. Soils can be either natural, enhanced or replacement fills.

Diaphragm wall structures are applicable to all kinds of terrain, except where there are settled rocks at depths that hinder or prevent the attainment of the necessary embedment depth. Nevertheless, they tend to be a competitive solution, especially in less deformable soils composed of sand and gravel. The terrain acts as an agent and also as a resisting element to which the resultant forces are transferred. A thorough working knowledge of the terrain is required (see ROM 0.5).

Piled structures are applicable to all kind of terrain. Their use is recommended for those grounds where the resistant substrate is excessively deep relative to the design draught. This solution may be competitive when compared to gravity works for significant draughts (> 25 m), if there are competent soils located at accessible depths. Nevertheless, in piled backfilled structures, the relation between platform width and dredging slope must be taken into account; if the soil quality is poor, the slope will be very gradual, possibly implying a large deck width and leading to instability during construction phases, thereby losing its advantage over other typologies.

In heterogeneous terrain, where foundation conditions may vary significantly even over short distances, the adaptive flexibility of the different typologies should be assessed. In principle, piled structures adapt well to such variability.

2.5.3 Morphological Considerations

The combination of the availability of ground surface area, the slope of the terrain and natural draughts at the berthing structure site may influence the choice of the structural typology.

In general, gravity works constructed for significant draughts occupy a large surface area, because of the need for large foundation berms, so they are not suitable for areas with limited space. In such cases, diaphragm wall solutions, sheet pile cells, spatial trusses, piled works or floating structures are generally more convenient. Also the last three solutions are usually more suitable for large natural ground slopes, because gravity solutions normally require very significant dredging/fills in such conditions. In addition, differential settlement may occur because of an irregular foundation.

When a berthing structure must be constructed in places where the sea floor is much higher than the required draught or even above sea level, diaphragm wall structures are the most competitive solution, greatly facilitating the construction, which can then be done from the ground surface or even overland. Also, significant dredging is avoided, which would otherwise be required for gravity structures, and the natural ground may be directly incorporated into the backfill, reducing the required fill volume. On the other hand, if the existing natural draughts are much higher than those required by the berth, piled solutions, spatial trusses and floating solutions may be more convenient.

2.5.4 Climatic Considerations

The maritime climate at the site may also influence the selection of the berthing structural typology, although it may be more convenient, if operational requirements allow, to choose according to the physical configuration of the structure. In any case, with a severe maritime climate and an exposed structure, given the magnitude of the resultant forces, it would be necessary to resort to an open or floating typology.

When turbulence problems arise from a partial shelter of the structure and/or from wave reflections being able to significantly limit the operational capacity levels of either the structure or the harbour basin, open or hollowed gravity structures are more suitable, due to the reduction of reflected waves. In any case, fixed berthing and mooring structure projects should specify the reflectivity of the work, depending on the frequency of waves and that of the floating structure, as well as the float oscillation characteristics as a function of the incident waves.

Whenever the interaction between the structure and the local maritime climate (waves, currents, tides, ...) may have a significant effect on local sediment dynamics (increasing erosion or sedimentation), open or floating structures may be more suitable as they imply less variation of the previous hydraulic patterns, reducing the annual requirements for draught maintenance or additional protection elements against erosions, when compared to other solutions.

In areas where ice formation on the sea surface is possible, this circumstance should be taken into account when selecting the typology. The action of ice on the structure is a compression, usually represented as a linear force applied at the most detrimental water level. With these considerations, floating typologies are the least recommended, followed by open and closed fixed works, in that order.

Maritime climate may also condition the typology in so far as it greatly affects the construction process, especially in unsheltered waters. In these cases, prefabrication is clearly advantageous because it allows maximum use of the climatic working windows. Gravity structures in floating caissons require, at the anchoring phase, the presence of small wave heights and periods ($H < 0.80$ m and $T < 9$ s), so this can affect the construction timeline, depending on the available annual climatic windows. Cell enclosure construction is very sensitive to waves until the cells are totally filled, although in this case for reasons relating to stability.

2.5.5 Environmental Considerations

The existence of environmental problems related either to the opening and exploitation of quarries, or to the transportation of construction materials or to the removal and disposal of dredging products, may discourage the use of gravity or column typologies whenever they imply large foundation berms and/or large dredging volumes to reach firm foundation levels. In such cases, piled open solutions, space trusses, floating structures or massive piles (driven caissons, sheet pile cells) may be much more convenient.

When the environment is not so sensitive to the transportation and disposal of dredging products, the selection of typologies that allow the reuse of dredging as fills is a good environmental option and reduces the need for new filling materials. Massive structures can be convenient in this case.

When the site of the berthing and mooring structure is unsheltered, the effect of wave reflection and/or radiation on the environment should be taken into account, mainly in the presence of fine-sand beaches inside its area of influence, as these are more sensitive to changes in the characteristics of incident waves.

Finally, whenever possible, typologies which promote water quality and flow and the non- retention of floating elements should be selected.

2.5.6 Construction and Materials Considerations

The local availability of materials: rockfill and aggregates, concrete and steel, and their economic cost is an important aspect to be considered in the selection of the structural typology. In the current European situation, the most significant element relating to materials that can influence the choice from among the different structural typologies is the availability and proximity of deposits or exploitable quarries, capable of supplying rockfill, lending materials for berms, and fills and aggregates for concrete. Any difficulties in this regard usually makes gravity solutions less advisable, as they require larger volumes of these materials. In extreme cases where there is no recourse, wide scale prefabrication and transportation of precast elements from areas with the available resources should be effected.

The severity of the maritime environment, existing limitations on the performance of submerged works, as well as the difficulties associated with the underwater inspection of the works, recommend the consideration of construction methods allowing the greater part of the works to be done above sea level. Accordingly, it is convenient to choose solutions that can be constructed using the greatest number of precast or dry-built pieces as is possible (blocks, floating caissons, sheet piles, L- shaped pieces, piles.). All these structural typologies are capable of incorporating a high degree of prefabrication, making the choice between one or the other typology dependent in each case on the work commissioning options or the execution of each precast element as a function of aspects such as production capacity, placement and/or the load bearing capacity of terrestrial or floating equipment in the market which can be made available locally. Additionally, prefabrication may be an advantageous construction method in ports with very limited space, as manufacturing and storage can be done elsewhere without occupying the areas close to the berth.

In extreme cases, when the berthing structure must be built at a site where the sea floor is much higher than the required draught and/or not very far from the emerged ground, diaphragm or piled solutions, made entirely from the dry ground surface using conventional land methods are usually competitive, even when provisional fills are required.

To avoid lessening the competition among construction companies it is not advisable to select solutions which require the use of exclusive equipment or those with very limited availability. On the contrary, simple solutions which allow a high degree of flexibility in the application of different construction procedures, well adapted to the experience and available resources of each of the construction companies is recommended.

In those cases, where it is necessary to reduce the execution time to the minimum, this aspect may decisively influence the choice of the structural typology, which will mainly depend on local circumstances: availability of materials and construction resources, as well as the experience and productivity associated with them.

2.5.7 Seismic Considerations

In those areas where seismic agents are relevant, the selection of the structural type may be influenced by the terrain's response to dynamic forces, soil-structure interactions and structural response.

In the presence of a backfill, massive fixed structures will be penalized with respect to open and floating ones due to increases of free water hydrodynamic pressures and ground pressures, except for backfill materials which are "permeable" enough, allowing the rapid release of the interstitial pressures caused by seismic actions. Additionally, the liquefaction potential of the actual grounds should be evaluated to prevent this phenomenon which occurs in certain soil types, mainly in loose non-drained saturated sands. Liquefaction is that state where the effective soil pressure is nullified.

When fixed open piled structures are used in seismic zones it is not advisable to use sloped piles, since this configuration is less flexible in countering horizontal loads, causing difficult to repair failures at the joints between the pile heads and the upper deck, due to a high increase of the shearing forces in those joints, unless flexible connectors are installed between the pile head and the deck, acting like a "fuse" whenever the horizontal forces exceed a certain value.

In non-backfilled structures, inertial forces will govern the design, making floating structures the most advantageous, followed by the gravity ones.

2.5.8 Maintenance Considerations

Due to the extreme severity of the maritime environment, any comparison of structural solutions should take into account the necessary costs to assure the durability of the structure during its expected useful life (increased thicknesses and/or cathodic protection for steel structures, greater coverage and higher quality concrete, etc.), or to consider those maintenance and repair costs deemed necessary for that period.

Because of the great difficulties and significant costs associated with maintenance and repair operations in the marine environment, as a general criterion, it is recommended that both concrete and steel structures, regardless of the structural typology, be designed with a durability strategy according to the material characteristics and properties that will reinforce their stability against environmental actions and to implement design and construction procedures which will allow them to adequately counter the anticipated degradation, thereby avoiding excessive or difficult maintenance and repair operations. Additionally, the necessary inspection procedures should be implemented in order to monitor the effectiveness of the adopted strategy and to make adjustments when and where appropriate.

The durability strategy should consider, at least, the following aspects:

- For concrete structures:
  - The selection of appropriate structural forms.
  - The quality of the concrete, in particular its impermeability to chlorides.
  - Armor coating
  - The control of the maximum value of cracks and fissures.
  - The provision of surface protections.

- For steel structures:
  - Over-dimensioning of sections, providing additional thickness in anticipation of the expected corrosion during its useful life.
  - The adoption of protective measures such as exterior paint and/or galvanizing, cathodic protection and concrete covering in major corrosion areas.

Ultimately, even given the prudence of adopting a durability strategy, it is difficult to prioritize, in general, one structural solution as being more convenient than another on the basis of repair and maintenance considerations, which are heavily influenced by local conditions and costs. Notwithstanding the foregoing, steel solutions are usually the most competitive for works with short or very short useful life while concrete solutions are preferable for those with long useful life.

Plastics should be mentioned here as one of the most durable and resistant materials to sea water. The explosion on the market of these materials, with an increasingly broad range of application, signals that in the very near future its frequent use in berthing and mooring structures, at least for ancillary elements will need to be given due and proper consideration.

Chapter III

Plan and elevation layout, design requirements and general project criteria

Índex Chapter III

CHAPTER III. PLAN AND ELEVATION LAYOUT, DESIGN REQUIREMENTS AND GENERAL PROJECT CRITERIA

3.1 INTRODUCTION

The aim of the project is to obtain a berthing and mooring structure that meets functional, economic and environmental optimization criteria and which, in its entirety, and in its subsets and elements, satisfies the reliability, service capability [(1)] and operational requirements of each phase of the project (See ROM 0.0 and Section 3.4.4 of this ROM).

The development of a berthing and mooring structure, its definition and verification, should be the result of, at least, the following sequence of activities:

1. The definition of the intended use and the operational and functional requirements of the berthing and mooring structure.
2. A description of the location, compiling topographical, geotechnical, morphological, climatic, and environmental data, materials availability, construction methods, operation, repair and maintenance capabilities, subsequently facilitating the determination of those project factors defining the geometry and characterizing the environment, terrain and materials, as well as the assessment of the agents and their actions.
3. An initial study of alternatives, in order to define, using economical, functional and environmental optimization criteria:
   - **a.** The most convenient physical berthing configuration (or configurations) satisfying the demanded functional and operational uses and requirements.
   - **b.** The most suitable structural typology (or typologies) fulfilling the use and exploitation requirements and the geotechnical, morphological, climatic, environmental and constructive conditions, and the conservation and maintenance protocols and materials existing on the site.
4. A definition of the plan and elevation layout of the berthing structure, to verify that the selected design alternative meets the functional requirements, considering the existing limitations at the site.
5. Establishing the general Project criteria: construction time periods, definition of spatial scales (subsets), general and operational characteristics, fixing of time scales (design phases) and their duration, reliability, service capability, and the operational requirements for each project phase and dismantling process, where appropriate.
6. The selection of the most suitable design alternative.
7. The predimensioning of the structure, subdividing it into subsets and sections, as necessary.
8. The verification of the whole set of the structure, its subsets and elements, as achieving the required levels of reliability, service capability, and operationality.
9. The optimization of the structure and its subsets and sections.
10. Project development.

The necessary criteria to undertake the entire set of activities included in the design of berthing and mooring structures are provided in this section and the ones following. However, the definition of the operational and functional uses and the requirements relating to them are developed in Sections 2.2 and 2.3. Additionally, Sections 2.3 and 2.5 are devoted to the criteria developed for the selection of alternatives, pertaining to either the physical configuration or the structural typology of the berthing and mooring structure.

3.2 PLAN AND ELEVATION LAYOUT

After the selection of the design alternative, both from the point of view of its physical configuration (monobuoy, jetty, quay, ...) and structural typology (gravity structure, diaphragm wall, piled, floating, ...), the operational aspects which fundamentally influence the main dimensions of the berthing and mooring structure in plan and elevation (the number of berths, the total length of the berthing line, the draught, the crown level, the longitudinal profile of heels and ramps, ...) are:

(1) In accordance with the UNE-EN 1990:2003. In the ROM 0.0 the term "service capability" is called functionality. Both terms are used interchangeably in this ROM.

- Predictions of the volumes and types of goods or passengers to be handled yearly at the berths.
- The size, composition and characteristics of the fleets expected at the berth.
- The statistical distribution of the time scales and time periods between consecutive ship arrivals.
- The distribution of the volume of loaded/unloaded goods by scale (traffic units).
- The distribution of the service time periods or berth usage times for two consecutive ships.
- The characteristics and productivity levels of the loading and unloading operations, including the number and performance yields of the handling equipment on site, as well as those used for the internal interconnection of the operation area to the storage area.
- The Service Quality Level I (τ) deemed admissible. The Service Quality Level is defined as the relative wait or average waiting time of ships in the harbor before being assigned to a berth because all the berths are occupied, or the congestion time ($\overline{t_e}$) divided by the average total time of ships in the berth or service time ($\overline{t_s}$). That is: $\tau = \overline{t_e} / \overline{t_s}$.
- The characteristics of maritime access.
- The size and configuration of the wharfs and the availability of areas for ships to perform access, berthing and exit maneuvers, as well as the structural typology of maritime constructions that conform them.
- Local climatic conditions.
- The resources and provisions for the maneuvering of the expected ships (propulsion systems, availability of towing, etc.).
- The distribution of the length of stay times of the goods in the storage areas.
- The surface area required for goods storage areas until their removal/reception by land transport means or their transfer to other types of ships, according to the type of goods and the handling systems used in the storage area.
- The removal/reception capacity of the land transport means, according to the equipment and specific transfer stations (storage equipments to support the various modes of ground transport, road systems, railway terminals...).

The minimum dimensions of a berthing and mooring structure in plan and elevation should be those which allow the safe handling of the expected traffic, with the requisite levels of service and functionality. To that end, the capacity of a berthing line for local conditions and specific operability, is defined as the maximum annual volume of goods that it is able to be handled in such conditions, as a whole, and per unit of length. It is expressed as t, the number of containers, TEU's [(2)], transport units (full trucks or UTI), vehicles or passengers (expressed as either the total number or per linear meter of berth).

The real capacity of a berthing and mooring structure cannot be determined solely by the capacity of its berthing line, but also by the storage capacity in nearby areas and/or by that of goods removal/reception through its terrestrial accesses. The ROM 3.2 (Terrestrial Harbor Port Configuration), develops these aspects. Nevertheless, this Recommendation includes some preliminary criteria indicative of the capacities of the esplanades and of the removal/reception through the terrestrial accesses, as well as other associated dimensions and indexes.

(2) TEU (Twenty-foot equivalent unit): the unit of measure for containers, expressed as container measure equivalent to 20' (6.10 m).

3.2.1 Plan Layout

The characteristics to be defined for a berthing and mooring structure regarding plan dimensioning subsequent to deciding on its location, are:

- Orientation.
- Alignments.
- Number of Berths (Na)
- Total Length of the Berthing Line (La).
- Position and Plan Dimensions of Heels and Ramps.
- Width (Am).
- Land Accesses.

3.2.1.1 Location

The berth's location, together with its plan and elevation layout, as well as the plan and elevation layout of access channels, maneuvering areas and wharfs, should guarantee some minimum operationality conditions established in accordance with Tables 3.4.2.3 and 3.4.2.4 of this Recommendation, taking into account all the stoppage modes.

In those climatic and metocean conditions, considered as limits of operationality and staying of ships at the berth (See Section 4.6.4.4.7.1.3.a4), the plan and elevation dimensions of the maritime accesses, maneuvering areas and wharfs, associated with the berthing installation, shall guarantee the access of the expected fleet's vessels to the berthing site from the open sea, departure from the site and the performing of berthing and unberthing maneuvers by specific auxiliary means (tugboats, navigational aids, ...) according to the means and exploitation conditions present in the port where the installation is located. Additionally, the sheltering conditions of the berthing line, together with other factors liable to cause a possible operational stoppage (see Chart 1.13.), should guarantee the staying of the ship at the berth and loading and unloading operations, as well as passenger boarding and disembarking, with the ship loading and unloading systems found in the terminal, in the operationality limit conditions established for these stoppage modes.

The criteria, design factors and procedures for the plan and elevation dimensioning of maritime accesses, maneuvering areas and docks/wharfs are included in the following ROM document:

- ROM 3.1-99. Design of the Maritime Configuration of Ports. Approach channels and Harbour basins

  In turn, the criteria and procedures for the verification of the shelter conditions in the berthing line are available in the following ROM:

- ROM 1.0-09. Recommendations for the Project Design and Construction of Breakwaters. (Part I: Calculation and Project Factors. Climate agents)

3.2.1.2 Orientation

Berthing and mooring structures with a fixed alignment should be oriented, as far as possible, so that local climatic agents (currents, wind and waves) will have minimal effects on its operability. Therefore, the berthing and mooring should be situated in such a way that the longitudinal axis of berthed/moored ships will be as parallel as possible to the most frequent directions of the climatic actions or, if this is not possible, to the most frequent prevailing direction. Ultimately, the action which produces the least level of operational disruption should be selected.

For example, in sheltered areas from swell where there are strong currents (tidal or fluvial), this action tends to be prevailing, so berthed ships should be aligned in the direction of the current. When the current is weak, ships should then be aligned with the prevailing wind direction. In unsheltered areas, waves are generally the prevailing action, and therefore the berthed/moored ship should be aligned in the most frequent wave direction or provided with a single mooring point (mono-buoy), allowing the ship to rotate freely against the incident actions.

Berthing orientation may also be important to the wharf's agitation levels caused by wave reflection, as well as to the possible phenomena of dynamic amplification (resonance), both in the wharf and in the ship/mooring ropes/fenders system, associated with swells or long waves. The effects of these phenomena should be reduced by employing the correct orientation, structural typology and berthing configuration, especially avoiding making sheltered areas come into resonance (See ROM 1.0), and keeping the natural oscillation periods of the most critical motions of the moored ships as far away as possible, from those periods corresponding to the acting forces. The orders of magnitude of the natural oscillation periods for a moored ship are included in Section 4.6.4.4.7 of this Recommendation.

In berthing and mooring structures for dangerous goods, orientation selection will assume priority consideration that will improve the maneuvering conditions for ships during berthing and unberthing operations as well as facilitate their quick departure in emergency situations.

Berthing orientation may also influence the sediment dynamics at the site. This effect should be analyzed in those areas where silting or erosion, both on site and in nearby zones, or modification of the natural environment is anticipated.

3.2.1.3 Alignment

In general, for a multiple berthing structure, it is advisable to design it with a single alignment. If possible a discontinuous lifting system should be used on site, to provide maximum operational flexibility and optimum use of the available handling equipment and the adjacent esplanade, where appropriate.

For continuous handling systems or passenger traffic, the location of berths in single or multiple alignments usually does not influence the operationality of the installation. In such cases, the berthing line layout into one or more alignments is mainly a function of the available room. Nevertheless, the layout in various alignments in the case of multiple berths may necessitate longer global berthing lengths if the expected fleet is very heterogeneous, in order to maintain the operational flexibility associated with berth assignment.

Regardless of the above, for the berthing of dangerous goods it may be more suitable to use an isolated and discontinuous berthing layout in one or more alignments in order to maintain safe distances between ships, and consequently avoiding their mutual interaction in emergency situations.

3.2.1.4 Number of Berths

The designated number of berths (N_a) should be the minimum having the capacity to serve the expected fleet with the forecast traffic units, according to the local conditions and site exploitation, with the requisite ship waiting times (serviceability levels) as well as with the levels of inoperability of the installation associated with the paralysis of the loading and unloading or passenger boarding and disembarking operations, or the suspension of maritime accessibility and the staying of ships in the berth (See Section 3.4.).

Accordingly as a first approach, the Designer should obtain from the Developer of the installation, as a minimum:

- The maximum annual volume (C_t) by type of goods to be handled at berth, as well as the fleet characteristics: Regular, Tramp [3] or mixed traffic and their degree of seasonality, where appropriate. This is

(3) The English term "Tramp" is generally used for non-regular or occasional traffic.

expressed as t, the number of containers, TEU, transport units (truckloads or UTI: trailers, semi-trailers or platforms), vehicles or number of passengers. In this case this must be defined for each type of goods or by cargo and differentiated transport unit ($C_{t,i}$).

- The mean traffic unit, which is to say the average volume of loaded/unloaded goods in each call, considering the expected fleet at berth ($\bar{C}_u$). This may be obtained as an average of the traffic unit distribution function. In case of the expected fleet at the berth being defined by means of project ships (See Section 4.6.4.4.1), the average traffic unit will be considered as the mean value among those associated with the maximum, mean and minimum ship. The average traffic unit will be defined for each goods type; or differentiated unit of cargo or transport; to be transported (vehicles, truckloads, UTI or platforms and TEU), according to the average capacity distribution among them corresponding to the ships, as estimated by the Developer ($\bar{C}_{u,i}$). The average cargo unit associated with the expected ship fleet at berth depends not only on ship size but mainly on other factors such as the characteristics of the shipping lines using the installation (regular/tramp, transoceanic/short-sea shipping), the type of terminal (import-export, transit or mixed), the traffic generated in their area of influence (hinterland) and on its characteristics (import/export ratio), whether it is a public or a dedicated terminal, the efficiency and productivity of the installations, the commercial organization of the calling shipping lines, and the commercial agreements between the shipping and cargo handling companies, among others (4).

- The number, characteristics and performance yields of the handling equipment (cranes for lift loading/unloading operations, tractor heads for non-self-propelled rolling operations or additional drivers for unaccompanied self-propelled rolling operations,.) that will be available per berth, working simultaneously at each docked ship for each load type, as well as the net productivity associated with the loading and unloading processes.

- The total useful work time available at the berths per year.

- The minimum acceptable operationality levels of the installation linked with the stoppage of loading and unloading operations or with passenger boarding and disembarking and the suspension of maritime accessibility, as well as the staying of ships at the berth.

---

(4) Although it is very difficult to generalize because of the great resultant variability depending on the characteristics of the factors influencing the traffic units at each location and situation, in the absence of some other more accurate data, in berthing installations for containers and Ro-Ro, as a first approximation, the following average traffic units corresponding to loading and unloading may be adopted for each ship of the expected fleet at berth, whenever the shipping lines will be regular ones and deemed consolidated:

- *Import-export Terminal*
  - Shipping line feeder or short sea shipping between two ports:
    - In loading and in unloading: 70% of the ship's loading capacity as measured in TEU's for container ships or in number of truckloads, vehicles, platforms or UTI for Ro-Ro and Ro-Pax ships.
  - Transoceanic or feeder shipping line calling at several ports:
    - In loading and in unloading in intermediate call: 20% of the ship's capacity.
    - In loading and in unloading in initial or final call of the shipping line: 40% of the ship's capacity.
- *Transit Terminal*
  - Shipping line feeder or short sea shipping:
    - In loading and in unloading: 70% of the ship's loading capacity.
  - Transoceanic shipping line:
    - In loading and unloading together: 30% of the ship's loading capacity.
- *Mixed terminal*

  For each shipping line, the weighted average of the above traffic will be adopted as traffic units, considering the existing ratio between import-export and transit traffic.

The above estimations of traffic units by call will be considered as applicable to public terminals. For dedicated terminals, increases of around 15% over those established for public terminals, (those where any shipping line may operate), may be assumed.

The traffic unit in tons corresponding to loading and to unloading in tons may be obtained by considering the average gross weight by loading unit or unit of handled and loaded transport and its tare when unloaded, as well as the relation between those transported as loaded and unloaded. In the absence of other data, in import-export terminals, it may be approximately considered that the last relation above is equivalent in loading or in unloading to that ratio produced in the terminal between import and export traffic. In occasional or Tramp lines with bulk traffic, traffic units in loading or unloading of 80% of the ship's capacity are usual.

- The required Quality of Service Level (t). In general, relative waits between 0.1 and 0.5 are considered acceptable, depending on the expected fleet's characteristics at berth. That is, average waiting times between 10% of the average service time (for totally regular traffic) and 50% (for totally Tramp traffic), with intermediate values corresponding to mixed traffic depending on the type of shipping lines using the berthing installation.

The number of berths may be obtained solving a waiting/queuing system defined by the required service level and by the distribution functions of scales or time periods between consecutive ship arrivals and that of the service time periods or usage time of a berth by consecutive ships. For this purpose, the service time (t_s) is defined as the time period when a berth is assigned to a calling ship. It may be broken down into:

- Active time or the net period of time used for loading and unloading (t_a).

- Unproductive time: The time taken for preparation tasks and ending of operations tasks, delays in loading and unloading authorizations, stoppage of loading and unloading operations caused by exceeding the climatic conditions operational limit or for other reasons, such as the end of shifts, the impossibility of unberthing or the ship departing due to climatic conditions or the lack of operative capacity of the auxiliary means needed for maneuvers, such as tugboats, ... (t_i).

- The time taken for berthing and unberthing maneuvers, and preparation tasks related to the servicing of the ship (t_m).

The sum of active time and unproductive time is called laytime (t_{pu}).

The distribution functions of calls and service times may be defined according to the following criteria:

a) The distribution function of calls or time intervals between the arrival of two consecutive ships.

From statistical analysis performed at berthing installations, it has been generally observed that if we consider a fixed time period, the arrival of ships to a maritime terminal is random, reasonably fitting a Poisson distribution. Therefore, the distribution function of time intervals between two consecutive ship arrivals during that period may be approximated by means of an exponential function for any type of berthing installation and independently of the characteristics of the shipping lines using the installation, even for very programmed ship calls and particularly when the berthing installation is composed of multiple berths and it's called by several shipping lines.

Therefore, in the event the Developer is not in a position to define the distribution function of the time periods between the arrival of two consecutive ships, the following exponential function may be adopted:

$$F(x) = e^{-\lambda_{max} \cdot x}$$

where λ_{max} is the frequency of monthly ship arrivals corresponding to the month of maximum frequency.

In the event the Developer is unable to establish the frequency of monthly ship arrivals corresponding to the month of maximum frequency, this parameter may be approximated from the maximum annual volume of goods handled at the berth (C_t) and from the average cargo unit ($\bar{C}_u$), differentiated where appropriate, by the type of goods and measured in homogeneous units, using the following formula:

$$\lambda_{\max} = \frac{1}{12} \cdot \frac{C_t}{\bar{C}_u} \cdot \gamma_p = \frac{1}{12} \cdot \frac{\sum_i C_{t,i}}{\sum_i \bar{C}_{u,i}} \cdot \gamma_p$$

Where γ_p is a peak factor used to take into account the non-uniform distribution of ship calls to the port throughout the year. In the absence of more accurate data, a value of 1.2 may be adopted.

b) The distribution function of service times or usage time of a berth by consecutive ships

From research on service times at berthing installations, it has been observed that their distribution, associated with a fixed time period, reasonably fits the distribution of a constant component

$$G(\bar{x},\sigma) = G(\bar{t}_s, \frac{\bar{t}_s - t_{cc}}{\sqrt{K}})$$

resulting from the combination of a constant component (t_{cc}) and a 4th or 2nd order or an exponential (K=1) Erlang distribution, assuming that the fleet's composition at berth and, consequently, the traffic units, are more or less homogeneous [5]. At the limit, in the case of a fully homogeneous fleet with identical traffic units, it would be an Erlang distribution with $K = \infty$. The constant component is due to the fact that the probability of having small service time below a certain threshold value (t_{cc}), must necessarily be null, as their occurrence is physically impossible.

Accordingly, in the absence of more accurate statistical data provided by the Developer of the installation or from the approximation of the service time distribution function using simulation models of the terminal operation adapted to the expected conditions, it may be assumed that the above functions represent the distribution of service time or usage of a berth by consecutive ships, establishing the average service time (t_s). To be on the safe side, in these cases the constant component (t_{cc}) is considered to be insignificant with respect to the average service time.

In the above cases, the average service time (t_s) adopted will be that obtained from the sum of the average laytime and maneuvering time periods. These average times may be estimated using the following formula:

- Average laytime ($\bar{t}_{pu}$)

$$\bar{t}_{pu} = \frac{\bar{C}_u}{\bar{N}_g \cdot \bar{R} \cdot \alpha_1 \cdot \alpha_2 \cdot \alpha_3} = \frac{\bar{C}_u}{\bar{P}_b \cdot \alpha_1 \cdot \alpha_2 \cdot \alpha_3} = \frac{\bar{C}_u}{\bar{P}_n}$$

Where:

$\bar{C}_u$: is the average traffic unit.

$\bar{N}_g$: is the average number of handling equipment (cranes for lift loading and unloading operations, tractor heads for non-self-propelled rolling operations or drivers for unaccompanied self-propelled rolling operations) expected to be available at each berth, working simultaneously on each berthed ship. The maximum number of handling equipment or of drivers working efficiently per berth, is limited by physical and operational conditions. For gantry cranes on rails, in order to calculate the average laytime, the maximum possible number to consider will depend on the ratio: average ship length/separation between crane guides [6] and on whether the loading and unloading is being performed from one side (conventional berth) or from both sides of the ship (new functional berthing designs such as the "ship in a slip" solution). For tractor heads, the maximum number usually ranges between 3 or 4 per operating ship ramp.

$\bar{R}$: is the average gross performance of each handling equipment unit or driver, as appropriate. It is measured in tons/h, TEU's/h, containers/h, UTI's/h or vehicles/h depending on the type of goods or

(5) The constant component distribution function is equivalent to the Erlang or Exponential displacement function of that value corresponding to the minimum possible usage time at berth. The variance of this distribution is the same as that of the non-constant component distribution function. That is:

$$\sigma^2 = \frac{(\bar{t}_s - t_{cc})^2}{K},$$

where K = 2 when the adopted non-constant component distribution function is a 2nd order Erlang and K = 1 when this function is exponential.

(6) The distance between standard gantry cranes guides can be consulted in Section 4.6.4.2.1.1.1 of this Recommendation.

units of cargo or transport handled. The average gross performance of handling equipment and/or drivers varies extensively in each terminal and country, depending on the characteristics and technological level of the handling equipment, the fleet composition, the ratio between loading and unloading traffic, the configuration and size of the terminal, the operational organization of the loading, unloading and stevedoring of the ship, the training and efficiency of the port manpower and on safety regulations. The indicative average gross performance of the goods handling equipment currently used in Spain are included in Table 3.2.1.1.

The indicative average gross performance for drivers (for Ro-Ro operations of accompanied self-propelled goods (e.g. vehicles as good)) currently in Spain is around 8-10 vehicles/h using two lanes on the heel or the ship's access ramp.

For each type of merchandise or cargo or transport unit handled in the terminal, the product $\bar{N}_g \cdot \bar{R}$ is called the average gross productivity of the loading and unloading subsystem per ship ($\bar{P}_b$) associated with each cargo type.

α_1: is the average coefficient of utilization of the working day or percentage of the net time used for loading and unloading operations with respect to the total effective working day (that passed during loading and unloading operations plus the necessary time periods for the preparation and completion if same, administrative procedures and controls…). In the absence of more precise data, typical values of the above coefficient are around 0.90 for continuous handling systems, 0.85 for batch lifting handling systems and 0.75 for rolling handling systems.

α_2 : is the average coefficient of berthing activity, or the percentage of the effective working time with respect to the total time of the ship at berth. In the absence of more precise data, 0.70 may be adopted if port manpower works two shifts a day in the terminal and 0.90 for three-shifts.

α_3 : is the operationality level of the berthing installation associated with ship loading and unloading operations or to passenger boarding and disembarking, and to the possible departure of the ship from the berth.

The operationality level of the terminal associated with these operations is defined as the percentage of useful annual time in which the ship may unberth and leave without problems and carry out loading and unloading operations without exceeding the threshold values of climatic or metocean agents preventing the ship from leaving and paralyzing the loading and unloading due to safety concerns, either of the handling equipment, the loading and unloading operation itself or because of the movement of the ship with respect to the equipment or from other causes (water overflow above the crown level, incompatible slopes and fittings between the sloped planes of the heels and ramps, or insufficient elevation of the port's cranes, ...).

Accordingly, each berthing installation should define the operationality level associated with the above operations. The operationality level may be obtained as the complementary value of the operational stoppage probability due to any cause of operational stoppage associated with the ship's loading and unloading operations or passenger boarding and disembarking or to maritime accessibility (See Sections 3.4.4. and Chapter 4).

The probability of operational stoppage may be estimated from the mean annual regime [(7)] of the on-site climatic and metocean agents (wind speed , wave heights, current speed, outer water levels regimes), obtaining the probability that the threshold values of the agents causing the operational stoppages, will be exceeded in the average year. In the absence of more accurate analysis, the threshold values of the climatic and metocean agents generally established as restrictive to ship loading and unloading operations and passenger boarding and disembarking, considering them individually as predominant agents, are included in Table 3.2.1.3. Since the threshold values of those agents corresponding to the suspension of maritime accessibility to berth (and to the departure of ships from the berth) cannot be less than those of staying ships at berth, the threshold values specified for ship staying in Table 3.2.1.3. may be adopted for maritime accessibility.

(7) The mean annual regime of a climatic agent is defined as the statistical distribution function relating to several values of the variable identifying the agent (wind speed, wave heights, current speed...) together with the probability that these values will not be exceeded in the average climatic year.

Table 3.2.1.1. Gross average hourly performances of the handling goods equipment currently used in the Spanish ports ($\bar{R}$)

Type of Goods		Cranes Fixed/ Mobiles (t/h)	Special Installations (t/h)	Container Cranes 1) (Unit/h)	Tractor head in not self-propelled Ro-Ro operations 2) (Unit/h)	Pipes or hose-arms (m^3/h)
GENERAL GOODS	Reel paper	80-180				
	Iron and steel products	175-575				
	Horticultural products	65-100				
	Forest products	60-260				
	Containers			18-30 6) 8)		
	Ro-Ro				5-7	
BULK SOLIDS	Clinker	375-500				
	Cement	120-275	200-300 3) 120-225 4)			
	Cereals/fertilizers	175-275	225-375 3) 125-300 4)			
	Coal and minerals (unloading)	235-375	500-600 5)			
	Scrap metal	100-140				
BULK LIQUIDS	Crudes (unloading)					5,000-10,000 7)
	Refined oils and chemicals					500-1,000 7)
	Liquefied gases (LNG)					1,500-3,000 7)
	Liquefied gases (LPG)					500-1,000 7)

(1) With a single spreader.
(2) With two lanes in heel or ramp to access the ship.
(3) Pneumatic vacuum cleaner on grantries.
(4) Worm (or continuous mechanical device).
(5) Gantry crane-conveyor belt.
(6) In the absence of another data, to convert Ut/h to TEU/h, an average factor of 1.5 may be adopted.
(7) By loading/unloading line.
(8) A medium container may be equivalent to 1.25 TEU. If this ratio is accepted, 18-30 containers/h are equivalent to 22.5-37.5 TEU/h. In doble-spreader gantry cranes of containers, the gross average performances could be considered as 50% higher.

For each type of cargo or transport handled in the terminal, the product $\bar{N}_g \cdot \bar{R} \cdot \alpha_1 \cdot \alpha_2 \cdot \alpha_3$ is called the average net productivity of the loading and unloading subsystem per ship during its stay at the terminal ($\bar{P}_n$) for that cargo type. This parameter is an indicator of the Quality of Service of berthing installation and should be identified by the Developer of the installation as one of the necessary project factors for the design and infrastructural dimensioning of the berthing installation.

For accompanied self-propelled transport units (truckloads, road trains and vehicles), it may be assumed that the usual average net productivity per ship of the loading and unloading subsystem ranges between 30-45 trucks/hr and 150-400 (8) vehicles/hr, for operationality levels of 100%. The highest values of the range are normally associated with smaller capacity ships and therefore with a smaller number of decks or holds.

When the average traffic unit is defined taking into account the different types of goods or cargo and/or transport units, the average laytime may be defined as the sum of the average laytimes corresponding to

(8) Up to 600 vehicles/hr in ships with a single deck or hold.

each of the goods, cargo or transport units which defined the average traffic unit when the loading and unloading of this type of goods is performed sequentially When performed simultaneously, the average laytime will be the highest laytime average of those corresponding to each good, cargo or transport unit.

- *Average maneuvering time* ($\bar{t}_m$)

The average maneuvering time depends on the port configuration, the maritime access characteristics (in particular, the distance between the anchorage or access point of the pilot and the terminal), the berth's layout with regard to the ease of performance of berthing and unberthing operations, the expected fleet's characteristics concerning size, displacement, speed in harbor areas, and propulsion and maneuvering systems, the average climatic and metocean conditions on site, and on the need to use and (in such cases) the efficiency of the technical-nautical services to the ship (pilotage, towage and mooring).

The Developer of the installation, taking all these factors into consideration, as well as the available statistics of the port housing the terminal, should define the average maneuvering time of the expected fleet of ships at the terminal.

Due to the amount of factors which depend, to a large extent on local conditions specific to the terminal location, it is quite difficult to generalize average maneuvering times. Nevertheless, in order to evaluate the maneuvering time component associated with maritime accessibility to or from the berth, it may be generally considered that the operational criteria of port installations limit the speed of all types of ships in the port's harbor area to 15 knots (7.5 m/s) in outer maritime access areas and to 10 knots (5 m/s) in inner areas.

Solving this queuing system allows the calculation of, among other results, the value of the relative wait (τ) as a function of a parameter designated as the occupancy rate (Φ). This solving may be done using numerical simulation techniques (e.g. Montecarlo simulation) or by applying Queuing theory.

The occupancy rate of a berthing installation (Φ), for a fixed time period, is defined as the relation between the berth's operation time with a berthed ship and the time of availability of that same berth. In other words, the time percentage when all the available berths are fully occupied or the ratio between the number of ships calling to the terminal in a time period and the number of ships that may be serviced in that time period. Adopting a year as the time period, the occupancy rate may be formulated as [9]:

$$\Phi = \frac{\text{annual No of calling ships}}{\text{No of ships served per year}} = \frac{\lambda_{\max}(ships/months)\cdot 12}{\dfrac{N_a \cdot t_{year}(h)}{\bar{t}_s(h/ships)}}$$

Where:

λ_{max} : is the frequency of monthly call of ships corresponding to the month with the highest frequency of calls.

N_a : is the number of berths.

$\bar{t}_s$: is the average service time.

t_{year} : is the number of operational hours of the berthing installation per year. The annual operational hours of the terminal are those corresponding to the useful yearly days of effectively available berths (ships may enter and stay at berth without trouble), as well as when loading and unloading operations may be carried out, according to available port manpower, as required. To evaluate this parameter, the annual number of days when port manpower is not available for loading and unloading operations for whatever reasons (public holidays, labor conflicts,..) should be considered, and those corresponding to operational downtime of the terminal associated with suspended maritime accessibility and staying of ships at berth, either from climatic conditions exceeding the operational limits or from any other cause of operational stoppage such as the unavailability of tugboats (See Section 4.1.1.3). In the absence of more detailed studies, threshold values of the climatic agents normally used, such as the operational limits for the above operations, are included in Table 3.2.1.3. The minimum acceptable operationality levels for berthing and mooring structures are also included in Table 3.4.2.3 of this Recommendation.

(9) If a time period other than one year is adopted, the formula parameters must be adjusted to that time period.

From the definition of the occupancy rate (Φ), the number of berths required, considering one year as the time period, may be obtained from the following formula:

$$N_a = \frac{12 \cdot \lambda_{max} \cdot \overline{t_s}}{\Phi \cdot t_{year}}$$

using as the value of the occupancy rate (Φ), that corresponding to solving the queuing system for the service level (relative wait, τ) determined by the Developer of the installation. The occupancy rate corresponding to the most characteristic queuing systems at berthing installations for relative waits of 0.10, 0.25 and 0.50 are included in Table 3.2.1.2

Table 3.2.1.2. Occupancy rate (Φ) corresponding to the most characteristic queuing systems at berthing installations, for relative waits (τ) of 0.10, 0.25 and 0.50

FOR RELATIVE WAIT (τ) OF 0.10										
CHARACTERIZATION OF THE QUEUING SYSTEMS	**OCCUPANCY RATE (Φ)**									
	NUMBER OF BERTHS (Nb)									
	1	2	3	4	5	6	7	8	9	10
$M/G_1/N_b$ and $M/G_\infty/N_b$ (Very heterogeneous or totally homogeneous unitary systems)	0.09	0.30	0.44	0.52	0.58	0.63	0.66	0.69	0.71	0.73
$M/G_2/N_b$ (Relatively heterogeneous unitary systems)	0.07	0.28	0.40	0.49	0.55	0.60	0.63	0.66	0.68	0.71
$M/G_4/N_b$ (Relatively homogeneous unitary systems)	0.08	0.29	0.41	0.50	0.56	0.61	0.64	0.67	0.69	0.72
FOR RELATIVE WAIT (τ) OF 0.25										
CHARACTERIZATION OF THE QUEUING SYSTEMS	**OCCUPANCY RATE (Φ)**									
	NUMBER OF BERTHS (Nb))									
	1	2	3	4	5	6	7	8	9	10
$M/G_1/N_b$ and $M/G_\infty/N_b$ (Very heterogeneous or totally homogeneous unitary systems)	0.20	0.45	0.57	0.65	0.70	0.74	0.77	0.79	0.80	0.82
$M/G_2/N_b$ (Relatively heterogeneous unitary systems)	0.17	0.43	0.54	0.62	0.67	0.71	0.75	0.77	0.78	0.81
$M/G_4/N_b$ (Relatively homogeneous unitary systems)	0.18	0.44	0.55	0.63	0.69	0.72	0.76	0.78	0.79	0.81
FOR RELATIVE WAIT (τ) OF 0.50										
CHARACTERIZATION OF THE QUEUING SYSTEMS	**OCCUPANCY RATE (Φ)**									
	NUMBER OF BERTHS (Nb)									
	1	2	3	4	5	6	7	8	9	10
$M/G_1/N_b$ and $M/G_\infty/N_b$ (Very heterogeneous or totally homogeneous unitary systems)	0.33	0.58	0.69	0.75	0.79	0.82	0.84	0.85	0.87	0.88
$M/G_2/N_b$ (Relatively heterogeneous unitary systems)	0.29	0.54	0.65	0.72	0.76	0.79	0.81	0.83	0.85	0.86
$M/G_4/N_b$ (Relatively homogeneous unitary systems)	0.31	0.56	0.67	0.73	0.77	0.80	0.82	0.84	0.86	0.87

Legend

$M/G_1/N_b$: Exponential distribution arrivals / Distribution of service times of constant component, as a result of combining a constant component and an Exponential distribution.
$M/G_2/N_b$: Exponential distribution arrivals / Distribution of service times of constant component, as a result of combining a constant component and an Erlang distribution of order 2.
$M/G_4/N_b$: Exponential distribution arrivals / Distribution of service times of constant component, as a result of combining a constant component and an Erlang distribution of order 4.
$M/G_\infty/N_b$: Exponential distribution arrivals / Distribution of service times of constant component, as a result of combining a constant component and an Erlang distribution of order ∞.

The determination of the number of required berths based on the above formula will be made using a process of trial and error, until the number of berths corresponding to that assumed to specify the occupancy rate for the considered queuing system, for the service level set by the Developer, is reached.

As can be deduced from the formula, the infrastructural berthing needs required to serve the fleet with the characteristics and traffic units expected at the berthing installation, are not absolute: they increase when the admissible relative wait times decrease or when the average service time increases, and decrease with the hours in which the berthing installation is operational. Accordingly, for a given service level, increasing the average net productivity per ship of the loading and unloading subsystem during its stay at the berthing installation (increasing the number of handling equipment and/or their gross per-

Table 3.2.1.3. Threshold values of climatic and metocean agents, usually adopted as a limit of the various modes of operational stoppage for berthing and mooring structures

A. DOCKS AND JETTIES	Absolute wind speed $V_{10.1\ min}$	Absolute current speed $V_{c.\ 1\ min}$	Wave height H_s
1. Berthing manoeuvre of ships			
Actions in the longitudinal direction of berth	17.0 m/s	1.0 m/s	2.0 m
Actions in the transverse direction of berth	10.0 m/s	0.1 m/s	1.5 m
2. Loading and unloading stoppage operations (for conventional equipments)			
Actions in the longitudinal direction of berth			
■ Oil tankers < 30,000 TPM	22 m/s	1.5 m/s	1.5 m
30,000-200,000 TPM	22 m/s	1.5 m/s	2.0 m
> 200,000 TPM	22 m/s	1.5 m/s	2.5 m
■ Bulk carriers Loading	22 m/s	1.5 m/s	1.5 m
Unloading	22 m/s	1.5 m/s	1.0 m
■ Liquefied Gas carriers < 60,000 m^3	22 m/s	1.5 m/s	1.2 m
> 60,000 m^3	22 m/s	1.5 m/s	1.5 m
■ Merchant vessels of general goods. High seas fishing and freezer vessels	22 m/s	1.5 m/s	1.0 m
■ Container ships, Ro-Ros and Ferries	22 m/s	1.5 m/s	0.5 m
■ Ocean liners and Cruisers (1)	22 m/s	1.5 m/s	0.5 m
■ Fresh fish vessels	22 m/s	1.5 m/s	0.6 m
Actions in the transverse direction of berth	22 m/s	1.5 m/s	
■ Oil tankers < 30,000 TPM	20 m/s	0.7 m/s	1.0 m
30,000-200,000 TPM	20 m/s	0.7 m/s	1.2 m
> 200,000 TPM	20 m/s	0.7 m/s	1.5 m
■ Bulk carriers Loading	22 m/s	0.7 m/s	1.0 m
Unloading	22 m/s	0.7 m/s	0.8 m
■ Liquefied Gas carriers < 60,000 m^3	16 m/s	0.5 m/s	0.8 m
> 60,000 m^3	16 m/s	0.5 m/s	1.0 m
■ Merchant vessels of general goods. High seas fishing and freezer vessels	22 m/s	0.7 m/s	0.8 m
■ Container ships, Ro-Ros and Ferries	22 m/s	0.5 m/s	0.3 m
■ Ocean liners and Cruisers (1)	22 m/s	0.5 m/s	0.3 m
■ Fresh fish vessels	22 m/s	0.7 m/s	0.4 m
3. Ships at berth (5)			
■ Oil tankers and liquified gas tankers			
Actions in the longitudinal direction of berth	30 m/s	2.0 m/s	3.0 m
Actions in the transverse direction of berth	25 m/s	1.0 m/s	2.0 m
■ Ocean liners and Cruisers (2)			
Actions in the longitudinal direction of berth	22 m/s	1.5 m/s	1.0 m
Actions in the transverse direction of berth	22 m/s	0.7 m/s	0.7 m
■ Sport vessels (2)	22 m/s	1.5 m/s	0.4 m
■ Actions in the longitudinal direction of berth	22 m/s	1.5 m/s	0.4 m
■ Actions in the transverse direction of berth	22 m/s	0.7 m/s	0.2 m
■ Other types of vessels	Contraints imposed by the design loads of berths, compatible with mooring configurations assuring the ship's safety		

Threshold values of climatic and metocean agents, usually adopted as a limit of the various modes of operational stoppage for berthing and mooring structures (Continued)

B. ANCHORAGE	Absolute wind speed $V_{10.1\ min}$	Absolute current speed $V_{c.\ 1\ min}$	Wave height H_s
1. Approach and mooring manoeuvre of ships	17.0 m/s	2.0 m/s	2.5 m
2. Sthips at berth (5)			
■ Swing anchorages	24.0 m/s	2.0 m/s	3.5 m/s
■ Two-anchor anchorages	30.0 m/s	2.0 m/s	4.5 m/s
■ Anchorages with bow and stern anchors			
Longitudinal actions	24.0 m/s	2.0 m/s	3.5 m/s
Transverse actions	Non-operational anchorage		
3. Approach and mooring manoeuvre	Depending on the equipment's characteristics		

C. DOLPHINS, BUOYS, BUOY FIELDS AND MONOBUOYS	Free-directed Mooring			Moorings of fixed direction (buoy fields,etc.)
	Monobuoys mooring	Minimonobuoys mooring (3)	Monodolphins mooring	
1. Approach and mooring manoeuvre				
■ Absolute wind speed $V_{10,\ 1\ min}$	17 m/s	17 m/s	17 m/s	10 m/s
■ Absolute current speed $V_{10,\ 1\ min}$	2.00 m/s	2.00 m/s	2.00 m/s	0.5 m/s
■ Wave height H_s	2.50 m/s	2.00 m/s	2.50 m/s	2.00 m/s
2. Staying of ship at anchorage				
■ Absolute wind speed $V_{10,\ 1\ min}$	30 m/s	24 m/s	30 m/s	30-22 m/s (4)
■ Absolute current speed $V_{10,\ 1\ min}$	2.00 m/s	2.00 m/s	2.00 m/s	2.00-1.00 m/s (4)
■ Wave height H_s	4.50 m/s	2.50 m/s	3.50 m/s	3.00-2.00 m/s (4)

Notes

$V_{10.1\ min}$ = Average wind speed, corresponding to 10 m height and 1 minute gust.
$V_{c.1\ min}$ = Average current speed, corresponding to a depth 50% of the dolphin's draught, in a one-minute time period.
H_s = Significant wave height on site, in the presence of thw work and without the ship (for more accurate researches the period effect will be considered).
Longitudinal = Wind, current or waves are considered as acting longitudinally when their direction range is ±45° with respect to longitudinal axis of ship.
Transversal = Wind, current or waves are considered as acting longitudinally when their direction range is ±45° with respect to transversal axis of ship.
(1) = Threshold values are referred to boarding and disembarking of passengers.
(2) = Threshold values are referred to limits in order ot keep an acceptable comfort of passengers on board.
(3) = Mooring to minimonobuoys or small buoys is usually applicable to fishing and sports vessels.
(4) = Firts number corresponds to actions longitudinally to ship and the second one to actions transversally to ship.
(5) = In those cases when the ship doesn't leave or cannot leave the berth because of operation conditions, but the treshold value of some climate agents is exceeded, storm mooring configurations for limit staying condictions must be foreseen in order to assure safety for both the ship and the structure, according to the extreme values of each climate agent. (See section 4.6.4.4.7).

formance, increasing the number of daily shifts of the port manpower,...) and/or increasing the operational hours in the terminal (working every day in the considered time period) should allow the same traffic to be serviced with a lower number of berths. The most convenient solution, amongst those possible on site, should be obtained using economical optimization research, selecting the solution which implies the least generalized global cost per ton, cargo or transport unit handled.

The methodology outlined to determine the number of berths needed to serve the expected fleet at berth with the traffic units expected, in the local and on-site operational conditions, may also be used in reverse order to estimate the capacity of a berthing line; that is, the maximum annual volume of goods that may be handled under those conditions (C_l). The formula to be applied in that case would be:

$$C_t = \frac{N_a \cdot \Phi \cdot t_{year} \cdot \sum_i \bar{C}_{u,i}}{\bar{t}_s \cdot \gamma_p}$$

Comment: as a guide, the current average values of berthing line capacity in Spain; that is, the average values of the maximum annual volumes per berth and per linear meter of dock, for container traffic considering a continuous dock, are as follows:

Table 3.2.1.4. Usual average values in Spain (2004) of the maximum annual volumes per berth and linear meter of dock, for containers traffic considering a continuous dock

NUMBER OF BERTHS	1-2	2-5	5-7	≥ 7
Total lenght	< 500 m	500-1,000 m	1,000-1,500 m	> 1,500 m
TEU/berth·year	80,000	120,000	170,000	190,000
TEU/m of berth·year	500	650	775	850

3.2.1.5 Total Length of the Berthing Line

3.2.1.5.1 Commercial, industrial and military use

The length of the berthing and mooring line (L_a) will be mainly determined as a function of:

- The number of required berths.
- The berthing line layout.
- The measurements of the maximum-length and type of ships expected to operate at the berthing installation.
- The type of traffic.
- The physical configuration adopted for the berth.
- The local climatic conditions.
- The configuration and size of the basin, as well as the structural typology of the harbor-forming structures.
- The proposed means for ship manipulation/maneuvering.

Isolated berth or two continuous berths in each alignment ($N_{a,\ aligment} \leq 2$)

The minimum length of the berthing line (L_a) should equal, per berth, the sum of the length corresponding to the longest ship ($L_{\max}$) plus the necessary safeguards between ships (l_0) and at both ends of the berthing structure (l). That is:

$$L_a = N_{a,alignment} \cdot L_{max} + (N_{a,alignment} - 1) \cdot l_0 + 2 \cdot l_s$$

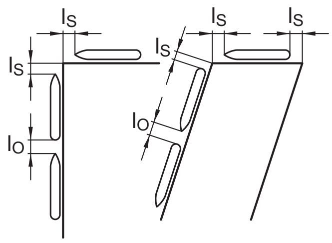
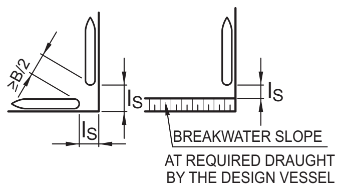
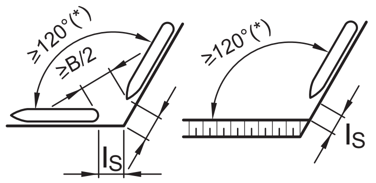
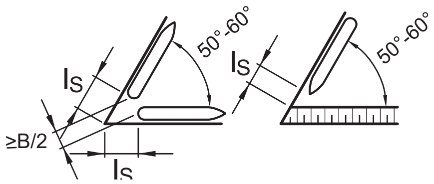
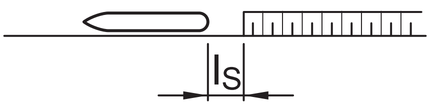
In Table 3.2.1.5 the recommended distances for the most general cases depending on the ship's length and the configuration and structural typology of the dock, are defined.

These dimensions consider the usual assumption that all berthed ships can provide long mooring lines from the bow and stern in normal conditions of up to 45° with the edge, so these dimensions may be less if the mooring system is modified. They also assume that the ships are not exposed to severe climatic conditions or are in sheltered waters. Other circumstances could imply the consideration, for simplicity, of distances twice those included in Table 3.2.1.5 or, more accurately, to gauge/assess the behavior of the moored ship with the configuration adopted for the mooring system in climatic conditions specified as the limit for staying the ship at berth, (See Section 4.6.4.4.7.1.1). In the latter case, it should also be verified that the ship has enough room for berthing and unberthing maneuvers.

In the case of berthing for dangerous goods, greater distances between ships than those included in Table 3.2.1.5. should be considered. The following considerations must be taken into account:

- The mooring lines of two berthed ships at the same alignment must not cross, which mandates a layout affording twice the distances, at least, of those recommended above.
- Specific regulations for the goods to be handled.
- Risk analysis for the loading/unloading of goods: risk of losses, safety conditions regarding other nearby traffic, etc.

Table 3.2.1.5. Recommended plan distances at berth alignments

DOCK REPRESENTATIVE LAYOUT	Variable values depending on total length (L in m) of the longer ship, affecting to determination of the analyzed dimension				
	Longer than 300	300-201	200-151	150-100	Shorter than 100 (1)
1. Distance "l_o" between berthed ships in the same alignment (m) 	30	25	20	15	10
2. Distance "l_s" between ship and alignment or structural typology changes (m)					
a) 	30	25	20	10	5
b) 	45/40	30	25	20	15
c) 	30/25	20	15	15	10
d) 	–/60	50	40	30	20
e) 	20	15	15	10	10

(1) For vessels with a total length shorter than 12 m "l_o" will be taken as 20% of "L", readjusting proportionally the remaining values.
(B) Width of the wider ship affecting the determination of the analyzed dimension.
(*) Angle limited to 160º. For higher angles (1) will be applied.

Due to the long distances required between ships for this type of traffic [(10)], discontinuous isolated berthing solutions are usually the most convenient in these cases, in order to optimize the berthing length.

More than two continuous berths in each alignment ($N_{a,\ alignment}$ > 2)

The minimum length of the berthing line (L_a) should equal the sum of the length corresponding to the longest ship (L_{max}) plus ($N_{a,alignment} - 1$) lengths corresponding to the typical length ship (L_b) defined (in section 4.6.4.4.1) plus the necessary safeguards between ships (l_0) and at both ends of the berthing structure (l_s).That is:

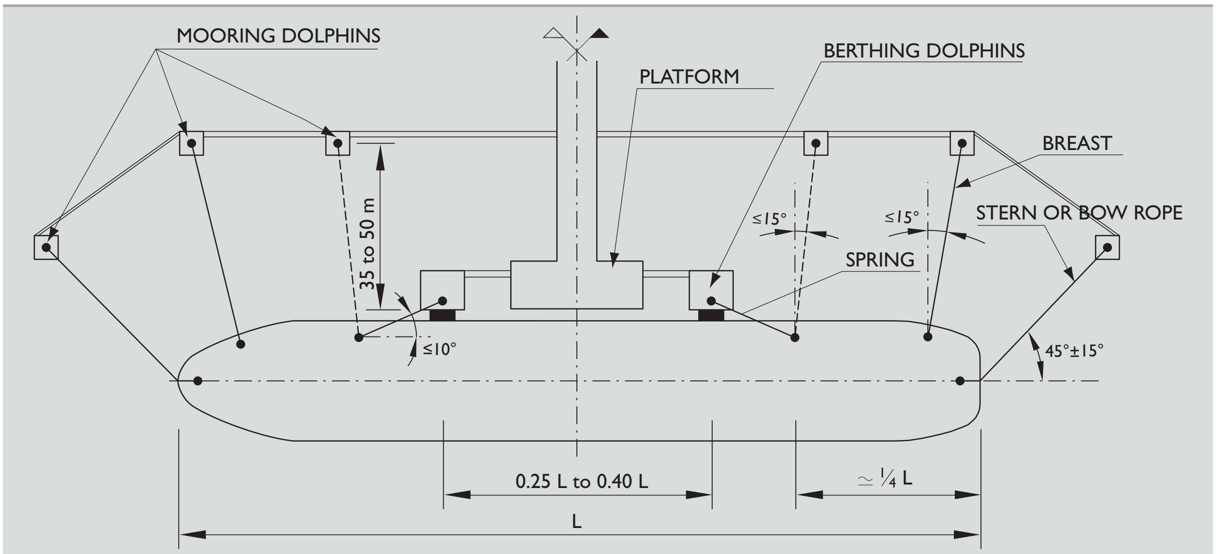
$$L_a = L_{max} + (N_{a,alignment} - 1) \cdot L_b + (N_{a,alignment} - 1) \cdot l_0 + 2 \cdot l_s$$

where safeguards are all defined as a function of the longest ship, in accordance with that previously outlined in the section on an isolated berth or two continuous ones.

In jetties that form discontinuous berthing lines corresponding to mixed solutions, in an isolated berth, the dimension of the berthing line consisting of two outer dolphins should be shorter than ¾ L of all ships anticipated at berth, so that the dolphins can maintain contact with the straight side of the hull, with a recommended value ranging from 0,25 L to 0,40 L (See Figure 3.2.1). If these conditions cannot be fulfilled for the entire fleet of expected ships, intermediate dolphins or fenders should be provided at the auxiliary loading platform. In cases where such a platform does not form part of the berthing structure, the dimensions of the same will be exclusively determined by the needs of the loading and unloading equipment (fixed equipment installed at a specific point or being able to roll to enter any point of the ship's holds) or by construction criteria. In the case of discontinuous berths accessible from both sides (discontinuous jetty) corresponding to mixed solutions, the above criteria will also be applicable.

The lengths corresponding to heels and ramps, where applicable, are not included as berthing lengths in the above formulas. Plan dimensions of heels and ramps are analyzed in section 3.2.1.6

Figure 3.2.1. Length of the berth alignment in isolated discontinuous berths



(10) Recommended ranges for security safeguards l0 in berths for dangerous goods
- Distance between a moored oil or crude or chemical products carrier and any other type of vessel: 30-100 m.
- Distance between a moored LNG gas carrier and any other type of vessel: 50-150 m.
- Distance between a moored LPG gas carrier and any other type of vessel: 30-150 m.

Recommended range for security safeguards (ls) is berths for dangerous goods: 30-100 m.
Recommended range for the distance between discharge points (manifolds) in berths for LNG and LPG gas carriers: 200-300 m.

In cases that include heels or ramps perpendicular to the berthing line (a typical layout of heels associated with continuous or discontinuous jetty type berthing configurations), safeguards between these and the ship, as provided for the comparable configurations shown in Table 3.2.1.5 should be considered, in order to leave sufficient room for berthing and unberthing maneuvers and also that the gangway of the ship does not have to occupy too much of the heel or ramp area. Likewise, when determining the length of the berthing line, the existence of a heel or ramp at one end of the berth should be treated as a change of alignment.

In the case of buoys, mono-buoys or buoy fields, one cannot properly speak of the berthing length, but rather the dimensions of the floating areas required for each of the necessary mooring points... Their dimensioning is a function of the adopted berthing configuration and other influential factors and is properly a maritime configuration problem and as such it is included in the ROM 3.1: The Design Configuration of Maritime Ports.

3.2.1.5.2 *FISHING USE*

For laterally berthed fishing boats, regardless of whether these are isolated berths or multiple berths in a single alignment, the berthing line length assigned to each boat may range between 1.0 to 1.5 times the length of the typical length ship (L_b), with the maximum values applicable to sites with significant tidal range or which are very exposed to wind and/or wave actions. These lengths, in stay and provisioning docks in Spain and under normal conditions usually allow 3 ships to be tied alongside and up to 6 in extraordinary conditions.

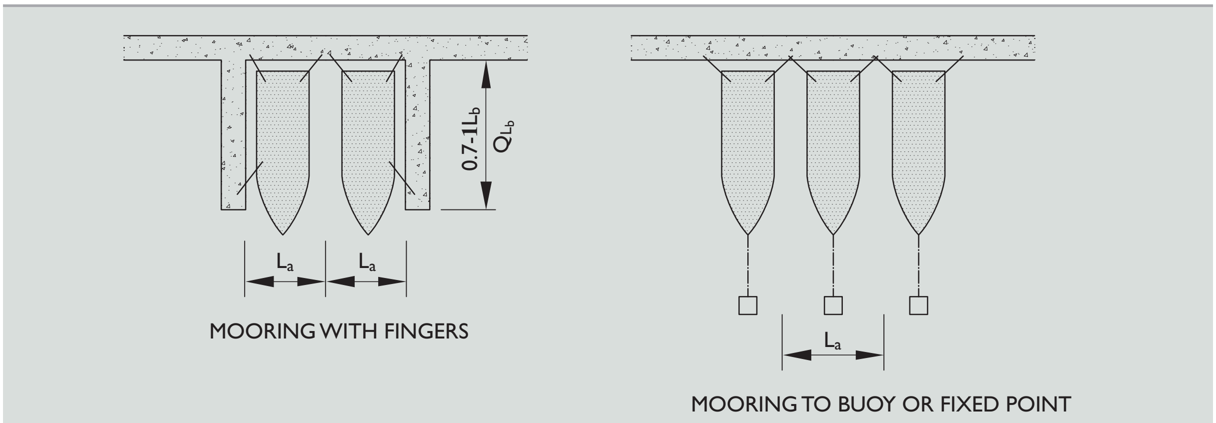
Perpendicular berthing (or Mediterranean berthing) tends to be used only for small boats (artisan fishing). In these cases, the calculation of the berthing length La follows the same rules set out in the following section for sport vessels.

3.2.1.5.3 *NAUTICAL AND SPORTING USE*

Although they can also dock lengthwise/sideways, nautical and sporting vessels are generally berthed perpendicular to berth (or Mediterranean berthing) at docks or fixed or floating jetties... Mooring is made to the dock or jetty and to auxiliary mooring elements (fingers) or to buoys or buoy fields (See Table 4.6.4.57). The length of the berthing line occupied depends on the width of the ship type and on the “thinning” or free spaces between ships, whose purpose is to allow berthing/unberthing maneuvers to be performed easily and safely and for the placing of small fenders between ships and between ships and fingers, as appropriate.

The length of the berthing line (L_a) assigned to each vessel, usually ranges between 1.15 and 1.25 times the width of the typical width ship (as defined in Section 4.6.4.4.1).

***Figure 3.2.2.* Length of the berth alignment occupied by a sport vessel perpendicularly berthed**



For those vessels not berthing perpendicularly to berth, the recommendations used to obtain the berthing length for fishing boats (L_a = 1 to 1,5 Lb) is also valid.

3.2.1.6 *Location and Dimensions of Heels and Ramps in Plan View*

At berthing installations where ship loading and unloading is totally or partially done using rolling means, docks and jetties should be complemented with heels whenever any of the ships included in the expected fleet at berth will conduct these operations through axial bow or stern ramps.

Heels are fixed or floating infrastructures, perpendicular to the berthing line, supporting the bow or stern ramps or the gangways of the berthed ship, either directly or through the interposition of ramps.

In order to facilitate loading and unloading ship operations using rolling means, and to ensure that they are carried out safely and efficiently within the range of variation of the considered outer water levels for the operational conditions of the berthing installation and for every ship load condition, the rolling handling equipment, vehicles, trucks, platforms and inter- modal transport units must bridge the differential level between the ship's hold or access deck and the top level of the berthing line installation, by observing the following two conditions:

- The maximum slope of inclined planes must not exceed 12.5%.
- The transitions between sloped planes must allow the smooth crossing of the rolling goods handling equipment, vehicles, trucks, platforms and intermodal transport units without them ever touching the structure or the ship's gangway. For this reason, the angle between said planes should range between 172° and 187° and the length of each plane must be greater than 5.0 m if placed between upward planes or between downward planes, and greater than 8.0 m if placed between an upward plane and a downward plane or vice versa in the direction of travel.

When at least one of the above conditions, cannot be met by means of a fixed heel, or with one or more sloped planes, it will be necessary to employ a floating heel and/or a mobile ramp... In such cases the choices are between:

- A mobile ramp which supports the ship's gangway, anchored on the sea-side by a fixed or floating structure, plus a fixed auxiliary heel, with or without sloped planes.
- A floating heel which supports the ship's gangway.

Consequently, the range of variation of the following characteristics of the expected fleet at the terminal must be ascertained:

- The height of the gangway's axis of rotation above the water level, in ballast and fully loaded.
- The length of the gangway.

In general, mixed Ro-Ro ships (Ferries and Ro-Pax) and pure Ro-Ro ships PTC (Pure Truck Carriers) have bow or stern gangways allowing them to reach the operating platforms at the top of the dock heels, with the maximum admissible slope, and, where appropriate, to access the ramps making contact with the ship around 1.50 to 3.00 meters above the outer water level in whatever loading situation, although there are also smaller ships (with Δ_{PC} < 10,000 t, in general) with gangways only reaching heights between 0.25 and 1.75 m. For these ships characteristics, when the difference between the maximum and minimum adopted operational levels for outer waters considering only long period sea oscillations (astronomical and meteorological tides and river flow regimes, where appropriate) or the outer waters operational window (also called operational tidal window) (11)

(11) In the presence of the minimum acceptable global operationality levels established in this Recommendation for berthing installations for general goods and passengers (See table 3.4.2.3) taking into account all the causes of operational stoppage (99%), it is worth considering that it is almost impossible to paralyze loading and unloading operations because of the outer water levels due to tides and river flow regimes, so that other sources of paralysis will really determine the operationality level of the terminal. In other words, the outer waters level due to tides and river flow regimes on site will not limit the operational capacity of the installation. Based on this

exceeds 1.50 m, solutions incorporating floating and/or mobile ramps should be adopted. In the latter case, the selection between floating heels with mobile auxiliary ramps or mobile ramps will depend on many factors, but mainly on the layout of the berthing line (mobile ramps need less room than floating heels) and on the need to misalign the ramp axis with the ship's longitudinal axis if there is no auxiliary heel, with a front perpendicular to the berthing line for each berth (floating heels allow this misalignment).

Fixed heels may serve a single berth or two berths situated either in a single alignment or in adjacent alignments with no reduction in the operational efficiency of the berth. On the contrary, mobile ramps and, generally, floating heels, serve a single berth, despite the fact that, where appropriate, they may share a fixed auxiliary heel.

In general, pure Ro-Ro ships configured as PCC (Pure Car Carriers) and PCTC (Pure Car and Truck Carriers) usually have additional side entrance gangways or ¾ gangways allowing them to operate without needing heels.

3.2.1.6.1 FIXED HEELS

Fixed heels usually have a rectangular shape in plan view.

3.2.1.6.1.1 Fixed heel serving a single berth

For a fixed heel serving a single berth, the plan dimensions are as follows (See Table 3.2.1.6.A.):

- *The transverse dimension ($l_{T,heel}$) in the direction perpendicular to the longitudinal axis of the ship:* The minimum heel dimension in the direction perpendicular to the longitudinal axis of the ship, measured from the berthing line, should equal the width of the "maximum width ship" of the expected fleet at berth (B_{max}), with a minimum of 32 m, plus the distance between the berthing line and the uncompressed fender line (c).

- *The longitudinal dimension ($l_{L,heel}$) in the direction of the longitudinal axis of the ship or of the berthing line:* The minimum heel dimension in the direction of the longitudinal axis will depend on the characteristics of the ships of the expected fleet, particularly on the operationality levels their ramps are able to reach, on the crown level of the berthing line according to the established outer waters operational window, and on the heel location in relation to the operation area.

  Assuming the crown level of the berthing line to be those recommended in section 3.2.2.1 for operational criteria (2,50 m above the upper operationality level defined for outer waters in ships exceeding 10.000 t of full load displacement and +1.50 m for ships up to 10.000 t of displacement), the minimum longitudinal dimension in plan view assigned to the sloped sections of the heel will not generally exceed 10,0-12.50 m respectively, of which 4.00 m corresponds to the area reserved to support the ship's ramp and 1.00 m to the sea-side safety interface, thus ensuring that the stipulated longitudinal gradients are preserved for rolling loading and unloading operations (see section 3.2.2.3.: Longitudinal profile of Heels

---

criterion, in order to design the heels, it is recommended to determine those upper and lower levels of outer waters, defining the operational tide window, as associated with the following options:
– For the upper level of the operational tidal window, the level assigned to an exceedance probability of 10^{-3} in the average annual regime of the upper waters level corresponding to tides and river flow regimes on site, will be considered.
– For the lower level of the operational tidal window, the level assigned to a non-exceedance probability of 10^{-3} in the average annual regime of the lower waters level corresponding to tides and river flow regimes on site, will be considered.
When the average regimes of outer water levels corresponding to tides on site are not available, it may be simply assumed that the agent levels used to define the operational tide window assigned to the mentioned probabilities are:
– In seas with significant astronomical tide: HAT (highest astronomical tide) and LAT (lowest astronomical tide).
– In seas without significant astronomical tide: ± 0.5 m with respect to the mean sea level.

and Ramps). Whenever the crown level of the berthing line is higher or lower than those indicated above, the minimum length should be adopted in order to keep the longitudinal gradients within permissible ranges.

In order to ensure that turns and other maneuvers of the transport units and handling equipment used for rolling loading and unloading operations can be performed safely and efficiently, irrespective of the heel location relative to the operation area and the operating conditions of the berthing installation, the minimum longitudinal heel dimension is recommended to be increased by an additional 15 m whenever the loading or unloading operation is expected to be done using two lanes on the heel or the ship's access ramp; that is, up to 25.0-27.5 m for the longitudinal dimension of the 10.0-12.50 m sloped sections in plan view. Whenever this operation may be carried out using more than two lanes, bearing in mind the "maximum width ship" of the expected fleet at berth, this dimension should be increased by 7.5 m for each additional lane. Also, whenever front-loaded forklifts are expected to load and unload goods from the ship, the minimum longitudinal heel dimension should be increased from 15 to 26 m when the operation is done using two lanes, so 13 meters should be added for each additional lane.

3.2.1.6.1.2 Fixed heel serving two berths situated in the same alignment

For a fixed heel serving two berths situated in the same alignment, the plan dimensions are as follows (See Table 3.2.1.6.B.):

- The minimum heel length in the direction perpendicular to the ship's longitudinal axis, measured from the berthing line ($l_{L,\,heel}$), is the same as that defined in the case of a fixed heel serving a single berth.
- The minimum heel length in the direction of the ship's longitudinal axis will be twice that defined for the case of a fixed heel serving a single berth, and is recommended not be less than 50-55 m for the longitudinal dimension in plan view of the sloped sections corresponding to each berth measuring between 10.0- and 12.5 m and bearing in mind that loading or unloading operations may be performed using two lanes per heel or per ship access ramp.

These dimensions must be modified when the number of lanes is more than two or when front-loaded forklifts are used to load and unload the ship's goods, according to the criteria established for this purpose in the corresponding section on a fixed heel serving a single berth.

3.2.1.6.1.3 Fixed heel serving two berths situated in different alignments

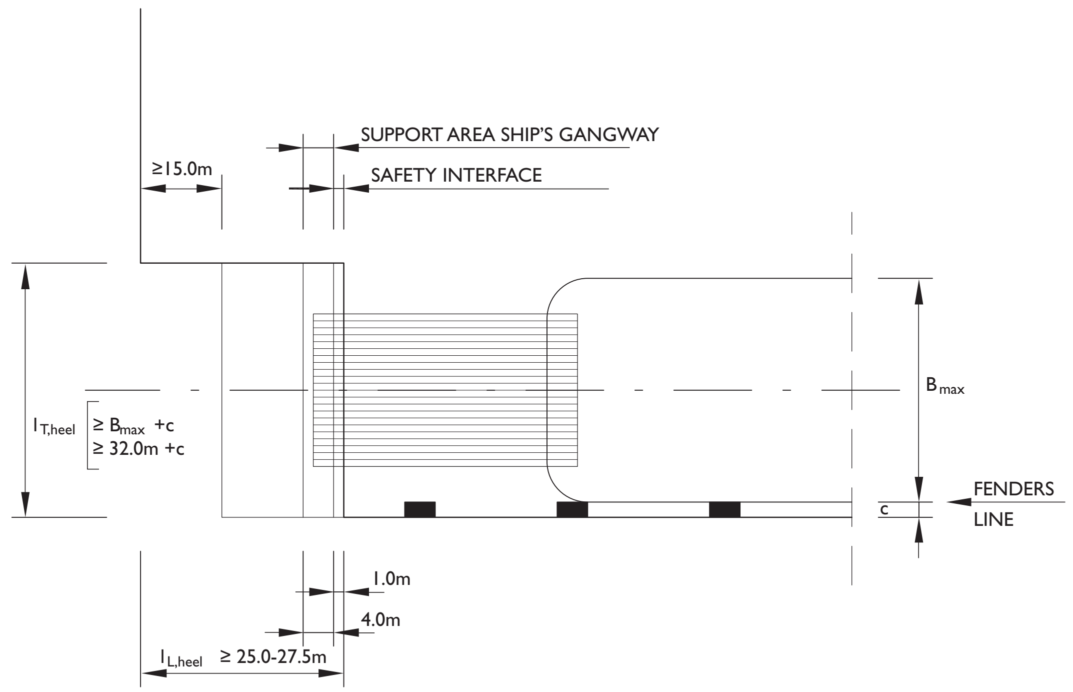
For a fixed heel serving two berths situated in different alignments, the plan dimensions are as follows (See Table 3.2.1.6.C.):

- One of the dimensions ($l_{1,heel}$), measured from the corresponding berthing line, should equal, as a minimum, the width of the "maximum width ship" of the expected fleet (B_{max}), with a minimum of 32 m, plus the distance between the berthing line and the uncompressed fender line (c), plus the longitudinal dimension in plan view of the inclined sections corresponding to each berth, defined according to that stipulated in the case of an isolated berth (in general 10.0-12.5 m), plus 15 additional meters to allow simultaneous loading and unloading operations without interference between the two berths in the instances when loading or unloading operations are performed with two lanes per heel or per ship access ramp.
- The other dimension ($l_{2,heel}$) will be at least equal to the one listed above, minus the additional length included in the same to facilitate loading and unloading operations without interference between the two berths. That is: $l_{2,heel} = l_{1,heel} - 15$ m.

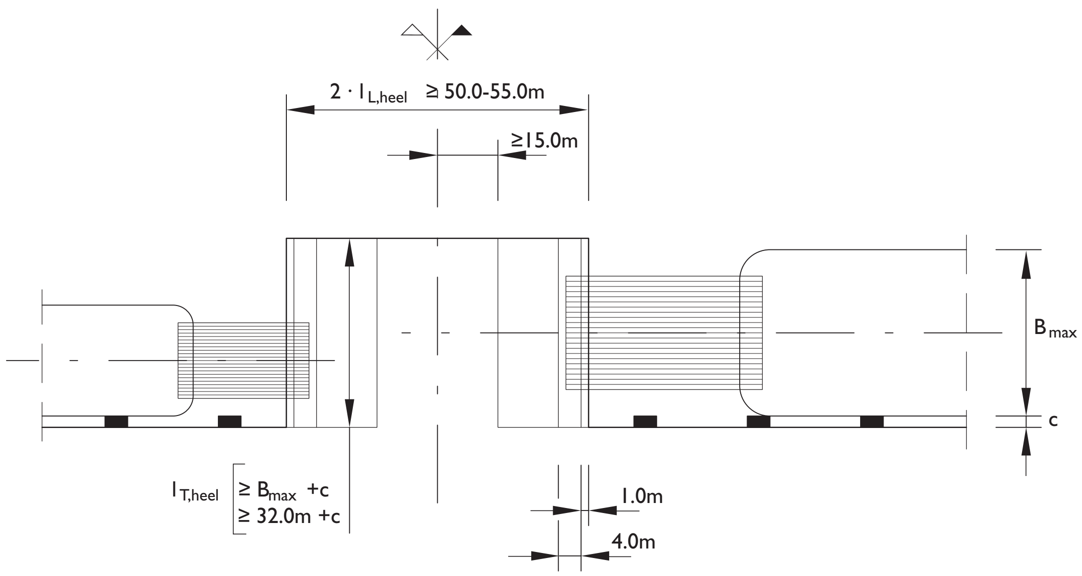
These dimensions must be modified when the number of lanes is greater than two or when front-loaded forklifts are used to load and unload the ship's goods according to the criteria established for this purpose in the corresponding section on a fixed heel serving a single berth.

Table 3.2.1.6. *Location and plan dimensions of fixed heels*

A. HEEL SERVING A SINGLE BERTH

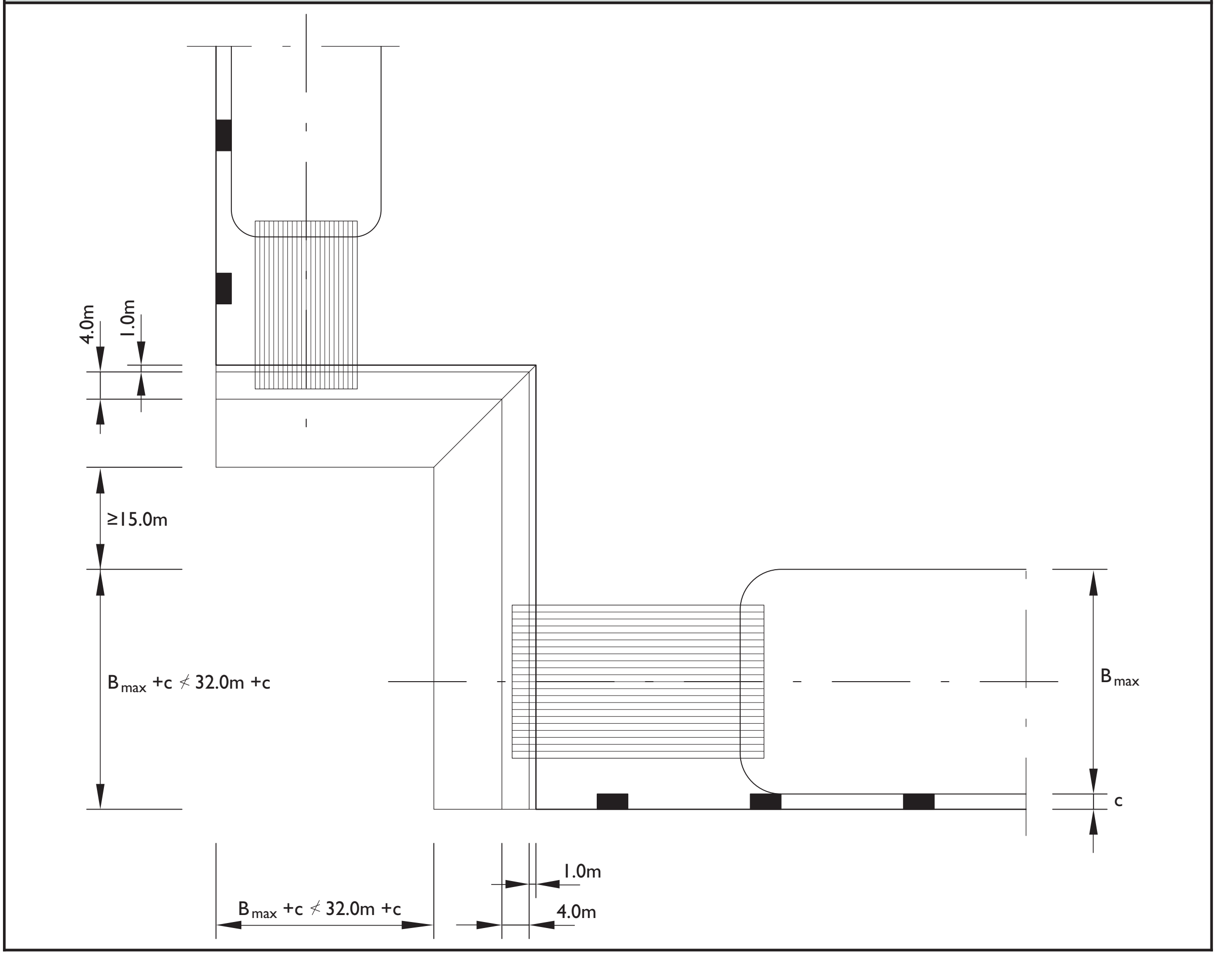


B. HEEL SERVING TWO BERTHS LOCATED AT THE SAME ALIGNMENT



Location and plan dimensions of fixed heels (continued)

C. HEEL SERVING TWO BERTHS LOCATED AT DIFFERENT ALIGNMENTS



3.2.1.6.2. MOBILE RAMPS WITH AUXILIARY FIXED HEELS

3.2.1.6.2.1. Movable ramps

The plan dimensions of mobile ramps are as follows (See Table 3.2.1.7):

- *The transverse dimensions ($l_{T,movable\ ramp}$) in the direction perpendicular to the longitudinal axis of the ship:* The minimum transverse dimension of the mobile ramp on the sea-side edge should be equal to the width of the widest entrance gangway of the ships in the expected fleet plus 3 m [see section 4.6.4.4.6.1] or to the width of the "maximum width ship" of the expected fleet (B_{max}), with a minimum of 32 m, measured from the uncompressed fender line, plus the maximum deformation of the berthing fenders (δ_f). This transversal dimension should be maintained, without variation, both at the safety interface and in the area reserved for supporting the ship's gangway (1.00 m and 5.00 m, respectively, in the direction of the longitudinal axis of the ship).

  The axis of the ramp in the land hinge line should be perpendicular to the sea-side edge of the ramp in its midpoint. The minimum transverse dimension of the ramp at that section will depend on the number of access lanes considered [12], plus 1.5 additional meters on each side for service aisles and to affix barriers and safety elements. The minimum total transverse dimensions recommended for this section are:

(12) The number of lanes influences the net productivity of the loading and unloading subsystems of the ship (See section 3.2.1.4).

- 4.50 m + 3.00 m for one lane.
- 8.00 m + 3.00 m for two lanes.
- 12.00 m + 3.00 m for three lanes.
- 16.00 m + 3.00 m for four lanes.

When the ramp is to be used exclusively for motor vehicles, whether as good or as passenge , the dimensions of the lane area may be reduced by 1.00 m. Whenever front-loaded forklifts may be used for loading and unloading ship's goods, the dimensions of each lane should be increased by 8.0 meters.

The transition between the ramp's transverse dimension at the inner boundary of the area reserved for the support of the ship's gangway and the land hinge line should allow turns and maneuvers of the transport units and handling equipment used for rolling loading and unloading operations to be made safely and efficiently. Accordingly, for the most eccentric position of the ship's gangway, trajectory deviations should be limited to 4 (longitudinal) by 1(transversal) (see Table 3.2.1.7) for the transport units and handling equipment.

- *The longitudinal dimension of the mobile ramp* (IL,mobile ramp) *in the direction of the longitudinal axis of the ship:* The minimum dimension of the mobile ramp in the longitudinal direction is that which will ensure that the longitudinal slope between the crown level of the ramp at the inner boundary of the area reserved to support the ship's gangway and the crown level of the land hinge line does not exceed 10% at any time. The longitudinal dimension between the ramp's sea-side edge and the inner boundary of the area reserved to support the ship's gangway is 6.0 m, of which 5.0 m corresponds to the area reserved to support the gangway and 1.0 m to the safety interface.

  In order to determine this parameter, it is necessary to ascertain the maximum and minimum levels which will reach the inner boundary of the safety interface, the slope of the area reserved to support the ship's gangway and the crown level of the land hinge line.

  The crown levels of the sea-side edges of the mobile ramps should cover the entire range of operational levels of the bow and stern gangways of the ships in the fleet expected at the berthing installation.

  - For mobile ramps supported on the sea- side by fixed structures, including lifting devices capable of moving the ramp (See Table 3.2.2.5), given the typical operating levels of the ship's bow and stern gangways above the outer waters level (see section 3.2.1.6), the crown levels of the edge of the mobile ramp, measured at the inner boundary of the safety interface should range, in general, between the following levels (see section 3.2.2.3.: Longitudinal profile of Heels and Ramps), to give service to all types of ships:

    – Minimum upper level: the upper level of the outer waters operational window + 1.50 m.
    – Maximum lower level: the lower level of the outer waters operational window + 1.75 m.

    When all the ships of the expected fleet at berth have a full load displacement greater than or equal to 10,000 t, the minimum upper level and maximum lower level of the mobile ramp, measured from the inner boundary of the safety interface, will be:

    – Minimum upper level: the upper level of the outer waters operational window + 1.50 m.
    – Maximum lower level: the lower level of the outer waters operational window + 3.00 m.

    If, on the other hand, all the ships of the expected fleet at berth have a full load displacement less than 10,000 t, then the minimum upper level and maximum lower level of the mobile ramp, measured from the inner boundary of the safety interface will be:

    – Minimum upper level: the upper level of the outer waters operational window + 0.25 m.
    – Maximum lower level: the lower level of the outer waters operational window + 1.75 m.

- *In the case of mobile ramps supported on the sea-side by floating means* (See Table 3.2.2.6), the ramp's freeboard at the inner boundary of the safety interface should not be more than 1.75 m for an unloaded ramp and not less than 1.50 m for a fully loaded ramp, in order to serve all types of ships.

  When all the ships of the fleet expected at the berth have a full load displacement greater than or equal to 10,000 t, that freeboard should not be more than 3.00 m for an unloaded ramp and not less than 1.50 m for a loaded ramp.

  If, on the other hand, all the ships of the fleet expected at berth have a full load displacement less than 10,000 t, that freeboard should not be more than 1.75 m for an unloaded ramp and not less than 0.25 m for a loaded ramp.

  Therefore, the crown levels of the considered ramps for the purpose of defining their longitudinal dimension, in the case of ramps supported on the sea-side by floating means will be:

  – Upper level: the upper level of the outer waters operational window + the maximum freeboard of the ramp.
  – Lower level: the lower level of the outer waters operational window +the minimum freeboard of the ramp.

According to the longitudinal dimension and the recommended slope of the area reserved for the support of the ship's gangway (see section 3.2.2.3), the difference in crown level s between the inner line of the safety interface and the interior of the area reserved for the support of the gangway is 0.62 m when the slope between the onshore crown level and the inner boundary of the area reserved for the support of the ship's gangway is 10%.

The crown level of the ramp's land hinge line may be situated at any elevation that is at least 1.50 m above the upper level of the outer waters operational window. It should be placed at the level that, meeting the above condition, will result in the shortest longitudinal dimension of the mobile ramp.

3.2.1.6.2.2 Auxiliary Fixed Heels

The mobile ramp's land hinge line should be situated on a fixed auxiliary heel, with or without inclined planes, depending on whether or not the crown level of the hinge line coincides with the crown level of the berthing line. The plan dimensions of the auxiliary fixed heels are as follows (See table 3.2.1.7):

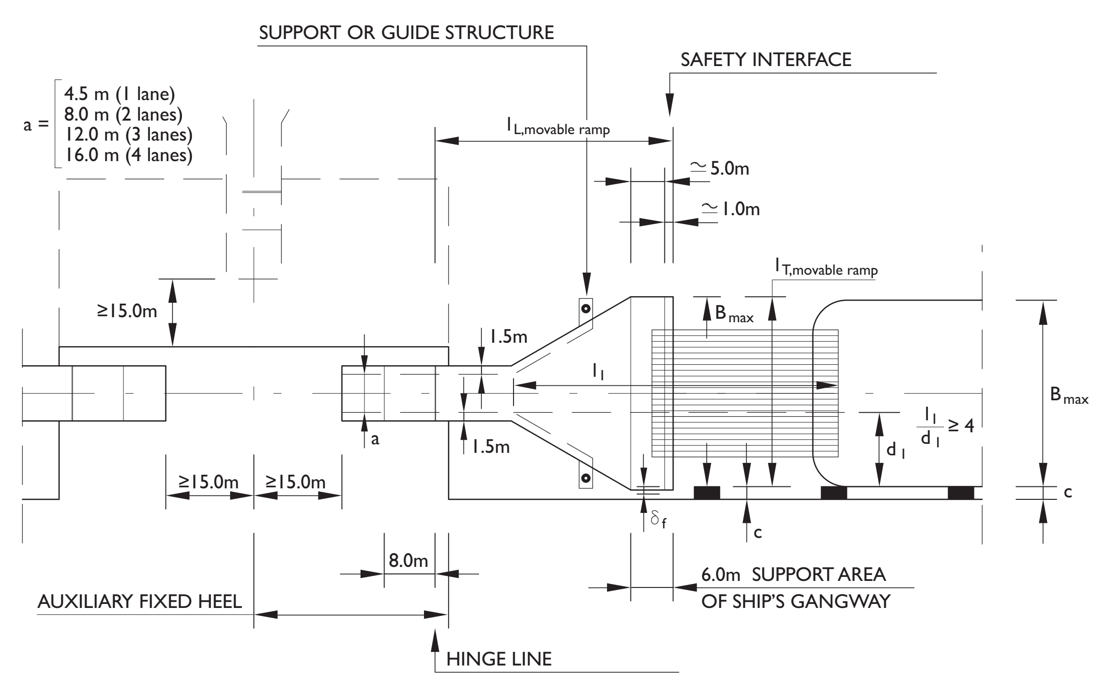
- The transverse dimension in plan view of the auxiliary fixed heel should be at least as long as the one at the ramp's land hinge line.
- The minimum longitudinal dimension in plan view of the auxiliary fixed heel will depend on the crown level of the berthing line with respect to the level of that situated in the mobile ramp's hinge line, the heel's location relative to the operation area, and the number of berths served by the auxiliary fixed heel (a single berth, two in the same alignment or two cater-corner). Where appropriate, the auxiliary fixed heel's sloped panes must conform to the stipulated maximum longitudinal gradients and the necessary alignment between the sloped planes: a maximum slope of 10% and a horizontal segment measuring a minimum of 8 m between an upward sloped plane and a downward one (see sections 3.2.1.6 and 3.2.2.3.: Longitudinal profile of Heels and Ramps).

  For a fixed heel serving a single mobile ramp, in order to allow turns and other maneuvers of the transport units and handling equipment used for rolling loading and unloading operations to be performed safely and efficiently, regardless of the disposition of the auxiliary fixed heel and/or ramp relative to the operation area and the explotation conditions of the terminal, the heel's minimum longitudinal dimension is recommended to be increased by 15 m from the starting line of the sloped segments when loading and unloading operations are carried out using two lanes on the heel or access ramp of the ship.

When using more than two lanes or when front-loaded forklifts are used to load and unload the ship's goods these dimensions should be modified in accordance with the criteria outlined in the section corresponding to a fixed heel serving a single berth.

For a fixed heel serving two mobile ramps at the same or different alignments, additional space is recommended to be provided in order to allow the transport units and handling equipment sufficient room to maneuver simultaneously and without interference between berths, according to the layout depicted in table 3.2.1.7.

Tabla 3.2.1.7. ***Location and plan dimensions of movable ramps and auxiliary fixed heels***



3.2.1.6.3 Floating heels and auxiliary ramps

3.2.1.6.3.1 Floating Heels

Floating heels generally have a rectangular-shaped plan. Their dimensions should be (See table 3.2.1.8):

- The transverse dimension of the floating heel ($l_{T,floating\ heel}$) in the direction perpendicular to the longitudinal axis of the ship: the transverse dimension in plan view of the floating heel in the direction perpendicular to the longitudinal axis of the ship, measured from the compressed fender line is the same as that recommended for the mobile ramp's sea-side edge.

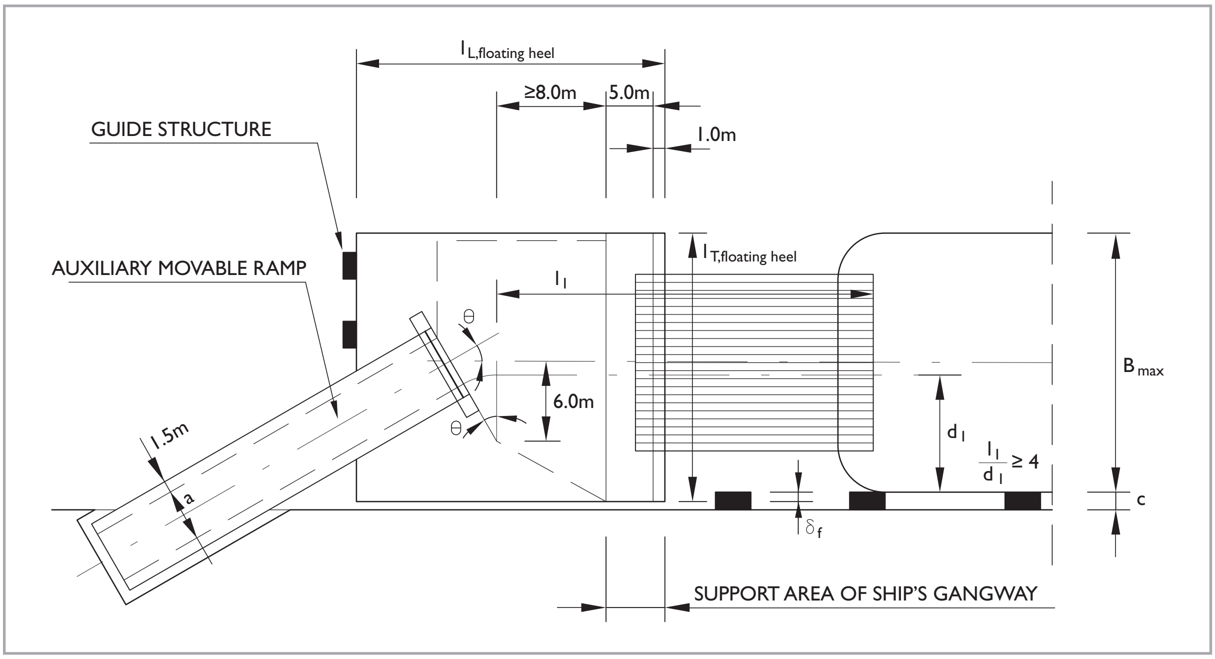
- The longitudinal dimension of the floating heel ($l_{L,floating\ heel}$) in the direction of the longitudinal axis of the ship: the minimum longitudinal dimension in plan view of the floating heel in the direction of the longitudinal axis of the ship, will be generally conditioned by the buoyancy, stability and maintenance requirements of the heel's freeboards. In any case, as a minimum, it should accommodate the safety interface (1.0 m), the area reserved for supporting the ship's gangway (5.0 m) and the transition area between the heel's transverse dimension at the inner boundary of the area reserved for supporting the ship's gangway and the transverse dimension of the auxiliary ramp at its support line with the heel, necessary to allow the transport units and handling equipment assigned to the rolling loading and unloading operations to turn and maneuver safely and efficiently. The transverse dimensions of the auxiliary ramp, as well as those of the transition area, may be obtained from the criteria established for this purpose outlined in the section corresponding to mobile ramps, considering, where appropriate, the possibility that the auxiliary ramp's axis may not be perpendicular to the seaside edge of the floating heel and that the dimensions may need to be adjusted accordingly.

To maintain the necessary alignment between the rolling surfaces of the ramp and the floating heel, an additional condition must be imposed: the minimum distance in the direction of the longitudinal axis of the ship between the inner edge of the gangway support area and the auxiliary ramp support line on the floating heel should not be less than 8.0 m.

3.2.1.6.3.2 Auxiliary ramp

The minimum dimension of the auxiliary ramp should be that which ensures that the longitudinal gradient between the support levels on the floating heel and those on the berthing line or, where appropriate, on the auxiliary fixed heel, will not exceed 10% in any case (See table 3.2.1.8).

Tabla 3.2.1.8. ***Location and plan dimensions of floating heels and auxiliary ramps***



To calculate this length, the minimum and maximum crown levels at the inner boundary of the safety interface, as well as the slope between the inner boundary of the safety interface and the auxiliary ramp support on the floating heel must first be determined. For the upper and lower crown levels of the floating heel, measured from the inner boundary of the safety interface, the same levels defined for mobile ramps supported on the seaside by floating means may be adopted here. Also, in accordance with the longitudinal dimensions and recommended slopes at each zone of the floating heel (see section 3.2.2.3), 0.125 m may be adopted as the elevation difference between the inner boundary of the safety interface and the floating heel's auxiliary ramp support line.

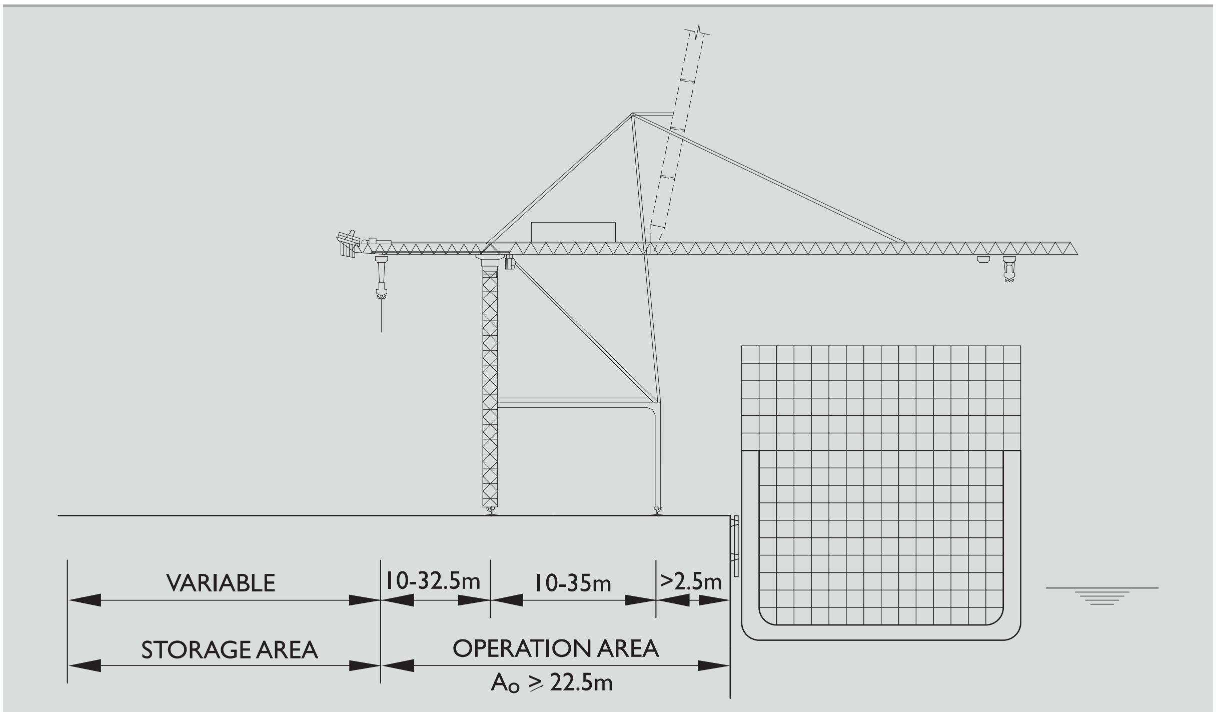
Secondly, the crown level adopted for the auxiliary ramp support, either directly on the berthing line or on an auxiliary fixed heel must be determined. When a mobile auxiliary ramp rests on an auxiliary fixed heel, the support level may be located at any elevation which is at least 1.50 m above the upper level of the operational tide window. This is recommended to be placed at the level resulting in the shortest longitudinal dimension of the auxiliary ramp, observing the last condition. In this case, to determine the dimensions of the auxiliary fixed heel, the criteria established for this purpose included in the section on mobile ramps should be applied.

3.2.1.7 Width

The width of a berthing and mooring structure (A_m) is defined as the average of those dimensions perpendicular to the berthing line necessary to enable the port operations of loading and unloading, storage and removal/reception of the expected traffic to be carried out in the local exploitation conditions with the requisite safety and service levels.

In order to determine the necessary width of the berthing and mooring structure for commercial uses, the operating, storage, auxiliary and complementary service areas should be differentiated (See figure 3.2.3):

Figure 3.2.3. Differentiation of land areas in a dock-type berthing installation, with commercial use and rail rolling equipment as the system for loading and uploading. Definition of widths



3.2.1.7.1 Operation area

The operation area is the area closest to the berthing line, dedicated to the activities of loading and unloading of ship's goods or to the boarding and disembarking of passengers from the same.

For each type of berthing installation, defined in terms of physical configuration (dock, jetty, etc.) and use (commercial, industrial, fishing, etc.), the general layout of the operation area, as well as its dimensions, depend on the following operational factors:

- The characteristics and amount of loading and unloading equipment for ship's goods and on the equipment for the boarding and disembarking of passengers, as well as, in the case of ship loading and unloading by rolling means, the tracks of self-propelled vehicles and auxiliary equipment used during the loading and unloading operations.

- The characteristics and equipment used for interior interconnection between the operations area and the goods storage area.

- The location of service areas or auxiliary or complementary operation areas associated with the ship and with its loading and unloading operations: temporary goods storage, placing of the ship's hold's covers, needs related to servicing the ship or/and the dock, etc...

The width of this area (A_0) will usually range between a minimum value of around 22.50 m and values higher than 100 m, depending on the physical configuration of the berth, the proposed handling systems at the berthing line and the operations required for loading and unloading and for interior interconnection between the operation area and the storage areas. Nevertheless, some reductions of that minimum value may be acceptable in continuous or discontinuous jetties (13), berthed only on one side, when neither goods handling equipment using lifting means, nor ship loading/unloading by rolling means, nor passenger boarding/disembarking is expected, down to a minimum of 12.5 m. When the passenger boarding and disembarking is expected, the minimum width for jetties increases to 15.0 m. To define the most appropriate dimension for this area, the following criteria should be considered:

- *For commercial use berthing installations with dock-type physical configurations employing restricted rolling equipment on rails for goods loading and unloading systems or for passenger boarding and disembarking:*

  a) The distance between the berthing line and, as appropriate, the rolling axis of the sea-side crane, or the ship's loading/unloading system or the passenger boarding/disembarking system, should not be less than 2.5 m, so that the necessary mooring system elements and other auxiliary ship elements (bollards, etc.) may be placed in this area, along with services.
  b) The space occupied by the rolling area of the loading/unloading equipment or by passenger boarding/disembarking equipment and typically by the transit lanes used to transfer goods to (or from) the ship to the land transport means, according to the established protocols, or for their provisional storage, as well as for auxiliary ship operations at the berth. In general, this distance will range between 10 m (2 traffic lanes) and 35 m (6 traffic lanes) if tractor-semitrailer units or multi-platform systems are used to interconnect the operation and storage areas. When straddle or shuttle type carriers are used for the interconnection, the above distances will range between 15 m (2 traffic lanes) and 39 m (6 traffic lanes). For exclusively passenger traffic, the minimum distance may be reduced to 7.5 m (1 lane).
  c) The zone between the loading/unloading equipment rolling area and the storage area boundary, the width of which should vary between 10 m and 32.5 m, depending on the land reach of the cranes and on the space reserved for auxiliary tasks such as the storage of the ship's hold's covers, as well as for cargo transfer operations, when appropriate. If unconventional container gantry cranes like the low profile models are used, then this distance may exceed 100 m. For exclusively passenger traffic the minimum distance may be reduced to 2.5 m.

Comment: *According to this section, in the specific case of a berthing installation for container use, the width of the operation area will usually range between a minimum value of about 30 meters, for container cranes for feeder ships with a capacity of less than 3,000 TEU, and values of more than 70 m, when container cranes are used for Malaccamax ships with a capacity greater than 12,000 TEU. Even longer dimensions may be deployed (around 125.00 m) for low profile cranes, whose stationary crane booms must be housed inside the operation area. The most common dimension for the operation area, associated with conventional container cranes with standard distances between lanes of 30.5 m, is about 50 m. These dimensions allow up to 6 traffic lanes between the crane legs for tractor plus semitrailer type auxiliary cargo transfer equipment (MTS), up to 4 lanes for SC (Straddle Carrier) type equipment, and up to 5 lanes for AGV (Automatic Guided Vehicle) equipment. In every case, an additional lane is recommended for unexpected emergency situations and to service the ship and the dock. This also provides a temporary covered storage area within reach of the crane for up to 5 rows of containers or 3 rows of containers and the ship's hold's covers.*

(13) In discontinuous jetties, the width of the operation area refers to the width of the auxiliary platform.

- *For commercial use berthing installations (excepting passengers) with dock- type physical configurations using goods loading and unloading systems by rolling:*

  a) The distance between the ledge line or berthing edge and the outer edge of the outer sea-side transit lane for self-propelled vehicles and, when appropriate, auxiliary transport and towing equipment, comprising the inner interconnection system between the ship's loading/unloading subsystem and that of storage, in order to allow 90° rotation of these vehicles and auxiliary equipment without interference between transit lanes. The minimum recommended distances as a function of the type of heel or ramp, are as follows:

     - In berthing installations with dock-type physical configurations with fixed heels or mobile ramps supported on auxiliary fixed heels, for ships operating using bow or stern axial ramps, the recommended distance between the berthing line and the axis of the outermost sea-side transit lane is about 35 m.
     - In berthing installations with dock-type physical configurations without heels (ships operating using lateral or ¾ ramps as well as axial ramps using floating heels and auxiliary ramps directly supported on the dock), a distance of about 20 m between the innermost land position reached by the ship's ramp or the auxiliary ramp on the dock and the axis of the outermost sea-side lane is recommended.

  b) The distance between the sea and land boundaries of the outermost lanes comprising the inner inter- connection system between the ship's loading/unloading subsystem and that of storage. The minimum recommended width of each lane, as a function of the maximum width of the vehicles or auxiliary cargo equipment, will be:

     - 3.50 m at berthing installations exclusively devoted to loading and unloading of self-propelled vehicles and road-driven goods transport elements (e.g. import-export vehicle terminals and terminals linked to "Motorways of the Sea").
     - 13.00 m in general Ro-Ro berthing installations where can be operated with auxiliary transport and towing equipment operations.

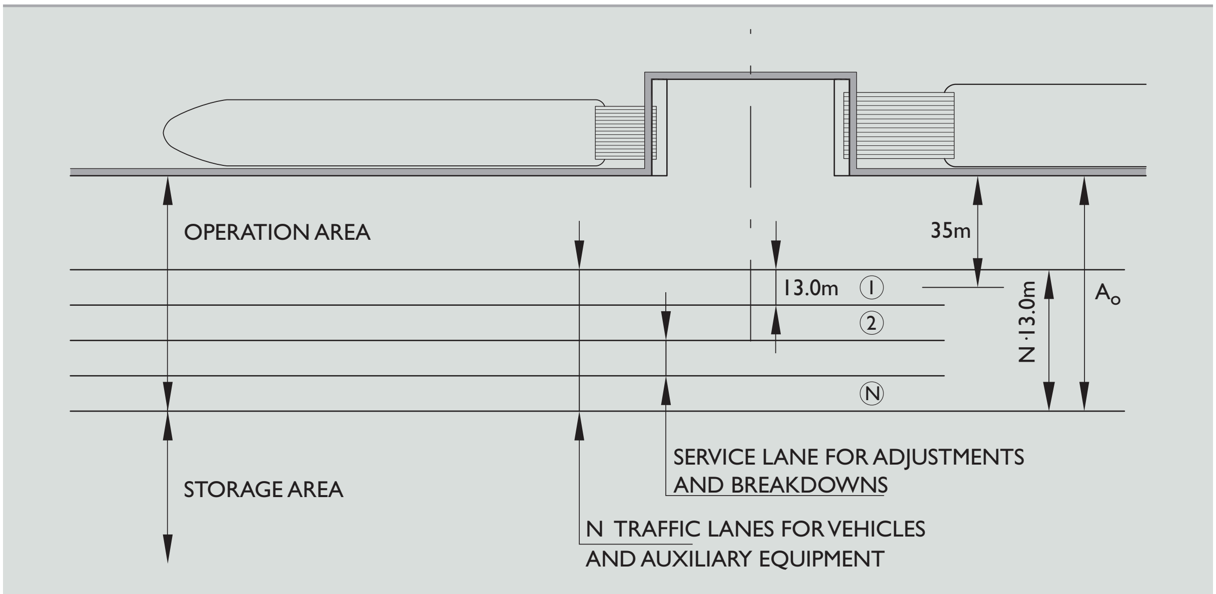
     To determine the number of lanes, the number of lanes on the heel or ship's access ramp, per berth, available to simultaneously perform the ship's loading and unloading operations with the selected vehicles and auxiliary equipment, as well as the organization and routes of the self-propelled vehicle and, when appropriate, the auxiliary equipment associated with same, including a service lane for adjustments and breakdowns, should be taken into consideration.

  A diagram of the plan dimensions of the operation area of a prototype Ro-Ro berthing installation with a dock-type physical configuration with fixed heels is included in figure 3.2.4.

  These dimensions are also applicable to multipurpose Ro-Ro and passenger (Ro-Pax terminals) berthing installations, because the operation area between the berthing line and the vehicle and auxiliary equipment lane's sea-side edge has enough space to accommodate the last section of the mobile gangway used for passenger boarding and disembarking, which is normally supported by restricted mobility rolling gantries on rails.

  These dimensions are also applicable to multipurpose commercial use berthing installations, simultaneously employing goods loading and unloading systems using restricted rolling equipment on rails and by rolling (e.g. Con-Ro terminals), provided that there are no more than two berths per alignment and the circulation routes of the vehicles and auxiliary equipment associated with the loading and unloading operations carried out with equipment on rails and with the Ro-Ro operations do not share the same zones in the operation area along the berthing line. In these cases, the dimensions in plan view of the operation area in the direction perpendicular to the berthing line at each zone associated with each type of operation, may be respectively obtained according to those established for that purpose in the sections corresponding to the dimensioning of the operation area of each of the said operations.

Figure 3.2.4. ***Recommended plan dimensions of the operation area for a berthing installation of dock type with fixed heels, commercial use and using loading and unloading rolling systems by means of all kind of auxiliary handling equipment***



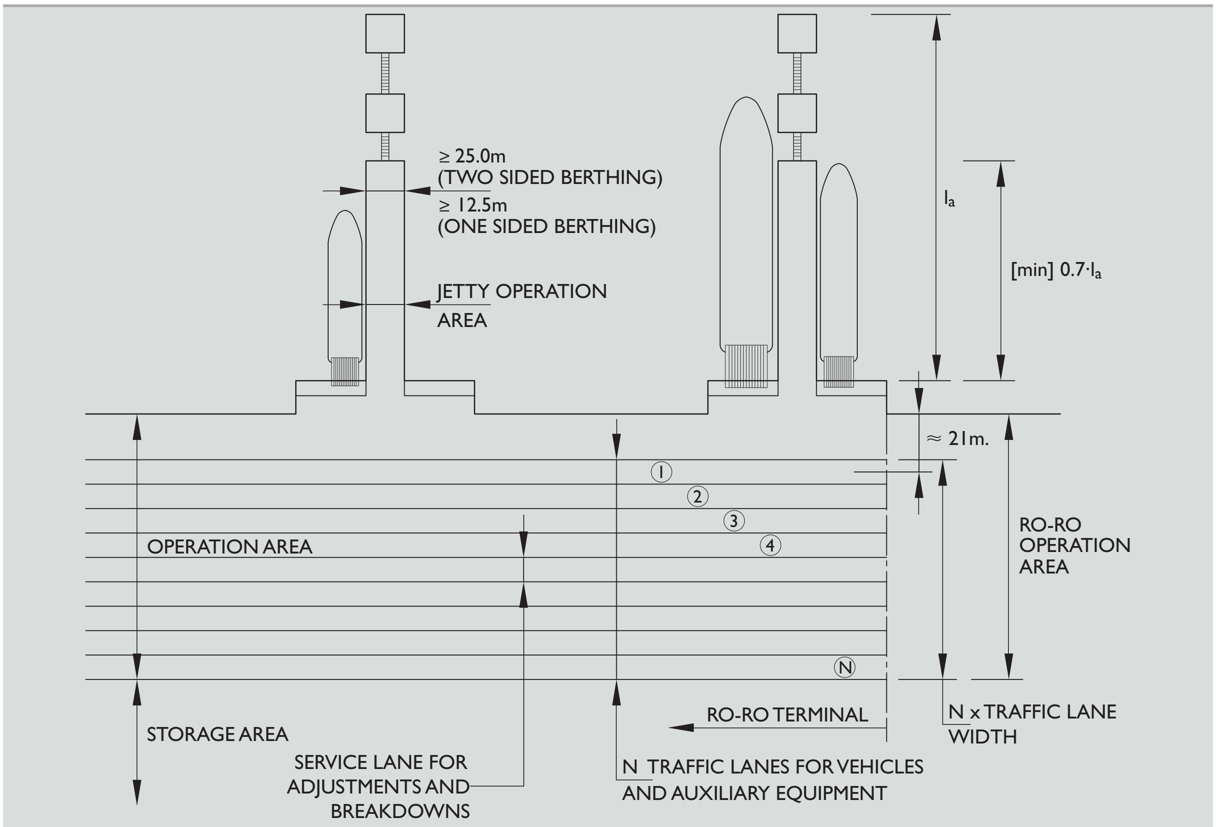
Comment: According to this section, the transverse dimension of the operation area in Ro-Ro berthing installations with a dock-type physical configuration, provided with fixed heels or mobile ramps supported on an auxiliary fixed heel may vary depending on the number of berths comprising the terminal and on the operational characteristics of the ship's loading and unloading subsystems and inner interconnections, ranging between a minimum indicative value of about 45.0 m for Ro-Ro terminals exclusively devoted to loading and unloading of self-propelled vehicles and elements of road-driven (trailers and semi-trailers), goods transport with two lanes per heel or per berthing ramp and with the circulation routes associated with each berth being independent of each other, up to values greater than 100 m for general Ro-Ro terminals where all the auxiliary transports and towing equipment used in this type of terminal may operate, with multiple berths, with more than two lanes on the heel or ramps per berth and with the circulation routes associated with each berth not being independent of each other. In Ro-Ro berthing installations with dock type physical configurations of the berthing structure, where lateral or ¾ ship ramps or auxiliary ramps directly rest on the dock, the minimum value of the operation area transverse dimension will be about 65.0 m.

- *For commercial use berthing installations with a jetty-type physical configuration using goods loading and unloading systems by rolling*

At Ro-Ro berthing installations with jetty-type physical configurations, both the jetty itself, used for operations associated with serving the ship and dock and for passenger boarding and disembarking as appropriate, as well as the zone perpendicular or oblique to the berthing line where those operations associated with the interconnection between the ship's loading and unloading subsystem and the storage area are carried out, may be considered as being part of the operation area. (See figure 3.2.5).

The determination of the transverse dimension of this last zone is obtained similarly to that described above for the operation area of Ro-Ro berthing installations with dock-type physical configurations, although the minimum value of the distance between the berthing line and the axis of the outermost sea-side lane may be reduced in these cases by about 60% with respect to that defined for these installations because only a turn of 90° is necessary for vehicles and handling equipment. Therefore, the minimum value of the operation area corresponding to this zone in berthing installations exclusively devoted to loading and unloading of self-propelled vehicles and road driven (trailers and semitrailers) goods transport units, with two lanes on the heel or ramp per berth and with the vehicle and equipment routes associated with each berth being independent of each other, may be reduced from 45 to about 30 m.

Figure 3.2.5. Plan dimensions of the operation area for a two-sided berthing installation of jetty type, commercial use and using loading and unloading rolling systems (jetty unsuitable for boarding or disembarking passengers)



When the jetty is not used for passenger boarding and disembarking, its minimum width in the direction perpendicular to the berthing line should be 12.50 m for one-side berthing jetties and 25.0 m for two side berthing, regardless of that width being not necessarily uniform along the entire length of the jetty (for example, in the case of discontinuous jetties with berthing dolphins and/or mooring on its outer sea-side). In general, the jetty area accessible to rolling traffic serving the ship, with the recommended width, is recommended to occupy at least 70% of the berthing length.

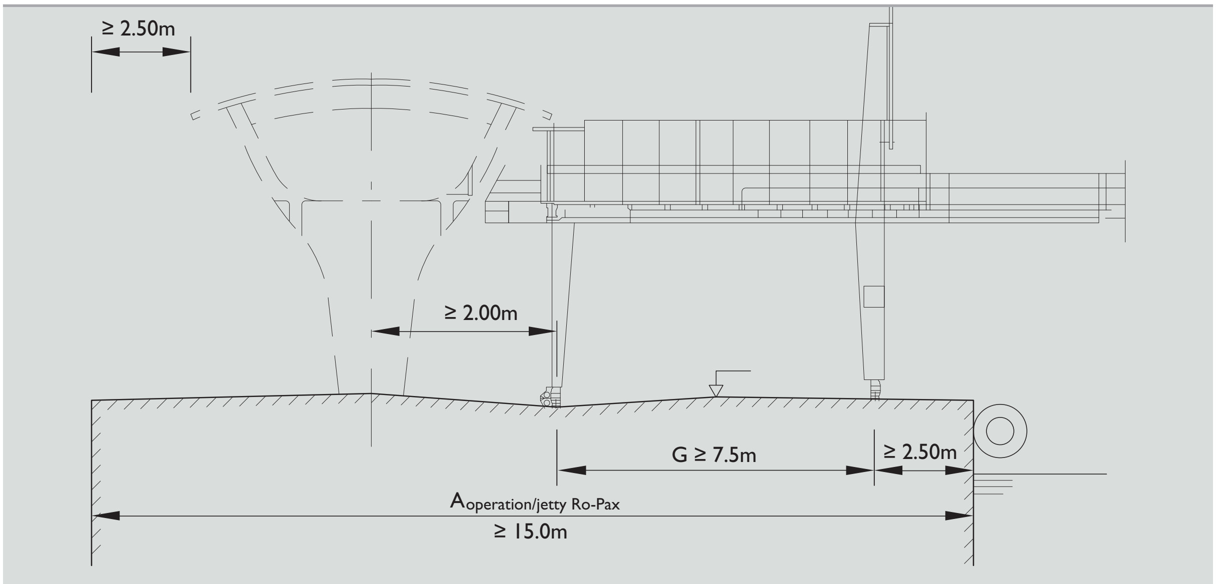
A diagram of the plan dimensions of the operation area of a prototype Ro-Ro installation with a jetty type physical configuration is included in figure 3.2.5.

When the jetty forming the berthing line may be used for passenger boarding and disembarking, the following distances should be considered in order to define the jetty's width (See figure 3.2.6):

a) The distance between the ledge line or berthing edge and the sea-side lane of the mobile equipment used for passenger boarding and disembarking. This distance should not be less than 2.50 m.

b) The space between the lanes of the mobile equipment used for passenger boarding and disembarking. This distance typically ranges between 7.50 and 10.0 m (See table 4.6.4.26).

Figure 3.2.6. **Plan dimensions of the part of the operation area corresponding to the jetty in a multipurpose standard ro-pax berthing installation with jetty type physical configuration (one-sided berthing)**



c) The space between the axis of the support structure of the fixed elevated access gangway to the mobile boarding/disembarking equipment and the land side lane of that mobile equipment. The minimum recommended distance between the lane axis of the land side equipment and the edge of the fixed walkway supporting structure is 2.0 m.
d) The distance between the support structure axis of the fixed gangway and, where appropriate, the ledge of the jetty's non-berthed side. For maritime safety reasons, the minimum distance between this ledge and any part of the fixed gangway should be not less than 2.50 m.

According to these criteria, the minimum transverse dimension of the jetty for a multipurpose Ro-Pax berthing installation, in the area accessible to rolling traffic and to passengers, may range, for two-sided berthing jetties, between 25-30 m, when the oscillation level of the outer waters operational window is not very significant and the composition of the expected fleet at berth is relatively homogeneous, up to values greater than 40-45 m when different circumstances obtain. In one-sided berthing jetties, the minimum transverse dimension may range between 15 m and values greater than 20-25 meters, depending on the above-mentioned circumstances.

The longitudinal dimension of the jetty in a Ro-Pax berthing installation, including the dimensions of its area accessible to rolling traffic and passengers, should meet the same requirements as those established for a Ro-Ro terminal.

3.2.1.7.2 STORAGE AREA

The storage area associated with a berthing installation, also known as the yard, is the area, not necessarily but conveniently located adjacent to the operation area, designed for the temporary storage of goods. The fundamental mission of the storage area is to make compatible the different existing paces between the loading and/or unloading of goods and/or cargo units (e.g. containers) and/or transport elements (trucks, trailers, semi-trailers, ...) from the ship and the entrance or exit of those goods, units and transport elements from the port by means of land (road and railway), maritime or internal navigation transport modes. It is also charged with executing the requisite internal operations relating to the ordering and control of these goods, cargo units and transport elements, to improve the efficiency of the operations related to ship loading and unloading and to the access and exit of goods.

From the infrastructural point of view, this area is composed by esplanades having either proper warehousing areas or temporary storage such as lanes, and the areas needed for terrestrial access (and where appropriate, for internal navigation) of the merchandise and for internal interconnection with the operation area.

The design and infrastructural and operational dimensioning of the esplanades forming the storage area should be addressed to make the required storage capacity of the terminal compatible with the availability of the existing land and with the requested service levels (acceptable wait times for the inner interconnection subsystems and ground access), considering the characteristics, flow, and operational performance of the loading and unloading subsystems and inner interconnection, as well as the distribution of consecutive arrivals and departures related to the delivery and receipt operations and consecutive ship calls. The main factors affecting the design and dimensioning of the storage area are as follows:

- The type, dimensions and characteristics of the goods, cargo units and/or transport elements handled (tracking, arrangement and maximum stacking heights).
- The distribution of the volume of loaded/unloaded goods (traffic units) per call (see section 3.2.1.4).
- The distribution of calls or time intervals between consecutive ship arrivals (see section 3.2.1.4).
- The annual volumes and distribution of goods, cargo units and/or transport elements handled by type, 4 dimensions and characteristics (import/export/maritime transit regimes [14], empty/full cargo units, complete/unconsolidated, self-propelled/non-self-propelled, unaccompanied/self-propelled, accompanied transport elements, etc..).
- The organization of operations in the storage area (plan layout of goods, units and transport elements, stacking height, the number, characteristics and performance of the handling equipment in the yard and with internal interconnection, as well as those assigned to delivery and receipt operations...).
- The patterns of delivery and receipt of cargo units and transport elements, including the distribution of their staying times in the terminal.
- The relevant social-labor circumstances (work shifts, effective working time periods, holidays, labor conflicts,…).

3.2.1.7.2.1 Required storage capacity

The storage capacity required in the storage area ($C_{storage}$), for a specific annual volume of handled goods in the ship's loading and unloading subsystem (C_t), is defined as the maximum number of tons of goods, cargo units and transport elements that can possibly accumulate in the storage area at any given moment.

The infrastructural dimensioning of the terminal, the storage capacity needed for each goods type, cargo unit or differentiated transport element handled at the terminal (*i* = tons of goods, number of containers, truckloads, loaded and unloaded goods using rolling platforms or without wheels, accompanied vehicles, ...), depends not only on the volume of goods of that type handled in the loading and unloading subsystem but also on its arrival and exit patterns inside the terminal, whether by land or sea. It may be approached by the definition of the following factors:

- The annual volume ($C_{t,i}$) of each cargo unit and transport element to be handled in the loading and unloading subsystem (See section 3.2.1.4).
- For each goods type, cargo unit and transport element, the distribution of that annual volume with the ratio (μ) between loaded ($C_{tl,i}$) and unloaded ($C_{tu,i}$) volume, as well as between traffic under import/export or arrival/exit regimes ($C_{timport/export,i}$) and transshipment ($C_{ttranshipment,i}$).

$$C_{t\ transhipment,\ i} = \mu_i \cdot C_{t,i}$$

$$C_{t\ import/export,\ i} = (1 - \mu_i) \cdot C_{t,i}$$

(14) Maritime transit is the unloading of goods from ship to terminal and the subsequent loading from the terminal to another ship. Goods stay some time in the terminal, but do not enter the territory. This type of operation is also called transfer, but strictly speaking this term should be used for direct load transfer operations between ship and ship without crossing the terminal. The English term for maritime transit is transshipment.

- The distribution of calls or time periods between consecutive ship arrivals (an exponential distribution with average $1/\lambda_{max}$) and average traffic unit ($\overline{C}_{u,i}$) of each goods type (See section 3.2.1.4).

  In the absence of more precise data, in order to dimension the storage area, it may be accurate enough to adopt the following simplifying hypothesis for the average traffic unit:

  - The proportion of each goods type, cargo unit and transport element used at each call, as well as their distribution between traffic under import/export regime (arrival/exit) and transshipment, is identical for all ships, adopting the average distribution the Developer estimates will be generated by the expected ship at berth.

$$\overline{C}_{t\ transhipment,\ i} = \mu_i \cdot \overline{C}_{u,i}$$

$$\overline{C}_{t\ import/export,\ i} = (1 - \mu_i) \cdot \overline{C}_{u,i}$$

  - When considering the traffic units, measured as the number of cargo units or transport elements (containers and Ro-Ro), the average traffic units for loading and unloading corresponding to import-export traffic are identical (15). That is:

$$\overline{C}_{uu\ import,\ i} = \overline{C}_{ul\ export,\ i} = \frac{(1-\mu_i)\cdot \overline{C}_{u,i}}{2}$$

    For bulk solids, as well as conventional general goods, container and Ro-Ro, when considering traffic units in tons, the proportion of import-export traffic in the installation with respect to the total import-export traffic should be taken into consideration, in order to differentiate traffic units by loading and unloading according to that proportion. That is:

$$\overline{C}_{uu\ export,\ i} = \rho \cdot (1 - \mu_i) \cdot \overline{C}_{u,i}$$

$$\overline{C}_{uu\ import,\ i} = (1 - \rho) \cdot (1 - \mu_i) \cdot \overline{C}_{u,i}$$

    Where ρ is the ratio of export traffic (in maritime departure regime) with respect to the total import- export traffic in the berthing installation.

  - For each goods type, cargo unit and transport element, the average transshipment traffic units are identical. That is:

$$\overline{C}_{ul\ transhipment,\ i} = \overline{C}_{uu\ transhipment,\ i} = \mu_i \cdot \frac{\overline{C}_{u,i}}{2}$$

- For each goods type, cargo unit and transport element, the distribution of staying times in the goods storage area in import or entry ($t_{timp,i}$) and export or departure ($t_{texp,i}$) regime.

  In research conducted using registered data in different types of terminals, it can be observed that the distributions of the staying times of goods, cargo units and transport elements in the storage area, either in entrance or exit regimes overland (import/export traffic), reasonably approaches exponential distributions of type:

$$\left[f(t_t) = \frac{e^{-\frac{t_t}{a}}}{\overline{t}_t} \right], \text{ where } (\overline{t}_t) \text{ is the average staying time.}$$

(15) It is known that the annual number of cargo units or transport elements loaded in a terminal is almost the same as the number of unloaded ones, if the empty cargo units and transport elements are considered.

Nevertheless, for ease of calculation it is acceptable to conservatively consider that the staying times either of goods, cargo units or elements assigned to exit traffic or entry traffic, may be adjusted to uniform distributions in the interval [0, tmax]. That is:

$$\left[f(t_t) = \frac{1}{t_{t\max} - t_{t\min}}, \text{ when } t_{t\min} = 0 \le t_t \le t_{t\max} \right], \left[f(t_t) = 0, \text{ when } t_t > t_{t\max} \right]$$

Where the average staying time corresponding to that distribution is:

$$\overline{t_t} = \frac{t_{t\min} + t_{t\max}}{2} = \frac{t_{t\max}}{2}$$

In practice, it is equivalent to considering that the entrance or receipt of cargo units and transport elements in the storage area in import/export regime occurs uniformly along the period $0/t_{tmax}$.

The average staying period corresponding to each type of goods, cargo unit and transport element, either in exit or entry operations, may take very variable values, mainly depending on the type of goods, cargo units and transport elements handled at the berthing installation, the characteristics, structure and degree of development of their hinterland, and on other local conditions related to the exploitation of the terminal (e.g. the existence of tariff penalties for delays in the collection of goods, ...). To determine a value for this period it is suitable to analyze the registry entries made in terminals with similar characteristics and local conditions.

Although being very difficult to generalize, due to the great local variability of the factors influencing staying time periods, in the absence of more precise data, the following average staying time period values may be adopted, as a first approach in developed countries ($\overline{t_t}$) (16):

- *Containers*
  - In exit regime (export traffics): 5 days.
  - In entry regime (import traffics): 10 days.
- *Conventional general merchandise*
  - In exit regime (export traffics): 8 days.
  - In entry regime (import traffics): 15 days.
- *Accompanied self-propelled transport elements*
  - In exit regime (export traffics): 0.2 days.
  - In entry regime: (the disembarked transport element does not cross the storage subsystem).
- *Not self-propelled transport elements*
  - In exit regime (export traffics): 2 days.
  - In entry regime (import traffics): 3 days.
- *Unaccompanied self-propelled transport elements (vehicles in merchandise regime)*
  - In exit regime (export traffics): 5 days.
  - In entry regime (import traffics): 10 days.
- *Cargo units and other type of goods loaded and unloaded by rolling platforms or without wheels (cassettes)*
  - In exit regime (export traffics): 5 days.
  - In entry regime (import traffics): 10 days.
- *Bulk solids*
  - In exit regime (export traffics): 5 days.
  - In entry regime (import traffics): 20 days. (17)

(16) In developing countries the average staying times may be even triple with respect to those present in developed countries.
(17) If the storage area of the bulk solids terminal is used as a strategic reserve, average staying times may exceed four months.

The distribution of the staying time periods of cargo units and transport elements in transit regime has a more difficult parameterization and generalization. Performance models for this purpose are mainly related to the distribution of ship calls and to the type of shipping lines (transoceanic or feeder) accessing the berthing installation, or to the periodicity and marketing strategies of the shipping companies (hub/feeder, inter-liner or hub & relay). Nevertheless, if we consider the simplifying hypothesis as sufficiently valid with respect to the traffic units included in this section, it may be granted that the average staying time of transshipment merchandise depends solely on the arrival frequency of consecutive ships into the terminal [λ_{max}].

After defining the above project factors, the required storage capacity may be obtained through numerical simulation techniques.

Considering the simplifying hypothesis included in this section regarding the average traffic units and distribution functions of the goods staying times, per goods type, cargo unit and differentiated transport element, the required storage capacity ($C_{storage,\ i}$) may be approached using the following formula, as a function of the traffic regimes associated with each goods type, cargo unit or transport element (18):

- **Traffic in import-export regime exclusively (μ_i = 0)**

$$\begin{aligned}
&C_{storage,i} = C_{import\ traffics\ storage,i} + C_{export\ traffic\ storage,i} = \\
&\bar{C}_{u,import,i} \cdot \left[2 \cdot \bar{t}_{t,import,i} + \frac{30}{\lambda_{\max}} + 2\right] \cdot \frac{\lambda_{\max}}{2 \cdot 30} + \bar{C}_{u,export,i} \cdot \left[2 \cdot \bar{t}_{t,export,i} + \frac{30}{\lambda_{\max}} + 2\right] \cdot \frac{\lambda_{\max}}{2 \cdot 30} = \\
&(1-\rho) \cdot \bar{C}_{u,i} \cdot \left[2 \cdot \bar{t}_{t,import,i} + \frac{30}{\lambda_{\max}} + 2\right] \cdot \frac{\lambda_{\max}}{2 \cdot 30} + \rho \cdot \bar{C}_{u,i} \cdot \left[2 \cdot \bar{t}_{t,export,i} + \frac{30}{\lambda_{\max}} + 2\right] \cdot \frac{\lambda_{\max}}{2 \cdot 30}
\end{aligned}$$

With $\bar{t}_{t,\ import,\ i}$ and $\bar{t}_{t,\ export,\ i}$ expressed in days and being λ_{max} the monthly frequency of ships arrival to the terminal, corresponding to the most frequent month.

Therefore, considering the existing relation between the annual volume of goods, cargo units or transport elements handled in the loading and unloading subsystem and the average traffic unit corresponding to the traffic type *i* (See section 3.2.1.4):

$$C_{i,t} = \frac{12 \cdot \lambda_{\max} \cdot \bar{C}_{u,i}}{\gamma_p}$$

In an import/export terminal, the relation between the required storage capacity in the storage area and the annual volume of goods handled by the loading and unloading subsystems corresponding to traffic type *i,* may be expressed as:

$$C_{storage,i} = C_{t,i} \cdot \gamma_p \, \frac{\left[(1-\rho) \cdot \left[2 \cdot \bar{t}_{t,import,i} + \frac{30}{\lambda_{\max}} + 2\right] + \rho \cdot \left[2 \cdot \bar{t}_{t,export,i} + \frac{30}{\lambda_{\max}} + 2\right]\right]}{365 \cdot 2}$$

- **Traffic in transshipment regime exclusively (μ_i = 1)**

$$C_{storage,i} = C_{transhipment\ traffics\ storage,i} = \frac{\mu_i \cdot \bar{C}_{u,i}}{2} \cdot \left[1 + \frac{2 \cdot \lambda_{\max}}{30}\right] = \frac{\bar{C}_{u,i}}{2} \cdot \left[1 + \frac{2 \cdot \lambda_{\max}}{30}\right]$$

Considering the existing relation between the annual volume of goods, cargo units or transport elements handled by the loading and unloading subsystem and the average traffic units included in the last

(18) Obtained from the formula of I. Watanabe (2001).

paragraph, in a transshipment berthing installation, the ratio between the required storage capacity and the annual volume of goods handled by the loading and unloading subsystem corresponding to the traffic i, may be expressed as:

$$C_{storage,i} = C_{t,i} \cdot \gamma_p \cdot \frac{\left[1 + \frac{2 \cdot \lambda_{\max}}{30}\right]}{24 \cdot \lambda_{\max}} = C_{t,i} \cdot \gamma_p \cdot \frac{\left(\frac{30}{\lambda_{\max}} + 2\right)}{365 \cdot 2}$$

- **Traffic in mixed regime (0 < μ_i < 1)**

$$C_{storage,i} = C_{import\ traffics\ storage} + C_{export\ traffics\ storage,i}$$

$$+C_{transhipment\ traffics\ storage,i} = (1-\mu_i)\cdot(1-\rho)\cdot \bar{C}_{u,i} \cdot \left[2 \cdot \bar{t}_{t,import,i} + \frac{30}{\lambda_{\max}} + 2\right] \cdot \frac{\lambda_{\max}}{2 \cdot 30} +$$

$$(1-\mu_i)\,\rho \cdot \bar{C}_{u,i} \cdot \left[2 \cdot \bar{t}_{t,export,i} + \frac{30}{\lambda_{\max}} + 2\right] \cdot \frac{\lambda_{\max}}{2 \cdot 30} + \frac{\mu_i \cdot \bar{C}_{u,i}}{2} \cdot \left[1 + \frac{2 \cdot \lambda_{\max}}{30}\right]$$

Considering the existing relation between the annual volume of cargo units and transport elements handled in the loading and unloading subsystem and the average traffic unit corresponding to the traffic type *i* as included in the last paragraphs, in a mixed terminal (with both import/export and transshipment traffic) the ratio between the required storage capacity and the annual volume of goods handled by the loading and unloading subsystem corresponding to traffic type *i,* may be expressed as:

$$C_{storage,i} = C_{t,i} \cdot \gamma_p \cdot$$

$$\frac{(1-\mu_i)\cdot\left[(1-\rho)\cdot\left[2 \cdot \bar{t}_{t,import,i} + \frac{30}{\lambda_{\max}} + 2\right] + \rho \cdot \left[2 \cdot \bar{t}_{t,export,i} + \frac{30}{\lambda_{\max}} + 2\right]\right] + \mu_i \cdot \left(\frac{30}{\lambda_{\max}} + 2\right)}{365 \cdot 2}$$

As may be inferred from the application of this formula, in equal conditions with respect to the annual volume of goods to be handled in the ship's loading and unloading subsystem and the frequency of ship calls, the required storage capacity in the storage area of terminals moving goods exclusively in transshipment regime is much lower than that required in terminals with exclusively import/export traffic. The difference between them increases when the average wait times of the import/export traffic increases.

The required total storage capacity at the storage area will be the sum of that required for each goods type, cargo unit or differentiated transport element handled at the berthing installation. That is:

$$C_{storage,total} = \sum_i C_{storage,i}$$

3.2.1.7.2.2 Required storage area

After determining the required storage capacity ($C_{storage,i}$) according to the criteria established in section 3.2.1.7.2.1, the storage surface area ($S_{storage,i}$) required for each goods type, cargo unit or differentiated transport element (*i*) may be calculated using the following formula:

$$S_{storage,i} = \frac{N_{tracks,i}}{I_{track,i}} = \frac{C_{storage,i}}{I_{track,i} \cdot c_{track,i}}$$

Where:

$N_{tracks,i}$: number of tracks or *slots*. The ratio between the number of tracks and the required storage capacity is:

$$N_{track,i} = \frac{C_{storage,i}}{c_{track,i}}$$

Where:

$c_{track,i}$: is the storage unit capacity per track, corresponding to traffic *i*. That is, tons, cargo units or transport elements per track.
In the case of cargo units (e.g., containers) or transport elements (e.g., truckloads or UTI), when the required storage capacity is expressed as numbers of these units or elements, this parameter equals the average stacking level ($\bar{h}_i$ = average number of cargo units or transport elements stacked vertically. E.g. TEU/track). That is = $c_{track,i} = \bar{h}_i$.

In the general case:

$c_{track,i} = \gamma_i \cdot \bar{h}_i \cdot s_{track,i_i}$, expressed in t/track (19)

Where:

γ_i : is the apparent specific weight of goods corresponding to the traffic i. Representative values of this parameter are included in table 4.6.4.2 for each goods type.

$\bar{h}_i$: is the average stacking level of the tracks corresponding to the traffic *i* (average stacking height of goods, or the average number of cargo units or transport elements stacked vertically).
The average stacking level ($\bar{h}_i$) is a function of the characteristics of the goods and the horizontal transport system and the adopted storage system in the storage area, as well as, for cargo units and transport elements, of the number of removals, positioning and other movements in the interior of the storage subsystem due to operational needs. $\bar{h}_i$ is expressed in meters or in the number of units of height in the case of cargo units or transport elements, when the required storage capacity is expressed in numbers of these units or elements.
The maximum stacking heights of goods, cargo units and usual transport elements in port exterior esplanades are included in table 4.6.4.3, as well as in tables 4.6.4.17 and 4.6.4.24 for cargo units as a function of the adopted storage equipment.
The ratio between the maximum stacking height and the average height for a bulk solid stored in an esplanade, depends on the size of the track adopted for storage and on the natural bulk slope (See table 4.6.4.2). In the absence of more precise data, $\bar{h}_i = 0.8\ h_{a\ max,i}$. may be used. In the case of cargo units (e.g. containers) and transport elements (e.g. truckloads or UTI) mainly depends on the removals, positioning and other movements of the same established in the installation for operational needs.
In the case of cargo units and transport elements, in the absence of other specific data obtained from terminals with similar characteristics, for maximum stacking levels higher than the unit, it may be generally assumed that the average stacking level ranges between 0.60 and 0.80 of the value of the maximum level. The higher values may be adopted for the most predictable arrival or exit sequences (e.g., homogeneous destinations, land access through railway transport). For maximum stacking levels equal to the unit, it may be assumed that the average stacking level coincides with the maximum one for self-propelled transport elements and is 0.90 for other cargo units and transport elements.

s_{tracks,i_i} : is the net area of the track or net stacking area, corresponding to the traffic *i*, expressed in m^2.
The recommended track dimensions for different cargo units and transport elements are:

- Containers with truck platform- type handling yard systems (in this case each track is equivalent to 2 TEU): 13.50 x 3.50 m^2.

(19) For containers, when the required storage capacity i expressed in tons, the product $\gamma_i \cdot \bar{h}_i \cdot s_{huella,i}$ will be substituted for the average weight of the 20'container stack depending on the stacking height. Distribution functions of container stack weights in spain are included in section 4.6.4.1.

- Containers with forklift handling yard systems (forklift truck)/stacking type (Reachstackers): 6.40 x 2.75 m².
- Containers with forklift yard handling systems
- Containers with straddle carrier type yard handling systems: 6.40 x 2.45 m².
- Containers with gantry type (on tyres or rails: RTG, ASC, RMG) yard handling systems): 6.10 x 2.75 m².
- Full Truckloads: 16.50 x 3.0 m².
- Intermodal transport units: trailers or semitrailers (UTI): 16.0 x 3.00 m².
- Automobiles: 5.00 x 2.50 m².

For other types of goods, dimensions and track shapes vary significantly, depending on the adopted yard handling systems and interior interconnection equipment and on the operational organization of the storage area being compatible with them.

$I_{track,i}$: is the occupation index, defined as the number of tracks or slots per unit of area corresponding to the traffic i, considering the net stacking area as well as the interior lanes needed to develop operations. This parameter depends on the general design layout of the tracks compatibility with the handling systems used in the storage area, as well as the routes of the adopted horizontal transport equipment associated with the inner interconnection operations between the storage area, operation area and land accesses (See example of the arrangement of tracks and the routes assigned to the same in figure 3.2.7). Typical values of this parameter in container terminals are included in table 3.2.1.9.

Table 3.2.1.9. *Usual occupancy indexes at storage areas for container terminals*

HANDLING SYSTEMS IN OPERATION AREA	GENERAL LAYOUT OF SLOTS	OCCUPANCY INDEX ($I_{slot,i}$ = nr slots/ha)
TRUCK PLATFORMS	Perpendicular to berthing alignment	100-110
	Perpendicular to berthing alignment	115-120
FORKLIFT TRUCKS-FLT OR REACHSTACKES-RS	Perpendicular to berthing alignment	200-220
	Parallel to berthing alignment	230-240
STRADDLE CARRIERS-SC	Perpendicular to berthing alignment	250-350
	Parallel to berthing alignment	270-310
RUBER TYRED GANTRY-RTG AND RAIL MOUNTED GANTRY - RMG, AUTOMATIC STAKING CRANES - ASC	Perpendicular to berthing alignment	> 300
	Parallel to berthing alignment	250-280

The total storage area will be the sum of all partial areas (S_i) required for each handled goods type (*i*).

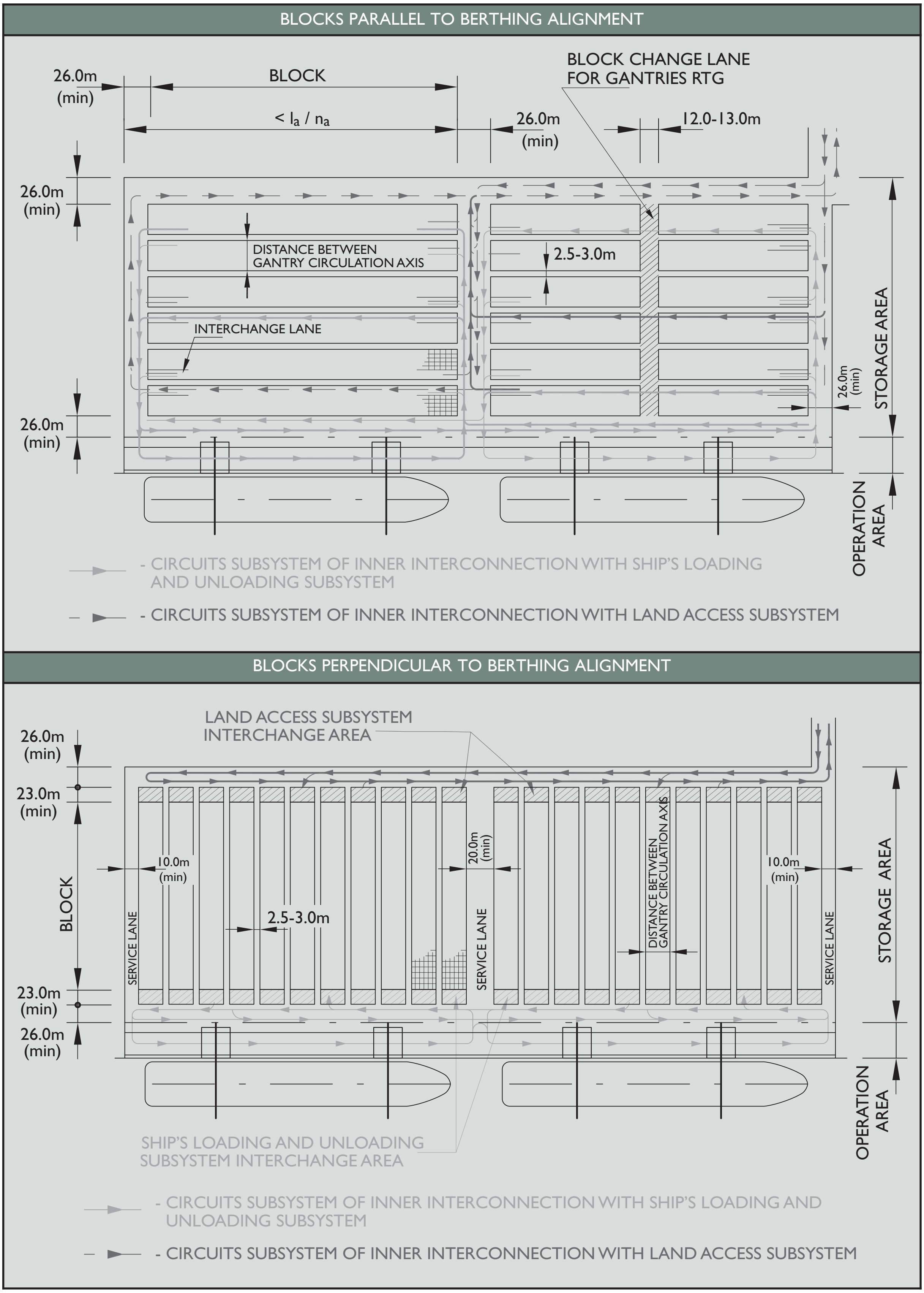
Comment: As a guideline, for container traffic actually in Spain, $S_{storage,i}/C_{storage,i}$ values off about 12 to 20 m²/TEU, are typical, being equivalent in terminals with mainly import-export traffic to $S_{storage,i}/C_{t,i}$ ratios of about 0,55 to 1,00 m² per TEU per year, resulting in average storage area widths of between 400 and 500 meters. In terminals with mainly transhipment traffic the range of values of Sstorage,i/Ct,i and therefore average widths, are noticeably less.

3.2.1.7.3 AUXILIARY AND SUPPLEMENTARY SERVICES AREA

Auxiliary and supplementary services areas are used to develop activities complementing those of the berthing installation improving its efficiency in various aspects or entailing value-added logistic activity, related to the maritime traffic developed there. Some of the supplementary services are the following:

- Administrative and control services relating to the terminal's operations.
- Inspection services (customs, sanitary and phytosanitary, security checkpoints, etc.).

Figure 3.2.7. **Standard layouts of slots and road lanes for handling systems in the storage yard**



- Maintenance or repair services of handling equipment, transport elements and/or cargo units.
- General services (cleaning of containers, service stations, electrical substations, supplementary services to the transport modes: rest areas and toilet facilities for drivers,).
- Storage service or depots for empty containers.
- Goods consolidation and deconsolidation services where groupage or cargo damage occurs [20].

It is not essential that auxiliary service areas form part of the berthing installation itself nor be situated adjacent or close to the storage area, although it may be convenient for certain types of traffic. In general, and in the absence of specific criteria from the Developer of the installation, the zones reserved for auxiliary and supplementary service areas should range between 30 and 60% of the required storage area.

3.2.1.7.4 DEFINITION OF THE BERTHING INSTALLATION WIDTH

In order to determine the average width (A_m), berthing and mooring installations may be considered as having none, one or all the areas described above, depending on their physical configuration; that is to say:

- Dolphins, buoys, buoy fields and mono-buoys: strictly speaking, none of these areas is properly present, so the only required width is that of the berthing and mooring structure itself.
- Jetties: in the jetty itself only an operation area is defined ($A_m = A_o$), notwithstanding this, other areas of operation, storage and supplementary services may be defined in zones perpendicular or oblique to the berthing line at the land side starting point of the jetty, like those in docks, as needed to develop the operations (See section 3.2.1.7.1). In jetties forming discontinuous berthing lines, an operation area will only be defined on the platform.
- Docks: Operation, storage and auxiliary and supplementary service areas will be defined. In this case:

$$A_m = A_o + \frac{\sum S_{storage,\square}}{L_a}$$

The widths recommended for commercial use berthing and mooring structures are not directly applicable to other uses, particularly to sporting uses. Nevertheless, the minimum dimensions above considered for operation areas (Ao) are applicable to fishing, industrial and military uses. Widths of operation areas for sporting uses generally range between 1.50 and 3 meters when used exclusively for pedestrian access and up to 10 meters in the other cases. For fishing use storage areas, average widths of 100 to 150 meters are typical.

3.2.1.8 Land Accesses

Berthing and mooring installations should have suitable road and railway accesses, so that the interchange between land and maritime transport modes can be affected safely and efficiently.

The methodology to obtain the required capacity to dimension the land accesses of a berthing installation will be included in ROM 3.2. Land Configuration of Harbors. Nevertheless, in the absence of specific studies, simplified formulas may be used such as the following one, corresponding to a multipurpose terminal. For other types of berthing installations this simplified procedure may be used with a suitable adaptation of the formula.

3.2.1.8.1 ROAD TRAFFIC FORECAST

The forecast of the road traffic generated in a multipurpose berthing installation for general cargo will be determined from the following formula:

(20) CFS (Container Freight Station) is the English term.

$$T = C_{t\,import-export,\,i} \cdot \frac{\alpha \cdot \beta \cdot \tau \cdot (1-\delta) \cdot \sigma}{360 \cdot W \cdot \mu}$$

where:

T = Predicted traffic density (vehicles/hour).
$C_{t\ import\text{-}export,\ i}$ = Annual goods volume of i type, handled at berthing installations in import-export regime (t). That is, excluding i-type traffic in transhipment regime $C_{t\ import\text{-}export,\ i} = (1 - \mu\ i) \cdot C_{t,i}$
W = Average tonnage moved by one truck (t).
α = Part of the transported merchandise in road mode (expressed as per unit).
β = Monthly variation index (peak month traffic/ordinary month traffic).
τ = Daily variation index (peak day traffic/ordinary day traffic).
δ = passive vehicle index (passive vehicles/transport vehicles).
μ = loaded vehicle index (loaded vehicles/transport vehicles).
σ = hourly variation index (peak hour traffic/peak day traffic).

In the absence of specific data, the use of those values included in Table 3.2.1.10, is recommended, as the values of the above parameters for break bulk general cargo and containers.

Table 3.2.1.10. Recommended parameters to determine road traffic forecasts as generated in a berthing installation

PARAMETER	FOR GENERAL CONVENTIONAL LOADING	FOR CONTAINERS
α (road and railway)	Min. 0.7	Min. 0.7
α (road only)	1.0	1.0
W (in t)	3.0	12.0
β	1.2	1.0
τ	1.5	1.5
δ	0.5	0.5
μ	0.5	0.5
σ	0.125	0.125

When the terminal allows the simultaneous operation of road and railway traffic, α will adopt the appropriate value of the expected distribution between both traffic by the Designer of the installation. Nevertheless, as a precaution against possible alterations to the initially forecast distribution between road and railway traffic from transitional causes or from demand evolution, in order to dimension the road accesses, it is recommended not to use a value of αlower than 0.7.

The resulting traffic forecast will be the sum of the ones generated from break bulk general cargo and from containers.

Using the above listed criteria with all the parameters recommended in table 3.2.1.10 (α = 1) allows the development of the following simplified formula:

$$T = (130 \cdot C_{t\ import\text{-}export,\ C} + 625 \cdot C_{t\ import\text{-}export,\ G}) \cdot 10^{-6}$$

where $C_{t\ import\text{-}export}$, C and $C_{t\ import\text{-}export,\ G}$ are the annual volumes of container goods and general convention- al cargo, respectively, handled at berthing installation under import-export regime, expressed in tons.

The above expression allows the determination of the traffic forecast for the main access road or on any secondary branch, depending on whether the values adopted to $C_{t\ import\text{-}export,\ C}$ and $C_{t\ import\text{-}export,\ G}$ are for the whole terminal or for the area served by the corresponding branch.

3.2.1.8.2 RAILWAY TRAFFIC FORECAST

The estimate of the railway traffic generated by a general cargo multipurpose berthing installation, assuming it to be equipped for this mode of transportation, will be determined by the following criteria:

- Container trains:

$$TC = C_{t\ import\text{-}export,\ C} \cdot IM \cdot AF \cdot (1/WC) \cdot (1/IC) \cdot 2 \cdot (1/NC) \cdot (1/NV)$$

- Break bulk general cargo trains:

$$TG = C_{t\ import\text{-}export,\ G} \cdot AF \cdot (1/WV) \cdot (1/IV) \cdot (1\ /\ IE) \cdot (1/NV)$$

- Total number of daily trains:

$$TT = (TC + TG)\ /\ (365 - DF)$$

- Maximum train length:

$$LT = LV \cdot NV$$

In the absence of specific data, it is recommended to use those values included in Table 3.2.1.11, as the values of the above parameters. Assuming that the terminal allows the simultaneous operation of road and railway traffic, the appropriate value of the expected distribution between both traffic will be adopted as the AF. Nevertheless, as a precaution against possible alterations in the initially predicted distribution between road and railways traffic due to transitional causes or from demand evolution, in order to dimension the road accesses, it is recommended not to use a value of α lower than 0.30.

Tabla 3.2.1.11. Recommended parameters to determine railway traffic forecasts of a berthing installation

PARAMETER	FOR GENERAL CONVENTIONAL LOADING	FOR CONTAINERS
LT (m)	750	750
AF (road and railway)	Min. 0.3	Mín. 0.3
AF (railway only)	1.0	1.0
AF (road only))	0.0	0.0
WC (t)	–	12
WV (t)	20	–
IC	–	0.85
IV	0.75	–
IE	0.75	–
NC	–	2
NV	70	70
DF	65	65
LV	13	13

Using the criteria outlined above with all the parameters recommended in table 3.2.1.11 assuming values of IM = 0.6 and AF = 1, allows the development of the following simplified formula:

$$TT = (3.4 \cdot C_{t\ import\text{-}export,\ C} + 5.1 \cdot C_{t\ import\text{-}export,\ G}) \cdot 10^{-6}$$

indicating the estimated number of 750 m (58 wagons of 13 m) trains per operation day.

Elevation Dimensioning

The characteristics to be defined at a berthing and mooring installation for its elevation dimensioning are:

- The Crest Level of the Berth's (n_c).
- The Berth's draught (h_a).
- The Longitudinal profile of heels and ramps
- The slopes of the operation and storage areas.

3.2.1.9 Crest Level of the Berth

The Top level of the berthing and mooring structure (n_c), measured from the berthing line, will be, as a minimum, that which allows its efficient operation and safe conditions for the ships fleet and expected port operations, with a certain operational level. Such a berth top level may influence the operational stoppage mode "paralysis of loading and unloading ship operations and boarding and disembarking of passengers", for the following reasons:

- Incompatibility with the ship's loading and unloading equipment or the boarding and disembarking of passengers, as well as not being adjusted to the operational requirements of the ships fleet and berthing installation [(21)].
- Overflow of the berth's top level by outer waters.
- Flooding of the top level of the berthing installation by the backfill water table.

The minimum top level of the berthing line (n_c) should be the highest level resulting from the consideration of the above sources of operational stoppage with their adopted corresponding appearance probability of outer waters levels applicable to each source or to water tables as appropriate. The top levels assigned to each cause will be determined from the definition of the outer waters level or water tables, as appropriate, assigned to the adopted appearance probability (reference level) and the minimum safety freeboard [(22)] associated with the analysed cause of stoppage.

From the acceptable minimum operational levels set up by this Recommendation for berthing installations (See table 3.4.3) taking into account all the stoppage modes and causes of operational paralysis, it is recommended to consider that practically no paralysis of loading and unloading ship operations or boarding and disembarking of passengers will be caused by the above reasons, but that other causes of paralysis will really determine the operational capacity level of the berthing installation corresponding to these operations. Also, in the case of overflows and backfill flooding, it is recommended to go further than considering its incidence on the stoppage of loading and unloading operations and to delimit the probability of overflows and flooding of the top of the berthing installation during its lifetime, in order to reduce to admissible levels, the possibility of damages to handling equipment and to goods stored in operation and storage areas from these causes. Therefore, according to these criteria, the reference levels of outer waters and water tables will be associated, respectively with (see section 4.1.1):

(21) This stoppage cause is fundamentally associated with the maximum lifting heights of cranes above the top level of the berthing installation.

(22) Freeboard is defined as the difference of height between the outer waters level and the top level of the berthing structure.

- The outer waters operational window due to tides and river flow regimes (operational tidal window) associated with an annual exceedance on-site probability (high levels) or of no exceedance (low levels) of 10^{-3}. This definition of the operational tidal window is equivalent to considering that the possible outer waters level due to tides and river flow regimes on site do not limit the operational capacity of the berthing installation.
- The outer waters extreme window, associated with an on-site probability of occurrence of 10^{-1} during the life-time of the berthing installation.
- The backfill water table extreme window, associated with an on-site probability of occurrence of 10^{-1} during the lifetime of the berthing installation.

For the purposes of this section, the top level of the berth does not refer to the sea-side crest levels of the heels and ramps required, in some cases, to allow the use of goods handling systems by rolling means, but to the crest level of the berthing line. The sea- side crest levels of heels and ramps are analysed in sections 3.2.1.6 and 3.2.2.3 of this Recommendation.

3.2.1.9.1 *Top level from operating conditions*

- *The outer waters reference level*

  The outer waters reference level used to determine the top level associated with the stoppage of loading and unloading operations or boarding and disembarking of passengers from operating conditions will be the upper level corresponding to the operational tidal window. That is, according to that recommended for this purpose in section 3.2.2.1, the upper level of outer waters due to tides and river flow regimes whose annual on-site exceedance probability will be 10-3.(23)

- *Safety freeboard*

  In general, given the maximum elevation heights above the top level of the typical berth in the standard ship loading and unloading equipment for lifting and boarding and disembarking passengers, commercially available at the present time (See sections 4.6.4.2.1.1 and 4.6.4.2.3), the freeboard characteristics of ships and vessels and the maximum stowage heights on deck, as well as the maximum ship motions acceptable at berth during loading and unloading operations or for the boarding and disembarking of passengers (See table 4.6.4.22), the minimum freeboards of the berthing line with respect to the upper level of the operational tidal window recommended for operating conditions, are included in table 3.2.2.1.

  If the cranes anticipated by the Developer of the terminal would not reach the typical values of the maximum elevation heights, the minimum freeboards included in the above table should be adapted (verified or reduced) in order to maintain similar safety margins.

  For floating berthing structures, the minimum freeboards in table 3.2.2.1 corresponding to operating conditions will be applicable to the maximum floating draught situations.

  For berthing installation with rolling handling systems, the operating condition used to define the top level is not strictly applicable. Nevertheless, from optimization reasons of the longitudinal dimension of heels and ramps (see section 3.2.2.3), the minimum freeboards included in the last table should also be applicable for this type of installation.

(23) When average upper level regimes of this variable is not available on site, it may be simply considered that the upper level of the operational tidal window associated with an exceedance probability of 10^{-3} is:
– In seas with significant astronomical tide: the HAT (highest astronomical tide).
– In seas without significant astronomical tide: +0.5 m with respect to the mean sea level.

3.2.1.9.2 TOP LEVEL FROM CONDITIONS OF NO OVERTOPPING OF OUTER WATERS

- *Reference level of outer waters*

The outer waters reference level used to determine the top level from no overflow conditions will be the upper level corresponding to the outer water level extreme window, considering all the site agents influencing the local outer waters levels. That is to say, long period oscillations (tides and river flow regimes) intermediate period (long waves) as well as the short period oscillations (swells or surf), as well as the wind. In other words, the outer waters upper level whose on-site exceedance probability during the lifetime of the berthing installation is 10-1. This level may be defined from the following approximations:

- Deterministic-probabilistic approximation

The most relevant site agent will be selected, based on its influence on the outer waters upper level as the predominant agent. In sheltered areas, the predominant agent is usually the upper level associated with tides and, where applicable, river flow regimes. In wide sheltered areas (e.g. estuaries or great basins) without significant astronomical tides, the predominant agent is usually the wind (over-elevations due to wind action). In unsheltered areas or areas with significant agitation, the predominant agent is usually waves [24], mainly for insignificant astronomical tides.

The outer waters reference level of will be calculated as the sum of the following levels:

- That corresponding to a return period (TR) associated with the probability of occurrence during the installation's lifetime of 0.10 [25], as obtained from the on-site marginal distribution function of the extreme outer waters upper level associated with the predominant agent [26]. When the predominant agent may be divided into distinct directions, the return period in the extreme directional regime corresponding to the most unfavourable direction will be adopted, in relation to the on –site outer waters upper level.
- The compatibility values for exceptional working conditions due to the extreme action of a climatic agent on the outer waters upper levels associated with the simultaneous action of the other agents influencing them. The compatibility values of the agents independent of the predominant one, will be those associated with an absolute no-exceedance probability of 85% in average regimes, considering the most unfavourable direction related to the outer waters upper level. For the agents independent of the predominant one or the other independent agents, the adopted compatibility values will correspond to a no-exceedance probability of 85% of the conditioned compatibility value distribution function and the adopted direction of the agent on which they depend (See section 4.1.1.1 b1).

When the predominant agent responsible for these effects cannot be identified, each agent affecting the on-site outer waters upper level should be successively considered as being predominant, adopting as the outer waters reference level the most unfavourable one obtained from those.

- Probabilistic approximation

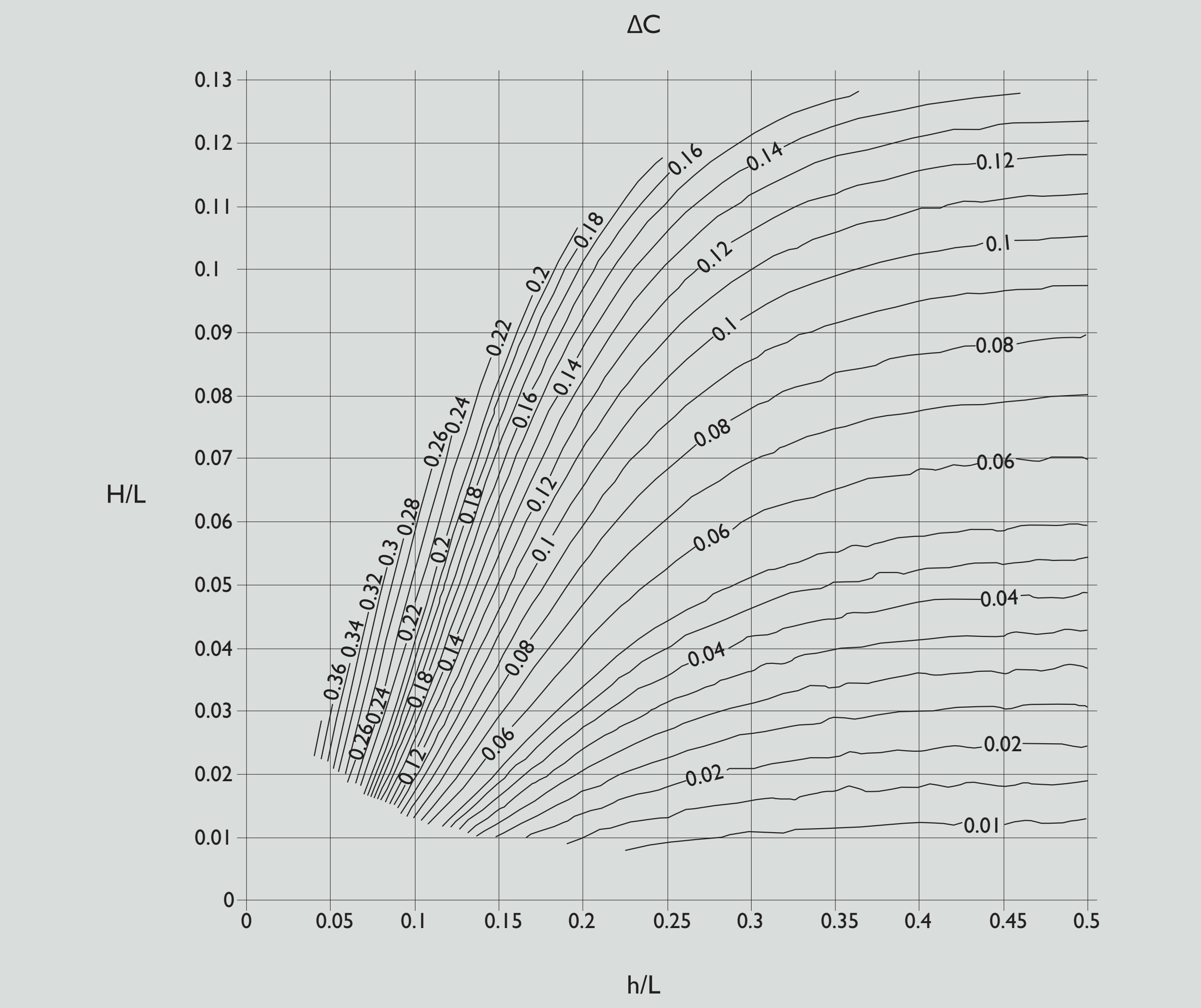
More precisely, the upper level of the extreme outer waters window will be associated with an on-site occurrence probability of 10-1 during the lifetime in the distribution function defined as the

(24) In order to define the outer waters operational and extreme windows, the representative on-site wave variable will be Hmax and in the presence of the berthing structure, considering the adopted outer waters level associated with tides and river flow regimes. Additionally, the possible non-linearity of the on-site waves should be evaluated, with possible asymmetries between crest and trough heights with respect to the average level. Over-elevation DC [Crest height with respect to the average level (H_{max}/2)] depends on the relative depth (h/L) and the wave slope (H_{max}/L), and may be approached by means of the graph in figure 3.2.8.

(25) For a 50-year lifetime, a probability of occurrence of 0.10 corresponds to a return period of 475 years.

(26) When the predominant agent is the upper level associated with tides, the extreme values of this variable associated with different return periods in Spanish coasts may be obtained from table 4.6.2.3. of this Recommendation.

Figure 3.2.8. **Estimation of the elevation wave crest elevation over the mean level, by using a non linear wave model**



derived function obtained from the adjustment of a distribution function of the randomly generated values (e.g. by means of the Monte Carlo method) from the directional occurrence frequencies of the extreme values and extreme regimes, directional ones when appropriate, of the agents affecting the outer waters upper level which may be independent of each other and from the distribution functions conditioned to each value and direction of those agents depending on them.

- *Safety freeboard*

The minimum freeboard of the berthing line with respect to the upper level of the outer waters extreme window recommended for no-overflow conditions is 0.5 m (See table 3.2.2.1).

For floating berthing structures, in order to determine the top level, the no-overflow condition should not be considered.

3.2.1.9.3 *Top level tables for no flooding conditions by backfill groundwater*

- *Reference level tables for backfill groundwater*

The reference level tables for backfill groundwater used to determine the top level forno-flooding conditions will be the upper level of the water tables corresponding to the extreme window. That is to say, the upper level of the water tables whose exceedance probability during the lifetime of the berthing installation will be 10^{-1}. This level may be defined by means of the following approach:

That corresponding to a return period (T_R) associated with an occurrence probability during the lifetime of the installation of 0.10 (27), obtained from the distribution function of the extreme soil saturation levels of the backfill.

In the absence of relevant statistical site data, to simplify, whenever the structure and the foundation are of low permeability ($k < 10^{-5}$ cm/s), a level increase which is equal to the maximum rainfall intensity in 24 hours with a return period of 500 years, expressed in terms of height/m^2, from the mean sea level (or the mean flood level in river currents) + 0.30 m, can be considered.

- *Safety freeboard*

The minimum freeboard of the berthing line with respect to the upper level of the extreme window of backfill water tables recommended for no-flooding conditions is 0.5 m (See table 3.2.2.1).

For floating berthing structures or fixed ones without backfill, in order to determine the top level, the no-flooding condition from the backfill water tables should not be considered.

3.2.1.10 Berth Draught

Independently of the existing draughts at access channels and other flotation areas conditioning the accessibility and departure of ships, the berth draught (*ha*) will be, as a minimum, that allowing the staying of all ships of the expected fleet at berth in expected loading cases, with a certain operating capacity level. To this purpose, the berth draught is defined as the distance between the sea floor level and the lower level of the operational tidal window adopted for the staying of ships at berth (reference level). To this purpose, the operational tidal window is taken as that formed by the upper and lower levels of those outer waters levels caused by tides and river currents which are established as operational thresholds for the staying of the ships fleet expected at berth. The breach of this condition must be regarded as an operational stoppage mode corresponding to the impossibility of staying the ship at the berth due to insufficient draught (See sections 3.3.4 and 4.6.4.4.7.1.3. a4).

Given the minimum global operational capacity levels required by this Recommendation for berthing installations, taking into account all causes of operational stoppage, it should be considered that suspension of the ship's staying at berth from insufficient draught should not occur, so that other stoppage reasons would really determine the operational level of the berthing installation. The converse would have a great impact on the quality of the service. For these reasons, in order to determine the berth draught, it should be noted that the outer waters levels due to tides and where applicable, river flow regimes, do not limit the staying of the ship at berth, adopting as the lower level of the operational tidal window for staying the ship at berth, that whose annual no-exceedance probability is 10-3, in accordance with that estimated for operating conditions in section 4.1.1 of this Recommendation.

Moreover, because the threshold values of climatic and metocean agents adopted as the limit for the performance of ship departure operations from the berth cannot be more restrictive than those for staying the ship at berth (otherwise, the ship could leave the berth but could not sail, which makes no sense), it may be advisable to dimension the access and manoeuvring areas using economical optimization criteria, to separate the suspension of ship's staying at berth from the suspension of maritime accessibility in relation to the adopted operational outer water level thresholds caused by tides and river flow regimes. Conveniently, this would virtually guarantee the staying of the ship at berth independent of the possible tide levels (extraordinary tidal window) at the site. In this case, in order to determine the draught, a draught associated with a probability of the ship hitting bottom during the lifetime of the berthing installation, of 0.10 should be adopted for berthing installation handling no dangerous goods or of 10^{-2} for other cases.

(27) For a 50-year lifetime, an occurrence probability of 0.10 corresponds to a return period of 475 years.

Table 3.2.2.1. **Criteria to determine the minimum top levels at fixed berthing structures**

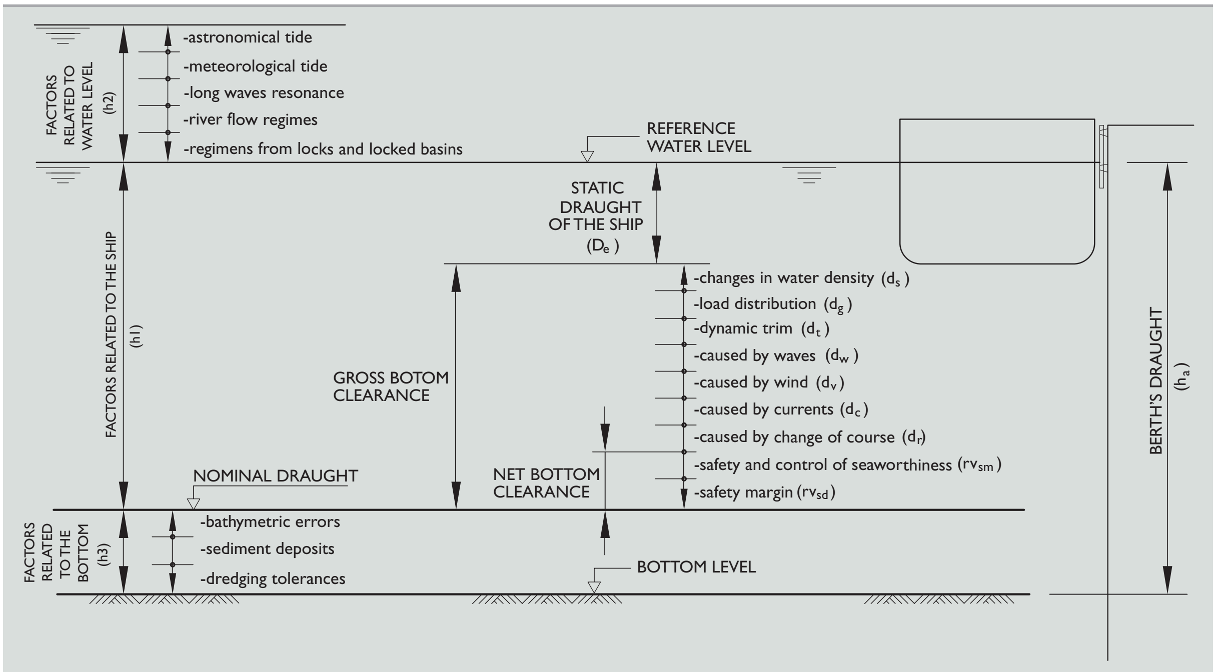
CONDITIONS TYPE	REFERENCE LEVEL OF OUTER WATER	USE OF THE BERTHING STRUCTURE	FREEBOARD (IN M)
FROM OPERATION CONDITIONS	Upper level of operational tidal window 1)	Commercial, industrial and military uses	+ 1.50 ~ + 2.50 3)
		Fishing use	+ 0.50 ~ + 1.00 4)
		Nautical-sports uses	+ 0.15 ~ + 1.00 5)
FROM NO OVERTOPPING CONDITIONS OF OUTER WATER	Upper level of outer waters extreme window 2)	All uses	+ 0.50
FROM NO FLOODING CONDITIONS OF BACKFILL WATER TABLES	Upper level of backfill water tables extreme window	All uses	+ 0.50

Notes

(1) Operational window associated to tides (astronomical and meteorological) abd river flow regimes, when appropriate.
(2) Extreme window of outer waters, considering all agents affecting levels of outer waters on site (tides, waves, long waves, ...).
(3) A freeboard of 1.5 m will be considered when displacement of the largest vessel of the expected fleet at berth is lower or equal to 10000 t. For higher displacement of that vessel, the adopted freeboard may be up to 2.50 m.
(4) A freeboard of 0.5 m will be considered for short length vessels (< 12 m). Also, it is recommended in these cases that, from the lower level of the operational tidal window, the resulting freeboard up to top level will not br higher than 1.5 m. When not possible, a floating solution will be adopted.
(5) A freeboard of 0.15 m will be considered for short length vessels (< 12 m). Also, it is recommended in these cases that, from the lower level of the operational tidal window, the resulting freeboard up to top level will not br higher than 1.00 m. When not possible, a floating solution will be adopted.

The necessary draught at the berthing line, with regard to the adopted outer waters reference level is a function of the following factors (See figure 3.2.9):

Figure 3.2.9. **Factors affecting the definition of the berthing alignment draught**



- *Factors related to the ship* (h_1):

  - The static draught of the ship (D_e).
  - The necessary safeguards because of static and dynamic factors related to the ship, which may cause the points of some hulls to reach levels lower than the static draught (mainly from climatic and metocean effects, the load distribution and the ships' motions).
  - Security safeguards established to ensure the manoeuvrability of the ship and to prevent the ship from contacting the sea floor. This safeguard is called "net under keel clearance".

  The full set of the above protections is called "gross under keel clearance". The static draught and gross clearance define the nominal draught.

- *Factors related to the sea floor* (h_3):

  - Sea floor clearances are established to cover bathymetric errors, dredging tolerances and potential sediment deposits in the admissible range.

    That is:

$$h_a = h_1 + h_3$$

A detailed analysis of each factor may be found in ROM 3.1-99: Recommendations for the design of maritime configurations of harbors, assuming as representative values of the variables of the different agents involved in the formulation (wind, currents, waves, ...) the following values (deterministic-probabilistic approach):

- *For a reference level of outer waters equal to the lower level of the operational tidal window*

  The compatibility values under operating working conditions of variables acting simultaneously, taking as the predominant agent the outer waters levels due to tides and where applicable, river flow regimes.

  That is, the compatibility values of variables of agents independents of the predominant one, will be associated with an absolute no-exceedance probability of 50% in the average on-site regime of the most unfavourable direction regarding the draught, without exceeding the operational limit values corresponding to the staying of the ship at berth, established for that variable in the considered direction. For the variables of the agents depending on the predominant one or on the remaining agents independent of each other, a compatibility value corresponding to a non-exceedance probability of 85% will be adopted in the distribution function conditioned to the adopted compatibility value and direction, as appropriate, for the agent on which they depend, without also exceeding, where applicable, the operational capacity limit values corresponding to the staying of the ship at berth, established for the considered variable (See section 4.1.1.1.c).

  In spite of the foregoing, particularly in unsheltered or partially sheltered areas or those with strong currents and especially with insignificant astronomical tides, the series of sea floor levels determined by analysing the above factors should be additionally checked for each ship, as they could be more unfavourable, successively considering each one of the factors involved in the formulation as being the predominant variable, assuming as its representative value that corresponding to its operational capacity threshold limit for staying the ship at berth. The representative values of the remaining variables acting simultaneously with the predominant one, will be their compatibility values under normal operating conditions, as obtained according to the methodology prescribed in the above paragraph. Therefore, the outer waters reference level for these situations will be, when the outer waters level is considered as being independent of the predominant agent, the level corresponding to a non-exceedance probability of 50% in the average regime of the outer waters lower level caused by tides or river flow regimes. When the outer waters level is considered depending on the predominant agent, the reference level will correspond to a non-exceedance probability of 85% in the distribution function of the outer waters level caused by tides or river flow regimes, conditioned to the value of the predominant variable.

- *For an outer waters reference level equal to the lower level of the extraordinary tidal window*

  In these cases, the outer waters reference level will correspond to a return period associated with an occurrence probability during the installation's lifetime of 10^{-2} or 0.10 (28)(29), depending on whether or not the berthing installation is for dangerous goods, obtained from the marginal distribution of extremes of the outer waters lower level caused by tides or river flow regimes.

  The compatibility values for the rest of the variables of the agents influencing draughts (waves, currents, wind, ...) will correspond to exceptional working conditions due to the presentation of an extraordinary level of outer waters caused by tides or river flow regimes for those variables acting simultaneously. That is, those associated with an absolute no-exceedance probability of 85% in the medium regime (variables independent of each other and of the outer waters level), without exceeding, where applicable, the operational capacity levels limit values corresponding to the staying of the ship at berth, as established for that variable in the considered direction and, for depending variables, those corresponding to a non-exceedance probability of 85% in the distribution function conditioned to the adopted compatibility value and direction for the variable on which they depend, without also exceeding, where applicable, the operational capacity levels limit values corresponding to the staying of ship at berth established for the considered variable (See section 4.1.1.1. b1).

More precisely, the sea floor level corresponding to each ship for both operating conditions and exceptional conditions, as applicable, may be obtained using probabilistic methods, with no need to define either outer waters reference levels nor compatibility values of the rest of variables influencing the formulation of this level, using the generation of sets of random values for these parameters (e.g. by means of the Monte Carlo method) and the subsequent definition of the sea floor level associated with them using the corresponding formulation, starting from distribution functions representing the water levels and from the rest of agents in the corresponding working conditions (medium on-site regimes for operational conditions and extreme on-site regimes for exceptional conditions of the variables, independent of each other and of the distribution functions conditioned by the variables depending on the first ones). With this methodology for each ship the appropriate sea floor level at the berth will be that associated with a probability of the ship contacting the sea floor during the lifetime of 10^{-3} for operating working conditions and 0.10 (berthing installation not for dangerous goods) or 10^{-2} (berthing installation for dangerous goods) for exceptional working conditions.

The above calculations should be done for every ship of the fleet and for limit loading cases expected at the berth, adopting as the sea floor level of the berthing installation the most unfavourable among those associated with the above-mentioned ships.

Simplifying, the berth draught may be estimated using previous calculations from the approximate formulation in table 3.2.2.2, as applicable to the maximum draught ship at its worst loading case, of the expected fleet at berth. That formulation is valid whenever the compatibility values of the on-site climatic variables compatible with the adopted outer waters reference level (operational or extraordinary tidal window depending on a more or less limitative maritime accessibility regarding the staying of the ship at berth in relation to the outer waters level) will not lead to limit conditions of ship's staying at berth classified as Type I according to those established in table 4.6.4.49 of this Recommendation.

Comment: *According to the criteria outlined in this section, the nominal draught of a berthing structure (h_l) located in sheltered waters whose maximum draught ship will be a container ship of 8,000 TEU's, with a full load static draught of 14.50 m, may be estimated at around 15.60 m under the adopted reference level for outer waters due to tides or river flow regimes (operational or extraordinary tidal window).the design draught considering the factors related to the sea floor will reach 16.60 m. if the design ship is a Panamax (up to 3,000 TEU), with a static full load draught of 12.50 m, the nominal draught may be estimated at around 13.50 m, and 14.50 m as the design draught.*

(28) For a lifetime of 50 years, an occurrence probability of 0.10 corresponds to a return period of 475 years.
(29) Extreme values of outer waters levels associated with different return periods at Spanish coasts may be obtained from table 4.6.2.3. of this Recommendation.

Table 3.2.2.2. Simplified formulation to estimate the berthing draught from the adopted reference level of outer waters (operational tidal window or extraordinary tidal window) 1)

LOCATIONS TYPE	SHIP OF MAXIMUM DRAUGHT UNDER THE WORST LOADING CASE OF THE EXPECTED FLEET AT BERTH	h_1 2)	h_3
BERTHING STRUCTURES LOCATED IN SHELTERED AREAS	Large displacement vessels (≥ 10,000 t)	1.08 D_e	1.00 m
	Small and medium displacement vessels (< 10,000 t)	1.05 D_e	0.75 m
BERTHING STRUCTURES LOCATED IN POORLY SHELTERED AREAS	Large displacement vessels (≥ 10,000 t)	1.12 D_e	1.00 m
	Small and medium displacement vessels (< 10,000 t)	1.10 D_e	0.75 m

Notes

(1) This formulation is valid whenever the compatibility values of site climate variables as compatible to reference level adopted to outer waters (*operational tidal window or extraordinary, as appropriate*) will not cause limit conditions of staying the ship at berth, classified as Type III according to the stated in table **4.6.4.49** of this Recommendation.

(2) In any case, the minimum gross bottom clearance ($h_1 - D_e$) should be 0.50 m for berthing structures od commercial industrial and military use and 0.30 m for berthing structures of fishing and sport uses. Nevertheless, when important scours are foreseen, as caused by propellers action, waves or other sources, the minimum bottom clearance should be increased up to 1.00 m. If protection elements against these effects are placed, they should be placed 0.75 m under the nominal bottom level, as a minimum.

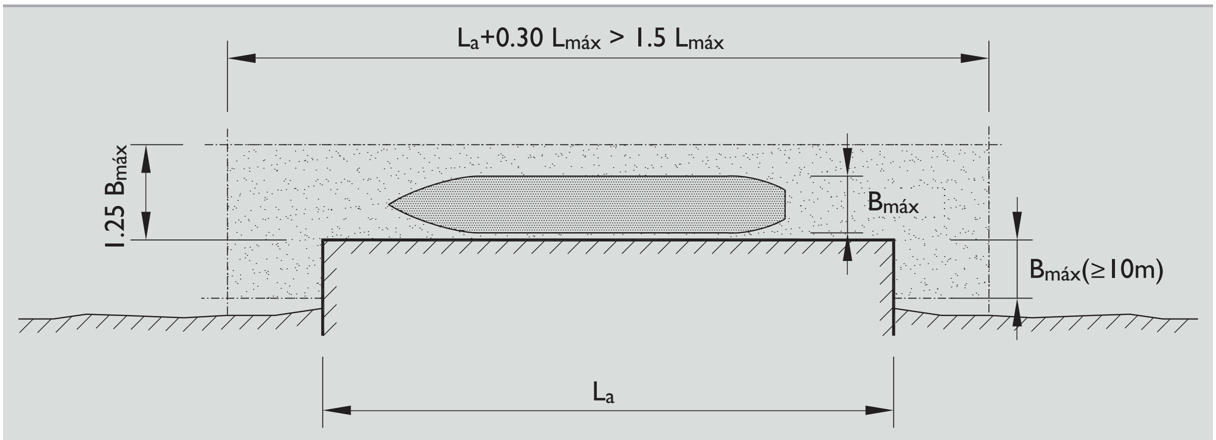
The berth's draught will be extended, as a minimum, to the total length of the berthing line, lengthened at each tip, when the berthing structure is not limited, by a length equal to 0.15 times the corresponding length of the maximum-length ship of the expected fleet at berth, (L_{max}), where the total length is in this case not lower than $1.5L_{max}$. That is, a length equal to

$$L_a + 0.30L_{max} > 1.5L_{max}$$ (30)

When considering in the design that the berthing and unberthing ship's manoeuvres will be performed using tugboats, the minimum length of the berth may be reduced to 1.25 Lmax.

And a width of 1.25 times the width corresponding to the ship of widest width (B_{max}) of the fleet. For berthing structures where the possibility of a false ship's manoeuvre moving the bow behind the berthing line exists, the design draught should also be extended by a width equal to Bmax behind that berthing line, of not less than 10 m. (See figure 3.2.10).

Figure 3.2.10. Minimum plan extension of the berthing draught



(30) When considering in the project that the berthing and unberthing ship's manoeuvre will be performed using tugboats, minimum length of the berth may be reduced to 1.25 L_{max}.

This area will form a berthing trench, when access channels and manoeuvring areas support its dimensioning with lower operational capacity levels due to draught limitations at the berth.

The dockside configuration may allow draught reductions at a distance between 0.50 and 1.50 m taken from the ledge, depending on the compressed fender width and on the transverse curvature of the ship's hull.

3.2.1.11. Longitudinal Profile of Heels and Ramps

In accordance with that established in sections 3.2.1.6 regarding the location and plan dimensioning of heels and ramps, in relation to:

- The operational levels that can be accessed by the ship's gangways.
- The definition of the operational tidal windows to be adopted.
- The heel or ramp type to be used depending on the variation range of the upper and lower levels of outer waters in the adopted operational tidal window.
- The necessary crest levels of the sea-side edges in heels and ramps.
- The crest levels at the berthing line.
- The required longitudinal slopes to perform the loading and unloading rolling operations safely and efficiently.

Consistent with the minimum longitudinal dimensions recommended in those sections, the longitudinal type profiles of heels and ramps in the direction of the longitudinal axis of the ships, are the following.

3.2.1.11.1 Fixed heels

For fixed heels, two longitudinal profiles may be distinguished depending on the range of operational levels to be reached by the ships gangways of the expected fleet at the terminal.

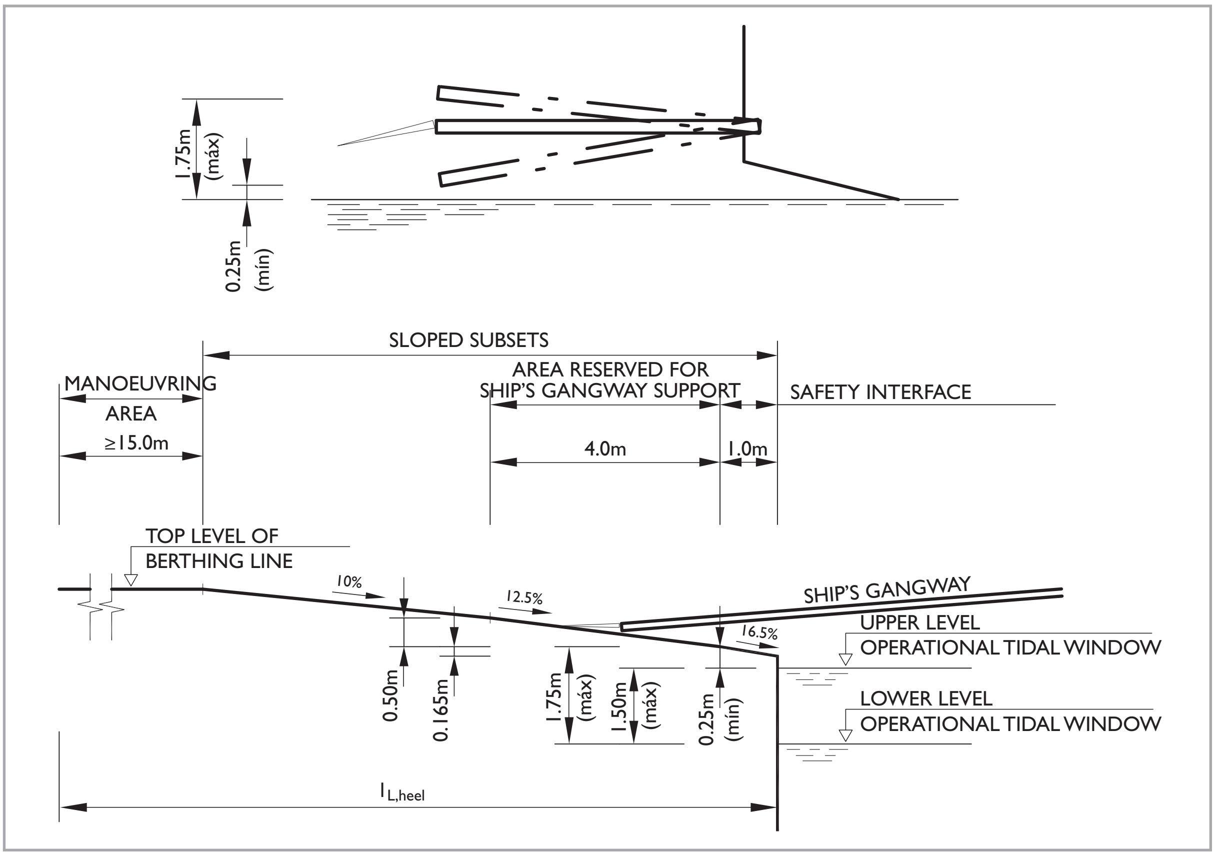
For a range between 0.25 and 1.75 m above the outer waters level, independent of the load situation (in general ships with $D_{PC} < 10{,}000$ t), the standard longitudinal profile is included in table 3.2.2.3.

For a range between 1.50 and 3.00 m above the outer waters level, independent of the load situation (in general ships with $D_{PC} \geq 10{,}000$ t), the standard longitudinal profile is included in table 3.2.2.4.

If the expected fleet at berth is made up of ships with different characteristics regarding the operating levels to be reached by their gangways, it should be disaggregated into two fleets in order to dimension the berthing line or to design a mobile ramp or floating heel solution to serve the whole fleet.

Nevertheless, when the range of variation of the outer waters in the operational tidal window would be very small (≤ 0.25 m), the standard longitudinal profile included into table 3.2.2.4 would allow all kinds of ships to be served in a single heel.

Table 3.2.2.3. ***Fixed heel. Standard or valid longitudinal profile to ships with operational levels at bow or stern gangways between 0.25 m and 1.75 m over outer waters level (ships with Δ_{PC} < 10,000 t, in general)***



3.2.1.11.2 *Mobile ramps and floating heels*

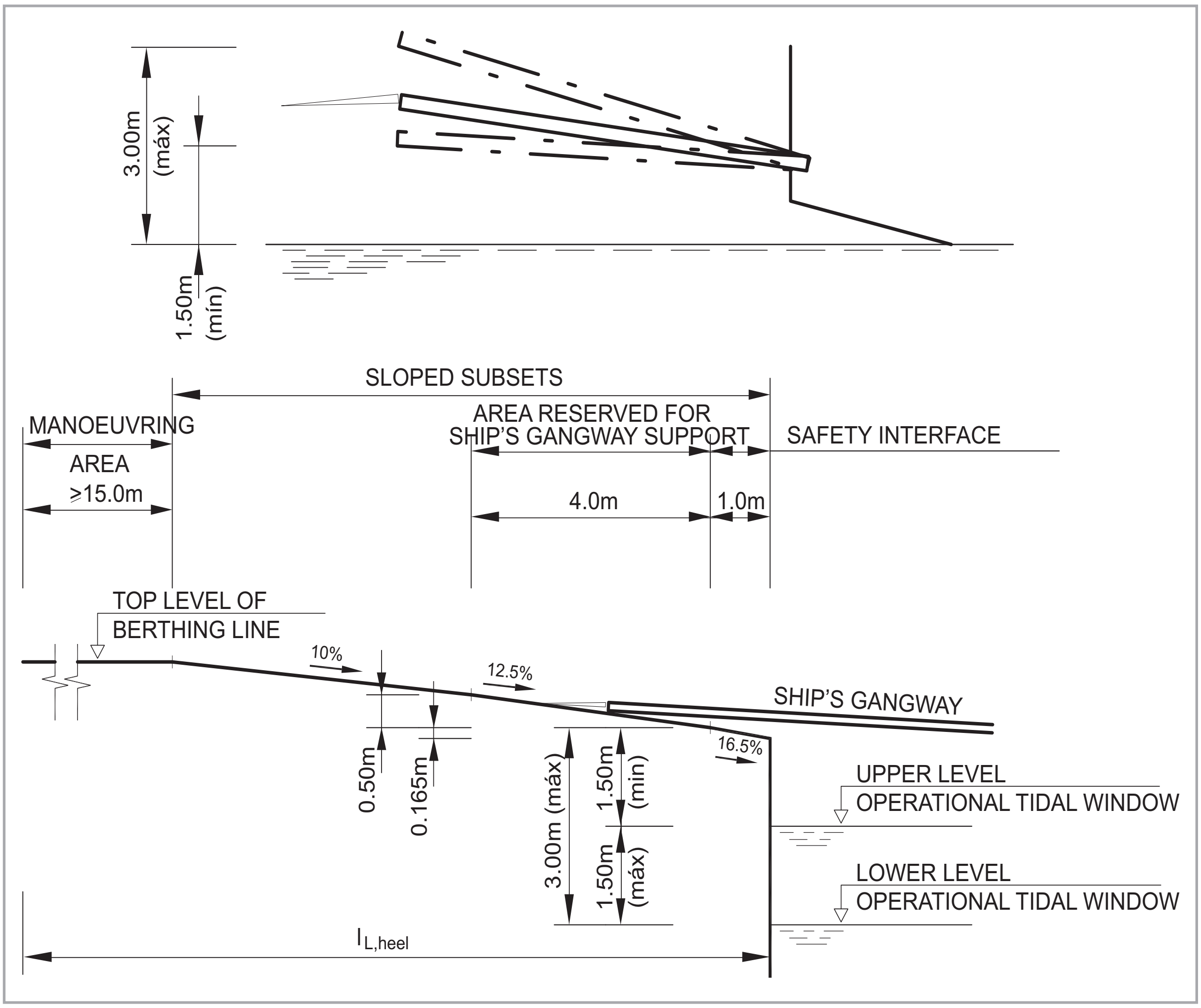
Contrary to the case of fixed heels, with mobile ramps or floating heels it is possible to serve, if desirable, the full range of existing operating levels at bow and stern gangways with a single type of longitudinal profile, independent of the fleet's composition and the range of variation of outer waters level in the adopted operational tidal window.

For that, in the case of mobile ramps supported on the sea side by fixed structures including lifting devices capable of moving the ramp, it is necessary that the upper level to be reached by the mobile ramp at the seaside, as measured at the inner side of the safety interface, will be at least the upper level of the operational window + 1.50 m, and the lower level of the mobile ramp at that point will be as a maximum the lower level of operational tidal window + 1.75 m (see section 3.2.1.6). In this case, the standard longitudinal profile is included in table 3.2.2.5.

In the case of mobile ramps supported on the sea side by flotation and floating heels, it is necessary that the ramp's freeboard at the inner boundary of the safety interface will not be higher than 1.75 m for an unloaded ramp or floating heel and not lower than 1.50 m for a fully loaded ramp or floating heel. For floating heels, the standard longitudinal profile is included in table 3.2.2.6. for mobile ramps, in table 3.2.2.7.

When the expected fleet at berth will be homogeneous regarding operating levels of the gangways, the above upper and lower levels to be reached at the sea side edges of ramps and floating heels may be modified, in accordance with the provisions established for this purpose in section 3.2.1.6, adapting the longitudinal profiles to the same and conserving the longitudinal slopes defined for each of the segments.

Table 3.2.2.4. ***Fixed heel. Standard or valid longitudinal profile to ships with operational levels at bow or stern gangways between 1.50 m and 3.00 m over outer waters level (ships with $\Delta_{PC} \geq$ 10,000 t, in general)***



3.2.1.12 Slopes of Storage and Operation Areas

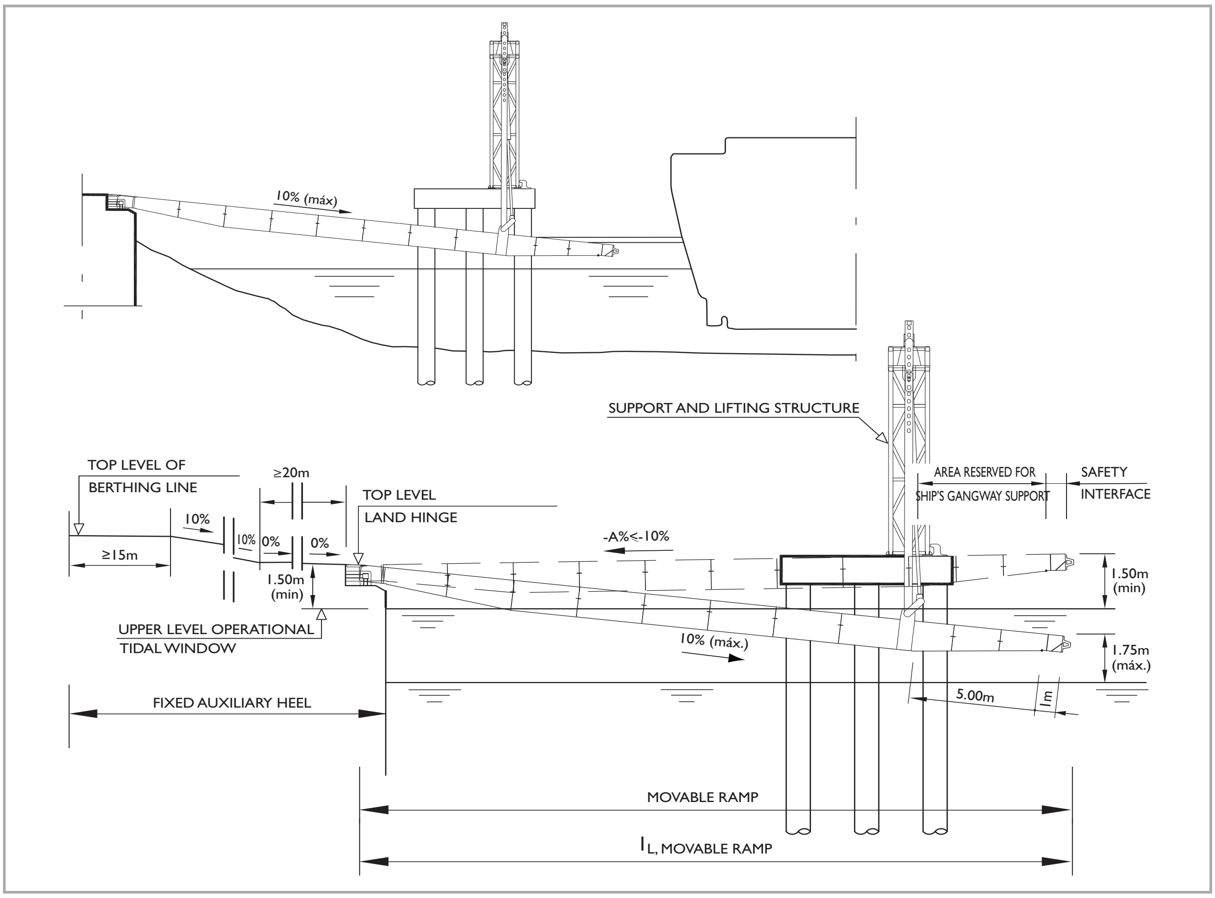
3.2.1.12.1 Storage and operation area slopes

- *For berthing installations with dock type physical configurations, for commercial use and employing goods loading and unloading systems, or boarding and disembarking passengers, by means of rolling equipment on rails.*

  - Transverse slopes

    The operation area will only be provided with transverse slopes (perpendicular to the berthing line). Due to the requirements established for operational and safety reasons for goods handling or passenger boarding and disembarking equipment on rails, the level difference between the upper levels of rails, measured at any section transversal to their driving direction, must never exceed 10 mm. For this reason, in order to avoid undesirable puddles at the area between rails, it is convenient to provide this area with transverse gabled slopes, falling between an intermediate axis situated at a higher altitude, coinciding, where appropriate, with the dividing line between the driving lanes of the

Table 3.2.2.5. Movable ramp supported on the sea side by fixed structures including lifting devices with a capacity to move the ramp. Standard longitudinal profile as valid for all kind of ships

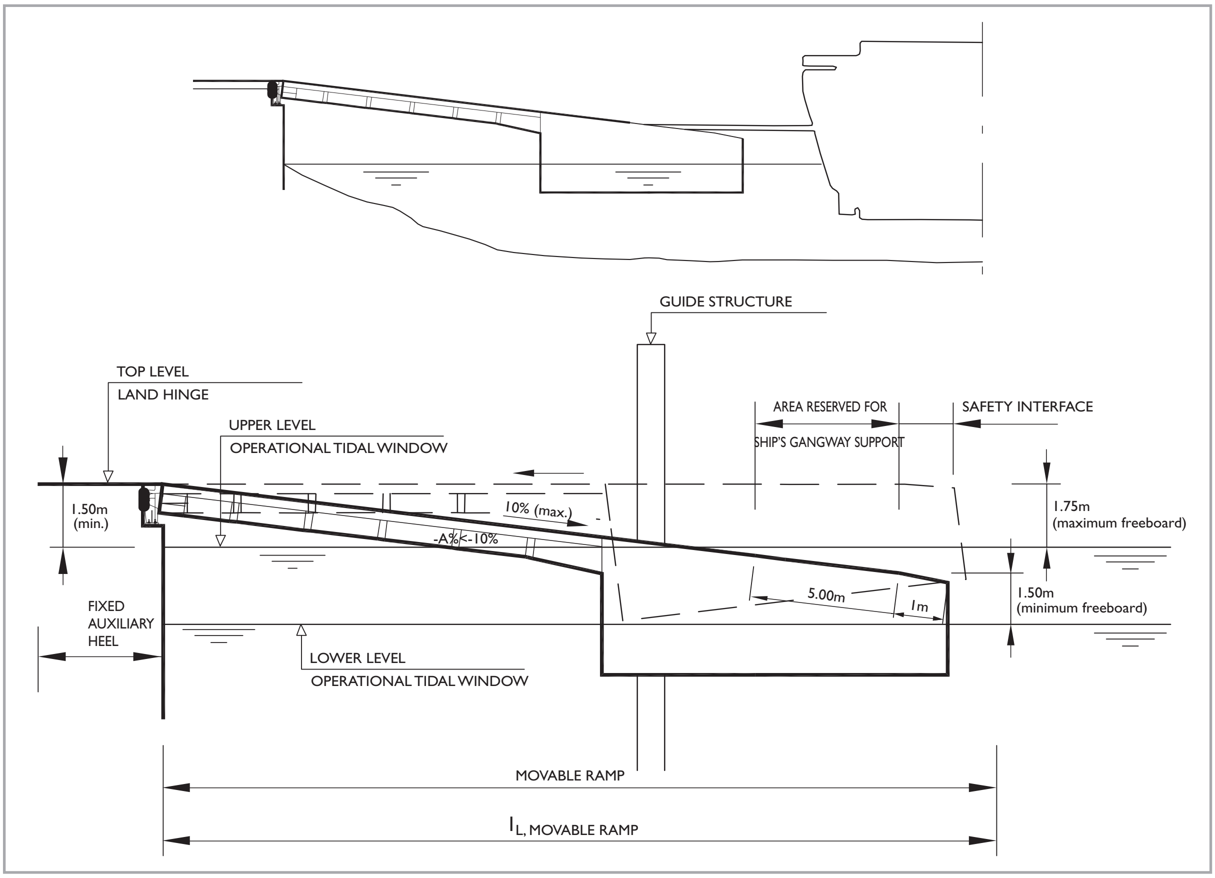


auxiliary equipment and each of the rails. The transverse slopes should not be less than 1.00% nor higher than 1.25%, if that area is devoted to temporary storage of goods and hold covers and up to 1.75%, if exclusively devoted to auxiliary equipment or transport vehicle traffic. In any case, the maximum acceptable level difference between rails at any moment during service periods must be maintained, taking into account settlements and deformations of the supporting infrastructure.

The area located between the berthing line and the sea-side rail will have a one-sided slope towards the ledge of between 1.0 and 1.75%. Conversely, in the area from the land-side rail up to the border of the storage area, the slope will be one sided up to the berthing line. In this case the slopes will range from a minimum of 1.0% to a maximum of 1.25%, whenever that area is assigned to the storage of goods and hold covers or 1.75% when assigned to cargo transfer auxiliary equipment traffic.

Rainwater collection will be performed by gutters (continuous drains) parallel to the berthing line, protected by steel grids resisting the concentrated loads transferred by the unrestricted rolling equipment at the installation, avoiding significant surface irregularities. As a minimum, one gutter will be placed between rails, as well as on both sides of the land-side circulation rail and adjacent to it (see figure 3.2.11). In bulk solid terminals runoff is not allowed to spill directly into the sea without previous filtering.

Table 3.2.2.6. Floating heel. Standard longitudinal profile suitable for all kind of ships



■ Longitudinal slopes

Due to requirements established for driving lanes for goods loading and unloading or passenger boarding and disembarking equipment for operational and safety reasons [31], as well as the convenience of having the crest heights kept constant along the entire length of the berthing line, it is not considered convenient to provide the operation area with a longitudinal slope (parallel to the berthing line).

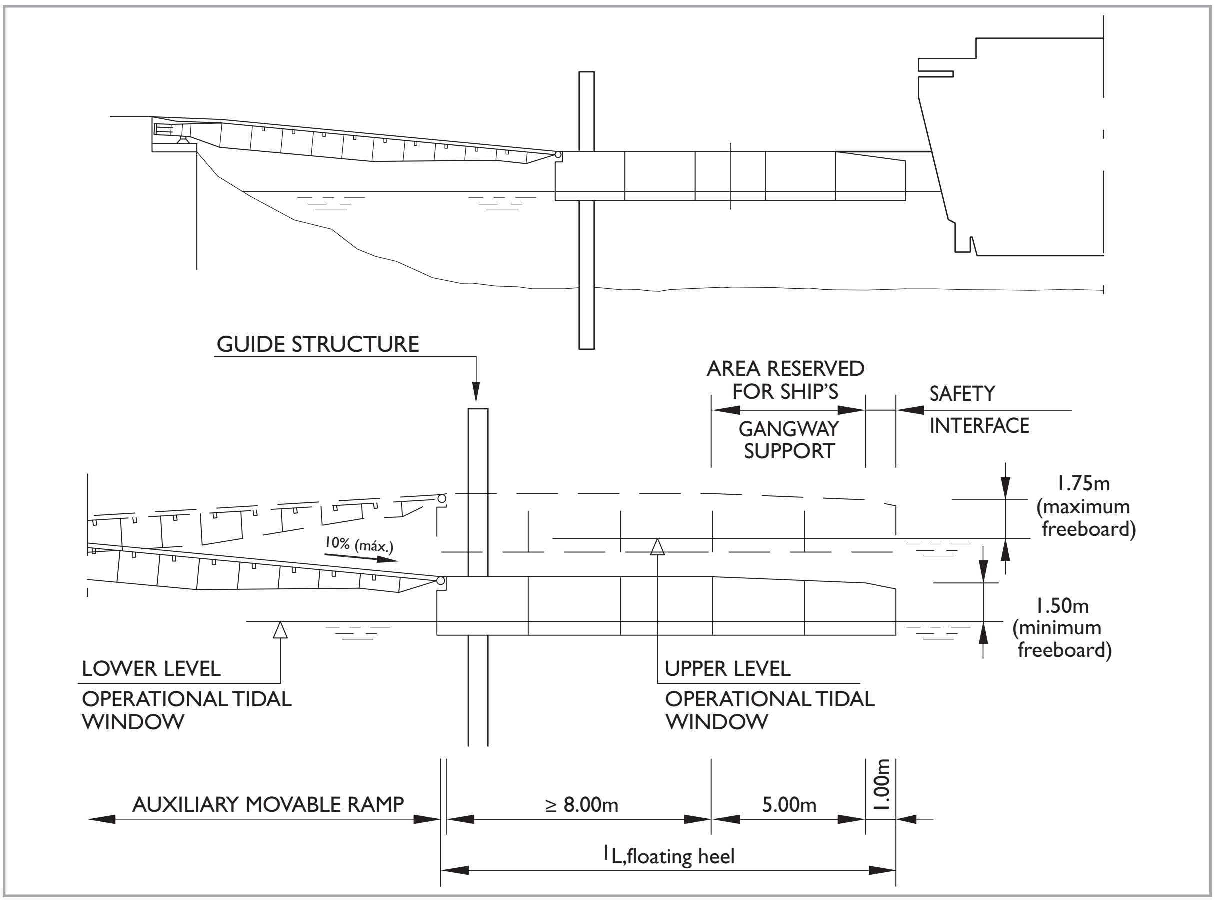
The maximum allowable vertical deviations of the upper rail levels, relative to their theoretical position, due to constructive causes or from deformations of the existing structure, as measured in the longitudinal direction, are the following:

– That relative between any two points of the same rail separated by a length (L) not less than 2.0 meters, will not be greater than L/2000.
– That of any rail point relative to its theoretical position will not exceed ± 10 mm.

◆ In berthing installations with dock-type physical configurations, for commercial use (excepting passengers) and using rolling systems for goods loading and unloading. The operation area slopes in berthing installations for Ro-Ro use with dock-type physical configurations, will be, as far as possible, only one-sided and transversal (perpendicular) to the berthing line, in order to maintain a constant height along the full length of the berth. Transverse slopes should be greater than 1% and lower

(31) See European Federation of Materials Handling codes (FEM).

***Table 3.2.2.7.* Movable ramp supported at sea side by a floating structure. Standard longitudinal profile as valid for all kind of ships**



than 1.75%. These slopes will continue into the heel's handling area to avoid undesirable puddles in that zone.

Rainwater collection will be performed by gutters (continuous drains) parallel to the berthing line. As a minimum, one gutter will be placed by the sea-side border of the operation area, situated as close as possible to the ledge, as the top superstructure of the berthing infrastructure will allow.

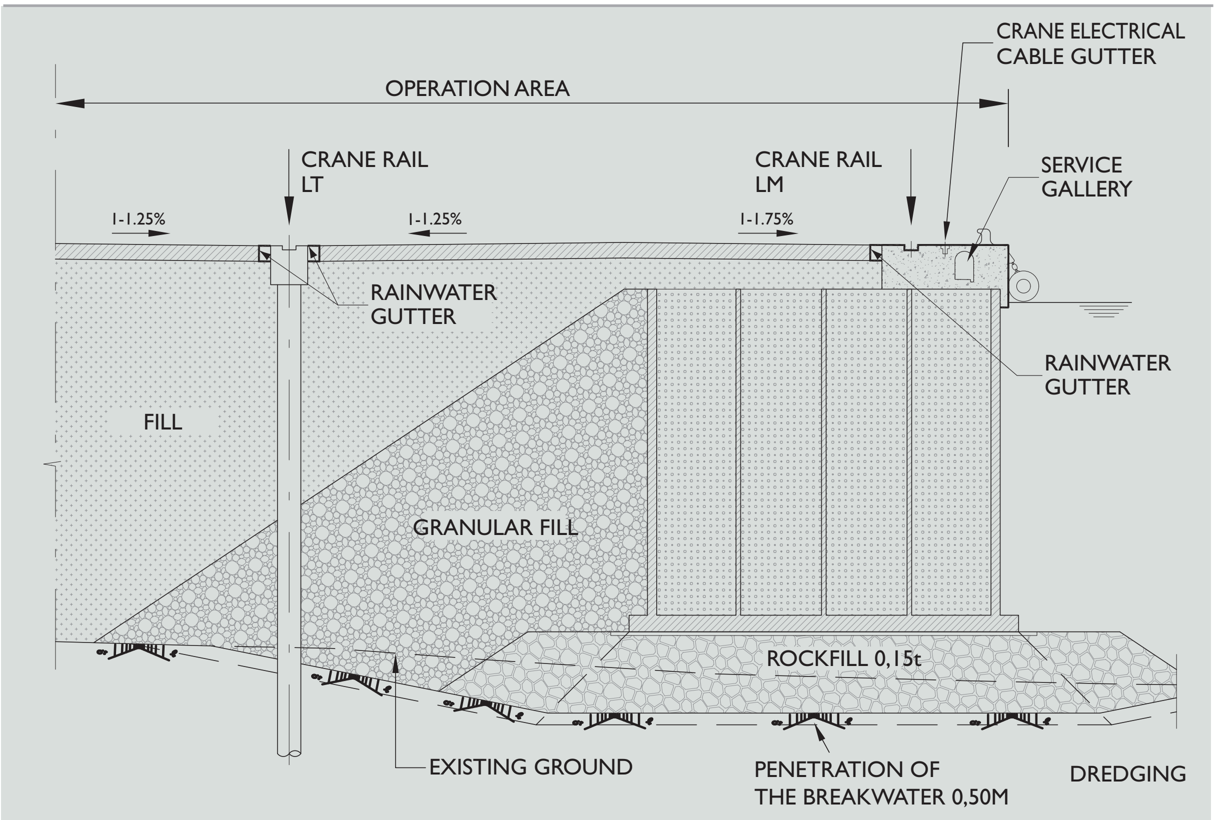
- In berthing installations with jetty-type physical configurations for commercial use (excepting passengers) using rolling systems for goods loading and unloading.

  In commercial Ro-Ro use berthing installations with jetty-type physical configurations, the criteria established for Ro-Ro berthing installations with dock-type physical configurations will also be applicable to that part of the operation area perpendicular or oblique to the berthing line.

  In the jetty itself, the slopes will be transversal (perpendicular) to the berthing line, gabled and falling between the central axis of the jetty at a higher elevation and the berthing lines. Slopes will be in the same range (1.0-1.75%) as those indicated for the other zone of the operation area (See figure 3.2.12).

  In the zone of the operation area perpendicular or oblique to the berthing line, gutters will be situated parallel to the sea-side border of that area, with the same longitudinal orientation as that zone of the operation area. As a minimum, one gutter will be placed at the sea-side border of that zone, located as close as possible to the ledge as the top superstructure of the berthing or fender infrastructure will

Figure 3.2.11. **Slopes of operational area in physical configurations of the berthing installation of dock type, with commercial use and using loading and unloading goods systems or boarding and disembarking of passengers by means of restricted rolling on rails**



allow, according to the physical configuration of the berthing structure. In the zone of the operation area coinciding with the jetty itself, it is not considered necessary to locate gutters and drains for rainwater collection.

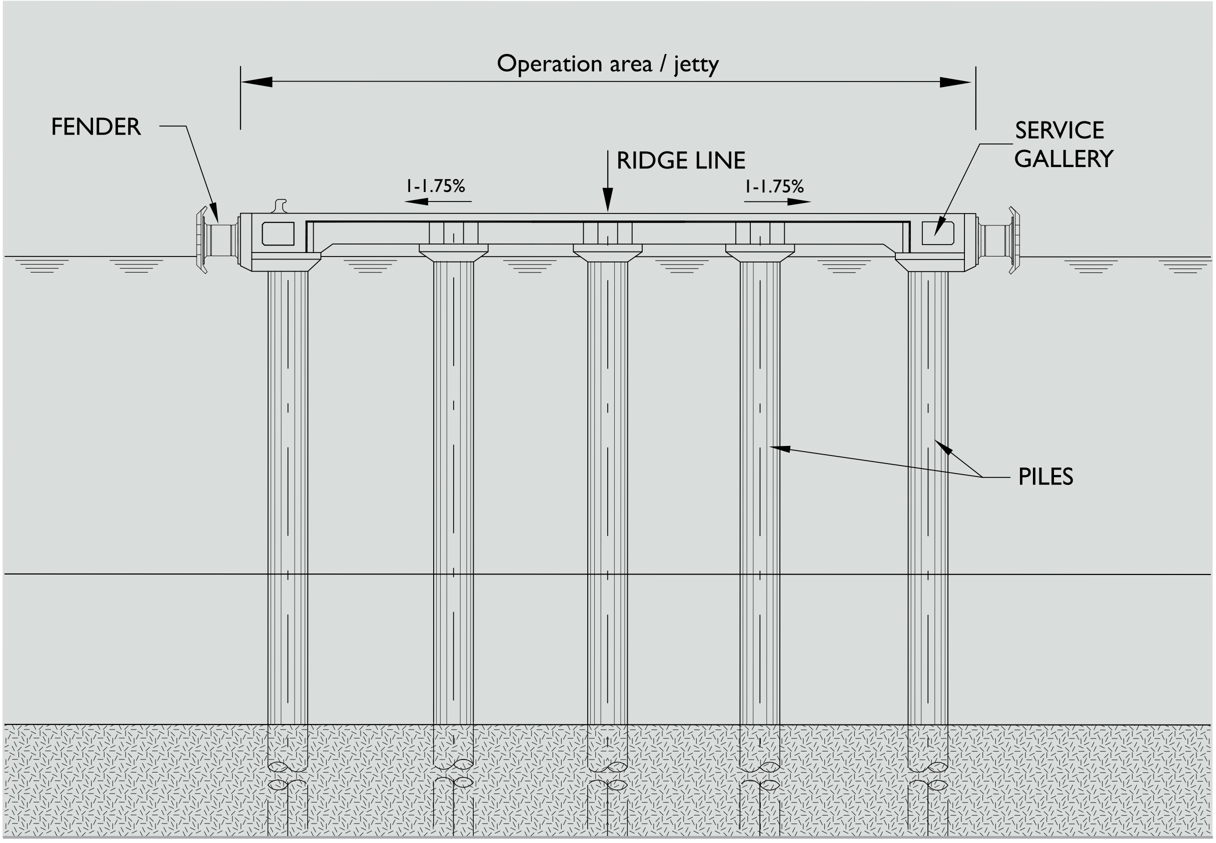
- In berthing installations with jetty-type physical configurations for commercial passengers use and using passenger boarding and disembarking equipment by means of restricted rolling equipment on rails

  At berthing installations for passengers with jetty-type physical configurations, the slopes of that zone of the operation area perpendicular or oblique to the berthing line, as well as the location of gutters for rainwater collection in that zone, will be specified according to the criteria established for the operation area of the Ro-Ro berthing installations with dock-type physical configurations.

  In the jetty itself, the slopes will be transversal (perpendicular) to the berthing line, with the following recommended values (See figure 3.2.6):

  - The strip between the ledge and the sea side rail of the mobile equipment for the boarding and disembarking of passengers: one-sided slope towards the edge between 1 and 1.75%.
  - The space between rails of the mobile equipment for passenger boarding and disembarking: : gabled descending slope between 1 and 1.75%, assuring the maximum admissible level difference between rails at any moment of the service period (10 mm), considering the settlements and deformations of the supporting infrastructure.
  - The area between the axis of the supporting structure of the fixed elevated walkway accessing the mobile passenger boarding and disembarking equipment and the land- side rail of that mobile equipment: one-sided slope towards the edge ranging between 1 and 1.75%.

Figure 3.2.12. ***Slopes of operational area in physical configurations of the berthing installation of jetty type, with a commercial ro-ro use without passengers***



- The area between the axis of the supporting structure of the fixed walkway and, when appropriate, the edge of the unberthed side of the jetty: one-sided slope of between 1 and 1.75% in the opposite direction to the berthing line.

In general, the jetty does not need to host gutters and drains for rainwater collection.

3.2.1.12.2 Slopes of storage area

The slopes in the storage area should be neither lower than 1% nor higher than 1.25%. They may be one-sided or multi-sided ones and should be compatible with the shape of the available area, the size and layout of the adopted tracks, and with the demanded requirements from the handling and transport equipment used in that area, as well as with the land side border levels of the operation area and with f land access levels, in addition to the location and capacity of rainwater evacuation systems.

For restricted mobility goods handling yard systems on rails or tyres (e.g. RMG, ASC, RTG, overhead cranes, ...), in the absence of specific criteria from the Developer of the installation, the requirements for longitudinal and transverse slopes previously established in this Recommendation for handling equipment on rails in the operational area will be applicable.

Despite the foregoing, whenever possible, it is recommended that the storage area be provided with transverse slopes exclusively (perpendicular to the berthing line).

3.3 DESIGN REQUIREMENTS

3.3.1 Verification Procedure

The verification of a berthing and mooring structure as a whole, subsets and elements, as attaining the levels of feasibility, suitability to service and operational capacity demanded, will be performed by means of supporting calculations, excepting those cases where the behavioural structural analysis would be more reliable using other procedures such as experimental or, prototypical models, or those proceeding from observational methods whose results may be generalized.

The calculations made to verify the designs included in the scope of this Recommendation should be framed, whenever possible, within the general analysis procedure known as the "limit states method". This procedure is outlined in detail in the ROM 0.0 and consists of the simplifying verification of the different failure or operational stoppage modes of only those states considered as being representative of the limit situations from the point of view of the resisting behaviour (ultimate limit states, ULS), the suitability for service (serviceability limit states, SLS), and of the use and operation (operational limit states, OLS), to which the structure is subjected. These limit states are known as project states and they are associated with occurrence probabilities at every solicitation cycle (working condition) to which the structure is subjected during the analysed project phase. The State is considered to be the time interval during which the Design factors and structural or functional responses of the work may be assumed to be statistically stationary, which allows the description of both by means of probability functions and their corresponding statistical descriptors.

Using this analysis procedure, it is understood that a berthing and mooring structure is reliable enough, suitable for service and operational when the probability of occurrence, during any Project phase, of a failure or stoppage mode corresponding to the failure tree or diagram of every series of limit states (ultimate, serviceability or operational, respectively) present in that phase, considering all the solicitation cycles to which the structure is subjected, is less than that required for each one of these modes, once the failure or stoppage probability established for the whole structure is proportionally distributed among them, which must be less than the maximum defined as admissible by this Recommendation for that structure at the considered phase (see section 3.4.4). In other words, when for each mode, there is no failure or operational stoppage of the structure in the states corresponding to each solicitation cycle whose overall probability of occurrence at the project phase will be greater than that assigned to each mode in the corresponding failure tree or diagram.

3.2.2 Failure Modes Associated with Ultimate Limit States (ULS)

Failure modes associated with ultimate limit states (ULS) are those causing the destruction of the structure or some part of it due to breaking or structural collapse. In order to arrange the calculations, in berthing and mooring structures the main failure modes to be considered associated with ultimate limit states may be classified into the following groups:

- EQU: ***Loss of static equilibrium***. The structure or some part of it loses its condition of stability without the structure's materials strength or soil bearing capacity playing a significant role. For example, the "rigid overturning" of a dock.

- STR: ***Structural or internal instability***. The whole or a part of the structure reaches its resisting capacity or excessive local or global deformations or geometric changes take place on it, causing the structural collapse. In these failure modes the strength of the constituent materials plays an essential role. Fatigue and geometric stability are considered as particular cases of this group of failure modes. An example of these failure modes may be the collapse of the outer wall of a caisson from tensile and flexural forces.

- GEO: ***Geotechnical or external instability***. These are those failures due to the breaking or deformation of the ground on which the structure rests, as excessive to structural safety. In these failure modes the ground load-bearing resistance plays an essential role. Loss of global stability is considered included in this group of failure modes. Bearing failure or deep sliding of a gravity structure may be considered to be examples of these failure modes.

- UPL: ***Failures due to excessive water pressure***. These are those failures caused by upheavals or subsidence due to hydrostatic or hydrodynamic pressure where the soil resistance and structure play a secondary role. An example of these failure modes may be the collapse of floating berthing or mooring structures in the service or construction phases caused by flooding.

- HYD: ***From hydraulic instability***. Failures caused by the presence of hydraulic gradients in the ground or fills, by dragging forces generated by them, as well as by movements of free outer waters. Examples of these failure modes may be the ground raising in front of a sheet pile quay or external erosions or under- mining of the intrados feet or the protection slopes of berthing structures due to action of natural currents or those generated by propellers and other ship propulsion and manoeuvring equipment or by waves.

These groups constitute a further development of those generally included in the ROM 0.0 in order to outline, systematize and facilitate the analysis of failure modes affecting berthing and mooring structures. Progressive collapse failure modes are not included because in this ROM it is recommended, as a simplification of calculations on the conservative side, not to take them into account in the verification process as far as the failure diagrams composed of serial failure modes are concerned.

Throughout this ROM the specific failure modes to be considered to verify the reliability of each one of the berthing and mooring structure typologies will be analysed and the criteria used to establish the corresponding verification equations will be provided.

3.3.3 Failure Modes Associated with Serviceability Limit States (SLS)

Failure modes associated with serviceability limit states (SLS) are all those causing the total or partial loss of functionality of the structure or some part of it, in a reversible or irreversible manner, due to a structural failure, whether formal, aesthetic, environmental or by legal constraint. Serviceability limit states include all the failure modes that, not being ultimate ones, reduce or limit the use and operation of the structure or may imply a reduction of its useful life.

In some cases, the assignment of a failure mode to ultimate or serviceability limit states is unclear. In such cases, an analysis of the failure type as well as its temporal nature is recommended. When the failure mode is due to a pathology or is caused by the action of one or several agents during a time period much shorter than the useful life of the structure, the failure mode should be assigned to ULS. On the other hand, if the appearance of the failure mode may be delayed or avoided by means of an appropriate conservation strategy of the structure, the failure mode may be assigned to SLS.

In berthing and mooring structures, the main associated failure modes that should be assigned to SLS may be classified into the following group:

- DUR: ***Durability***. These are failures due to loss of durability of the structure, defining durability as the combination of the capacity of the materials to maintain the specified design characteristics over time against the agents of the physical environment, the soil, construction or use and operation, taken together with the capacity of the structure to keep working during the whole of its useful life with acceptable service levels including after the onset of material degradation. An example of these failure modes is concrete cracking or the corrosion of a steel sheet pile.

- REP: ***Reparability***. These are those failures associated with the maximum level of damages to the structure allowing the use of foreseen and planned maintenance and repair procedures. An example of these failures is the start of damages in the protection layer of the breakwater slope of a piled quay.

- VIB: ***Excessive vibrations***. These are failures causing a loss of functionality of the structure because of the amplitude or frequency of vibrations on the same. An example of theses modes may be the damages to elements and handling installations in a jetty or dolphin from vibrations directly caused by wave action, long waves or mooring actions, with consequences for the normal operation of the installation.

- EXD: ***Excessive Deformations.*** These are failure modes causing a loss or limiting the normal operation of the berthing structure because of deformations, displacements or excessive settlements due to structural, geotechnical or hydraulic causes. An example of these failure modes may be a deflection exceeding the use and operation tolerances n of the handling equipment.

- AEST: ***Aesthetic.*** They are failure modes affecting the achievement of formal aspects required in the structure. The loss of alignment of the ledge or the verticality of a dock may be mentioned as some examples.

These groups constitute a further development of those generally included in the ROM 0.0 in order to outline, systematize and facilitate the analysis of the failure modes affecting berthing and mooring structures. Also, and for the same reason, almost all failure modes of a geotechnical origin assigned to SLS and included in the 0.5, are included here as failure modes of excessive deformations, because in that group are collected all failures caused by excessive deformations or movement independent of their originating cause.

3.3.4 Stoppage Modes Associated with Operational Limit States (OLS)

Stoppage modes associated with operational limit states (OLS) are those where the operation of the berthing installation is reduced or temporarily suspended for reasons external to the structure or its installations, with no structural or formal damage to them or any of their elements. In general, operation stops to avoid damages to the structure or its elements, the ship and goods handling or passenger boarding and disembarking equipment, unacceptable environmental and social consequences or to preserve the safety of passengers and goods. Once the cause of operational stoppage has ceased, the berthing structure recovers all the designed operational requirements. Generally, these states are assigned to exceedance of climate factors or to legal or safety conditions.

In berthing and mooring structures, the main modes of operational stoppage assigned to OLS may be classified into the following groups:

- ACS: ***Suspension of ship's accessibility to the berthing installation (and the possibility of ship's departure from berth)***. The operational stoppage of a berthing and mooring structure is caused by the impossibility of ships to call or leave the installation and to berth (or unberth) in safe conditions with the available means of exploitation (tugboats, fenders, etc.). The main stoppage modes or suspension causes of maritime accessibility to a berthing installation are:

    - Suspension due to insufficient draught at the access channel and manoeuvring areas.
    - Suspension for insufficient dimensions of the access channel and manoeuvring areas.
    - Suspension due to inoperative conditions of the auxiliary means needed for ship access and manoeuvres (tugboats, etc.).
    - Suspension due to insufficient visibility conditions.

    These suspension causes should not imply more restricting conditions than those due to suspension causes of staying the ship at berth, because access or departure of ships at berth for limit conditions of staying the berthed ship, have to be assured.

- ATR: ***Paralysis of the berthing operations***. The operational stoppage of the berthing structure is caused by the impossibility of carrying out the berthing manoeuvres in safe conditions with the available operational means (tugboats, etc..). The causes of stoppage of berthing operations ought to be the same as those pertaining to the suspension of ship's accessibility to the berthing installation, because it is convenient for ships to be able to berth if they are able to enter the berth, in order not to unnecessarily increase waiting times and therefore not to reduce serviceability levels. Nevertheless, when any cause of suspension of the staying of ships at berth would create more limitative conditions than those due to suspension of maritime accessibility, those suspension causes should also be considered as stoppage causes of berthing operations, because a ship should be able to stay at berth whenever it may berth therein.

- PER: ***Suspension of the staying of ships at berth***. The operational stoppage of the berthing and mooring structure is caused by the impossibility of ships staying therein under safe conditions with the available operational means. The main stoppage modes or suspension causes of staying the ships at berth are:

  - Suspension due to the inability to guarantee the ship's functionality at berth because of incompatibility between the configuration of the expected mooring system, the available auxiliary means at harbor (e.g. tugboats), where appropriate, and the ship's motions.
  - Suspension due to insufficient draught.
  - Suspension due to exceedance of the maximum acceptable load at the ship's hull or at any of the elements comprising the berthing system (fenders, bollards, mooring lines, ...).
  - Suspension due to emergency situations of the ship or berthing installation from internal or external causes.

- CAR: ***Paralysis of loading and unloading ship operations or passenger boarding and disembarking***. The operational stoppage of the berthing and mooring structure is caused by the impossibility of performing therein, the loading and unloading operations or passenger boarding and disembarking in safe conditions with the available equipment. The main stoppage modes or causes of paralysis of loading and unloading operations and passenger boarding and disembarking are:

  - Paralysis for safety reasons pertaining to the handling or passenger boarding and disembarking equipment, as well as to their operability, associated with resisting, functional or environmental aspects.
  - Paralysis due to incompatibility of the berthed ship's motions with loading and unloading operations or passenger boarding and disembarking.
  - Paralysis due to insufficient maximum elevation height of the ship's loading and unloading equipment above the berth's crest level.
  - Paralysis due to incompatibility between the sea-side border heights of heels and ramps and the ship's gangway levels, as well as between slopes and transitions between their sloped planes with regard to vehicles or other handling equipment with rolling means.
  - Paralysis for overtopping of the exterior waters or the backfill being above the berth's crest level.

  These groups constitute a further development of those generally included in the ROM 0.0 in order to outline, systematize and facilitate the analysis of the operational stoppage modes affecting berthing and mooring structures.

3.3.5 Calculation Methods

As stated above, the aim of the calculation methods of limit states is to verify that a structure or subset of the same, fulfils the safety, serviceability and use and operation requirements as mandated in this ROM and meets other applicable standards for each project phase. Accordingly, the design should be verified for each and every one of the failure and stoppage modes which can happen at each limit state, evaluating their occurrence probability and the joint occurrence probability of all the main failure modes, so that the recommended values will not be exceeded.

Failure or stoppage modes are defined, ordered, correlated and sequenced by means of the establishment of failure or stoppage trees, corresponding to each one of the limit states, which shows the different ways, forms or mechanisms where may produce respectively, the ultimate, service failure or operational stoppage of the structure or some section of the same.

From the full set of failure or stoppage modes, those occurring simultaneously, mutually exclusively or non-exclusively should be identified, and among the latter set, those which are mutually independent and those which are correlated. Nevertheless, because of the complexity of failure trees, whenever feasible, it is admissible on the conservative side, to simplify the process, to consider in the failure tree a full set of failure modes that do not occur simultaneously, where all the failure or stoppage mechanisms remain described, organizing them in series and considering them as mutually exclusive. This simplified failure tree is called a failure or stoppage diagram. The use of these diagrams allows much more simple analysis and to verify the structure on the conservative side.

The set of failure or stoppage modes established with this criterion, either as mutually exclusive or not, satisfies the Project requirement regarding the failure or operational stoppage probability if the sum of the occurrence probabilities of each mode included in the failure or stoppage diagram is less than the required joint probability, with that sum representing an upper limit of the failure or stoppage probability. Similarly, the verification of the full set of the structure may be easily transposed to the verification of each one of the modes included in the failure diagram, calculating that its occurrence probability will be less than that corresponding to it in every case, after appropriately distributing among them the joint probability of failure or stoppage established as a design requirement, (see section 3.4.4).

The failure or stoppage modes that contribute to a greater extent to the joint probability, having been assigned probabilities of the same order of magnitude as those joint probabilities, due to the fact that improving the feasibility, functionality or operational capacity of the structure against those modes is very difficult or only feasible by very significantly increasing the structural costs, are called principal failure or stoppage modes, considering that they are practically the only determinant modes for the joint probability. Conversely, non-principal failure or stoppage modes are those where relatively small structural cost increases may substantially improve the feasibility, functionality or operational capacity of the structure against them. The failure or stoppage modes considered as non-principal ones should be verified with an unconditional criterion of no-failure (probability of failure $p_f < 10^{-4}$ for failure modes assigned to ultimate limit states, probability of failure $p_f < 0.07$ for failure modes assigned to serviceability limit states and stoppage probabilities $p_{stoppage} < 10^{-3}$ for failure modes assigned to operational stoppage ultimate limit states).

The checking of the failure or non-failure of a certain mode is done using the formulation and resolution of a verification equation in the limit state corresponding to each solicitation cycle of the structure during the considered phase (deterministic and deterministic-probabilistic formulation) or in all the states of each solicitation cycle (probabilistic formulation). The verification equation separates the failure domain from the non-failure domain.

The verification equation is an equation of state and therefore, independent of the type of formula used for the same.

In general, this equation is formulated in terms of safety margin:

$$g\ (X_i) = R(X_1,..., X_m) - S(X_{m+1},\ ...., X_{m+n}) \geq 0$$

or safety coefficient:

$$g'(X_i) = R(X_1,..., X_m)\ /\ S(X_{m+1},\ ...., X_{m+n}) \geq 1$$

where X_i are the different project factors affecting the process, R is the full set of favourable terms (contributing to the non-occurrence of the failure), and S the full set of unfavourable terms (inducing or causing the failure).

The project factors X_i will be those corresponding to the considered limit state, defined by specific values representative of that state (deterministic and deterministic-probabilistic formulation) or defined by density or distribution functions representative of the considered solicitation cycle (probabilistic formulation).

In the latter case, the verification equations will be expressed in terms of probability of failure or stoppage during a reference period (project phase). That is,

$$p_f = Prob\ [\ g \leq 0]$$

$$p_f = Prob\ [\ g' \leq 1]$$

For those failure modes applicable to berthing and mooring structures i.e. verifiable ones according to a certain calculation method, the corresponding verification equations will be included in the Recommendations of series 2 (Recommendations for the project and construction of the berthing and mooring structures) for each of the berthing and mooring structures structural typologies. The verification equations of the geotechnical failure modes are included in the ROM 0.5. Geotechnical Recommendations for maritime and harbor structures and those corresponding to structural failure modes for the specific Standards or Instructions of materials (in concrete, steel, etc).

The verification equation of the stoppage modes will be of the following type:

$$p_{stoppage} \leq p_{f,\,ELO} = 1 - r_{f,\,ELO}$$

That is, it should be verified that the probability that in the average year (or in other time intervals such as seasonal periods depending on the characteristics of the berthing installation) a stoppage mode lower than the value assigned to that probability in the stoppage tree or diagram will occur.

To verify the stoppage modes the magnitude and direction of, the threshold values of the variables related to atmospheric and maritime climate agents must first be determined, as well as those from operational agents, successively considered as predominant ones, whose exceedance triggers the operational stoppage mode, which in turn defines the limit states of the solicitation cycles assigned to the exploitation of the berthing installation (operational working conditions) corresponding to the considered stoppage mode. Once these threshold values are defined, the failure domain allows the calculation of the stoppage probability corresponding to the considered stoppage mode, defined by the values exceeding the threshold values. That is:

$$X_1 > X_{1,0},\ X_2 > X_{2,0}, \ldots X_i > X_{i,0}$$

where $X_{i,0}$ is the operational capacity limit value of the variable X_i for the considered stoppage mode.

The equations which allow the determination of the operational capacity threshold values of those variables corresponding to each of the stoppage modes, are included in Chapter 4 of this Recommendation, because their resolution is essential to resolve the operational solicitation cycles affecting the analysed berthing installation (See section 4.6.4.2 for the stoppage modes associated with the paralysis of loading and unloading ship operations or passenger boarding and dis- embarking, section 4.6.4.4.3 for those related to the suspension of the berthing operations, section 4.6.4.4.7. for those related to the staying of the ship at berth and ROM 3.1-99 for those associated with the ship's accessibility to the berthing installation).

3.3.5.1. Formulation of the Verification Equation

The verification equation may be applied using the following formulas:

3.3.5.1.1 Deterministic formulation

This formula may be used whenever the variability of factors involved in the verification equation will not be significant during the considered solicitation cycle and for the analysed failure mode. It may also be used when all the design factors are defined by deterministic values, so that sufficient data on their on-site variability is not available.

The limit state corresponding to each failure mode and solicitation cycle (working condition) is defined from the nominal values (32) of the factors, whenever their variability is not significant or from deterministic values (33) when no feasible data are available regarding their variability, calculating all the terms of the verification equation with these values, affected by the safety coefficients defined as a function of the required safety or functionality objectives.

In this case, the verification equation is modified by assigning to the same, a global safety coefficient (F), also defined depending on the safety or functionality objectives. That is:

$$g\,(X_i) = R(X_1, \ldots, X_m) - S(X_{m+1}, \ldots, X_{m+n}) \geq \mathrm{F}_1$$

$$o$$

$$g'(X_i) = R(X_1, \ldots, X_m) \,/\, S(X_{m+1}, \ldots, X_{m+n}) \geq \mathrm{F}_2$$

The deterministic formulations do not allow the directly calculation of the occurrence probability of the failure modes, generally adopting global or partial coefficients associated with the unconditional non-failure condition ($p_f < 10^{-4}$) or, at best, with low occurrence probabilities (< 0.05).

In the subsequent series 2 Recommendations corresponding to each structural typology of the berthing and mooring structures, the global and partial coefficients included in the verification equations using deterministic formulations will be defined using nominal or deterministic values of the design factors, as well as the failure probabilities associated with them. Those corresponding to geotechnical failure modes, together with the global and partial coefficients to be used, are included in the ROM 0.5. Geotechnical recommendations for the Design of Maritime and Harbour works. In the case of structural failure modes, appropriate Standards or specific Instructions depending on the type of construction material, shall apply for this purpose. When specific global and partial coefficients for some of the verification equations are not available, verified or justified values may be used, either from previous experiences or from other Recommendations, Standards and Instructions.

It is recommended that the use of verification equations deterministic formulas be restricted to the verification of those failure modes where the variability and randomness of the design factors will not be significant to its safety or functionality. Unless expressly justified, it is not acceptable to use verification equations deterministic formulas for those failure modes with predominant physical-environmental, atmospheric climate, maritime climate or seismic agents.

Deterministic formulas cannot be used to verify stoppage modes, because the verification of this type of modes is directly associated with the variability of on-site climatic and operational factors.

3.3.5.1.2 Deterministic-probabilistic formulation

The limit state corresponding to each failure or stoppage mode and solicitation cycle (working condition) will remain defined by the values representing those factors, acting simultaneously, included in the verification equation, associated with joint occurrence probabilities in the considered solicitation cycle. The representative value of the predominant factor for the considered failure or stoppage mode and solicitation cycle is generally known as the characteristic value. The representative values of the remaining factors acting simultaneously will be compatibility values with the characteristic value, considering the joint occurrence probability in the solicitation cycle (combination values, frequent values or quasi-permanent values of the factors independent of each other, and compatibility values for the factors depending on the previous ones). The representative values of the design factors are obtained from the respective probability models, marginal or jointly, in the considered solicitation cycle, associated with certain non-exceedance probabilities for each of them, established taking into account the joint probability objective in that solicitation cycle.

(32) In general, average nominal values are adopted as values.

(33) In general, reasonable valuations of the average values or from the most unfavourable possible on-site values, are adopted as deterministic values.

The terms of the verification equation are calculated with those values representative of the Design factors, also affected by global and partial safety coefficients defined depending on the required safety or functionality objectives.

The deterministic-probabilistic formulas do not allow the direct calculation of failure mode occurrence probabilities. Its application requires the definition of the values representing the factors to be adopted, together with the global and partial coefficients leading to the objective failure probability. This should be done through application of probabilistic methods. In general, the majority of the verification equations of failure modes assigned to ultimate limit states expressed in deterministic-probabilistic terms are traditionally associated with the unconditional non-failure condition ($p_f < 10^{-4}$) or, at best, with low occurrence probabilities (< 0.05). For higher failure probabilities and in the absence of a previous calibration of the representative values and safety coefficients associated with the objective failure probability, it is acceptable to assimilate that failure probability with the occurrence probability of the predominant factor for the analysed failure mode in the considered solicitation cycle. In this case, the value representing the predominant factor will be that corresponding to this occurrence probability as obtained in its probability model and the values representing the remaining factors will be the compatibility values of the same, also obtained from their respective probability models in the considered solicitation cycle. In this case, the partial coefficients of those unit value factors are adopted, and a global coefficient greater than the unit, established as a function of the uncertainty associated with the failure mode verification equation used, of the predominant factor variability in the solicitation cycle and for the considered failure probability.

The criteria used to define the values representing the factors included in the verification equations corresponding to each solicitation cycle (working condition) and particularly to the agents and to the forces associated with these agents are included in Chapter 4 of this recommendation. Additionally, the applicable global and partial coefficients involved in the verification equations of each failure mode formulated with these representative values, as well as the failure probabilities associated with each set of representative values and coefficients, corresponding to each structural typology of berthing and mooring structures, is included in the subsequent Series 2 Recommendations. The coefficients corresponding to geotechnical failure modes are included in the ROM 0.5. Structural failure modes are included in the Standards and specific Instructions of the applicable materials.

By means of the deterministic-probabilistic formulation, the probability of stoppage corresponding to each stoppage mode may be obtained as the sum of the annual absolute operational capacity threshold exceedance probabilities (or in some other time interval such as seasonal periods depending on the characteristics of the berthing installation) associated with the considered mode, corresponding to each one of the independent variables , as obtained from the corresponding marginal mean scalar regimes, as well as from the operational capacity threshold exceedance adopted to the variables depending on the previous ones conditioned to a threshold no-exceedance value of the variable on which they depend in the considered direction, where appropriate (See sections 4.1.1.3 and 4.6.4.4.7.1.3.a4).

3.3.5.1.3 PROBABILISTIC FORMULATION

When probabilistic formulation is used for the verification equations, limit states are not defined, because the verification of each failure mode by means of the corresponding verification equation is not carried out in limit states but in each and every one of the states present in each solicitation cycle (working condition). In this case, limit states are the result of the process of resolution of the verification equation.

The terms of the verification equation should be defined using the distribution functions included in each failure mode, directly calculating the failure probability by joint integration of those distribution functions in the failure domain defined for the verification equation [$g \leq 0$ o $g' \leq 1$].

In this formulation, global and partial safety coefficients are not applied in the verification equation.

To verify an operational stoppage mode using the probabilistic formulation, the overall annual on-site density functions should be used (or in some other time interval such as seasonal periods depending on the characteristics of the berthing installation), corresponding to the variables where operational capacity thresholds limits for that stoppage mode have been defined. In this case the stoppage probability will be obtained by integrating the overall density function in the failure domain defined by the threshold values of the established variables of the considered stoppage mode.

3.3.5.2 Resolution Methods of the Verification Equation and Calculation of the Probability of Failure or Stoppage

The resolution methods of the verification equation of the failure modes are the following:

3.3.5.2.1 Level I methods

Level I methods may be applied to the verification equations of failure modes, formulated either with deterministic or deterministic-probabilistic criterion. As above mentioned, the feasibility and functionality design objectives are included in the verification equation affecting the nominal, deterministic or representative values of the design factors included in the same and defining the limit state, with suitable global and partial coefficients as a function of the required failure probability. These representative values and coefficients have been obtained a priori through their calibration by means of observation of the behaviour of the constructed Works or by applying Level II or III probabilistic methods to similar projects capable of being extrapolated based on the local on-site conditions.

The analytic resolution of the verification equation only determines for the values and coefficients assigned, whether or not the failure or operational stoppage mode occurs, assuming the verification process complete when the its result shows that the failure or stoppage mode does not occur.

For the operational stoppage modes, the resolution of the verification equation is equivalent to obtaining the sum of the absolute on-site exceedance of the operational capacity thresholds associated with the considered stoppage mode. The operational capacity threshold of each variable corresponding to a stoppage mode will be associated with the limit state when that variable is predominant, as adopted to verify the failure modes in the operational solicitation cycle (operational working condition) associated with that stoppage mode.

3.3.5.2.2 Level II and III methods

Level II and III methods are applicable to probabilistic formulations of the verification equation. The verification equation of a failure or stoppage mode should be expressed as a failure or stoppage probability, and its solution is the occurrence probability of the mode in the considered phase.

The failure probability is directly calculated by integrating of the joint density function of the design factors involved in the considered solicitation cycle in each failure mode in the failure domain defined by the verification equation. That is:

$$p_f = Prob[g \leq 0] = \int_{g \leq 0} f_X(x) \cdot dx$$

where f_X is the joint density function of the X variable involved in the verification equation in the considered solicitation cycle (working condition).

The stoppage probability is directly calculated by integrating the annual joint density function of those variables that could limit the operational capacity of the installation for the considered stoppage mode in the failure domain defined for the operational capacity threshold of those variables. That is:

$$p_{stopped} = \int_{X_i > X_{i,0}} f'_X(x) \cdot dx$$

where f'_X is the overall density function in the considered time period (generally one year, but also seasonal periods depending on the characteristics of the berthing installation) of those X variables that could limit the operational capacity of the installation for the considered stoppage mode and $X_{i,0}$ is the operational capacity threshold values of those variables corresponding to the stoppage mode.

These integrations may be performed by direct integration (rarely possible), by numerical simulation (Level III), or by transformation of the integrand in order to work with independent Gaussian variables (Level II).

A simple Level III method is the Monte Carlo simulation method, allowing the application of the verification equation to a large sample of equiprobable random value sets of the design factors involved therein, as obtained from the distribution functions, joint, marginal and conditional to them. As a result of all the simulations, some failure cases will be obtained, as a certain fraction of all the performed simulations. This fraction is the probability of failure or stoppage.

In this case, the verification process is completed if the probability of failure or stoppage is less than that established as a design objective for the corresponding failure or stoppage mode.

3.3.5.3 Criteria for the Application of Verification Equation Resolution Methods

The recommended verification equation resolution method for the failure and stoppage modes described in this Recommendation depends on the general character of the work and is a function of the Economic Repercussion Index (ERI) and the Social and Environmental Repercussion Index (SERI) of that work, according to that expressly indicated in the ROM 0.0 (See table 3.3.5.1). Nevertheless, to verify the failure or stoppage modes not considered as being principal, the application of only Level I methods will be sufficiently accepted, but only Levels II and III will allow the accurate definition of the safety, functionality and operational capacity conditions of the berthing and mooring structure, by the accurate identification of the limit states of the berthing installation. Accordingly, it is always advisable to also apply Levels II or III methods, regardless of the character of the work.

Table 3.3.5.1. Solving methods for the verification equation depending on the Economic Repercussion Index (ERI) and the Social and Environmental Repercussion Index (SERI)

ERI	SERI			
	s_1	s_2	s_3	s_4
r_1	(1)	(2)	(2) y [(3) or (4)]	(2) y [(3) or (4)]
r_2	(2)	(2)	(2) y [(3) or (4)]	(2) y [(3) or (4)]
r_3	(2) y [(3) or (4)]	(2) y [(3) or (4)]	(2) y [(3) or (4)]	(2) y [(3) or (4)]

(1) Level I Methods: Global safety coefficients.
(2) Level I Methods: Partial safety coefficients.
(3) Level II Methods: Statistical moments and optimization techniques.
(4) Level III Methods: Integration and numerical simulation.

According to these criteria and the ERI and SERI indexes recommended in this ROM depending on the type of berthing and mooring structure (see tables 3.4.2.1 and 3.4.2.2), to verify the principal failure and stoppage modes, it is usually sufficient to apply only Level I methods, excepting the berthing and mooring structures for commercial use with the handling of dangerous goods, military use structures, and those with a high economic repercussion index, as well as for those directly supporting or having close to them buildings (maritime station, fish market, ...), stores or silos possibly affected in cases of failure of the berthing structure.

Table 3.4.2.1. Recommended Economic Repercussion Indexes (ERI) and Minimum useful lives (V_{min}) for the berthing and mooring structures, depending on use

USE	GOODS TYPE		ERI INDEX 4		MINIMUM WORKING $V_{MÍN}$ 4) LIFE (AÑOS)
COMMERCIAL	Bulk liquids		r_3 (r_2) 1)	High (Medium) 1)	50 (25) 1)
	Bulk solids		r_3 (r_2) 1)	High (Medium) 1)	50 (25) 1)
	General goods		r_2	Medium	25
	Passengers	Ferries	r_3 (r_2) 2)	High (Medium) 2)	50 (25) 2)
		Cruisers	r_2	Medium	25
FISHING			r_1	Low	15
NAUTICAL-SPORTS			r_1	Low	15
INDUSTRIAL			r_2 (r_3) 3)	Medium (High) 3)	25 (50) 3)
MILITARY			r_3	High	50

(1) The ERI Index may be reduced to r_2 when bulk solid or liquid is not related to the energy supply or to mineral strategic raw materials and when alternative handling and storage systems are not available.
(2) The ERI Index may be reduced to r_2 when alternative installations are available.
(3) The ERI Index will be increased to r_3 when the industry served by the berthing structure will be associated to the energy production or to the transformation of mineral strategic raw materials.
(4) Indexes r_I and r_2 of the table will be increased one level every 25M€ of the initial investment of the berthing structure.

Table 3.4.2.2. Recommended Social and Environmental Repercussion Index (SERI) and maximum overall probabilities of failure during the useful life, corresponding to modes of failure assigned to Ultimate Limit States ($p_{f,ULS}$) and to Serviceability Limit States ($p_{f.SLS}$) for berthing and mooring structures, depending on use

USE	GOODS TYPE		ERI INDEX 2)		$P_{f,ULS}$ 2) 3)	$P_{f,SLS}$ 2) 3)
COMMER-CIAL	Graneles líquidos	Dangerous goods 1)	s_3	High	0.01	0.15
		No dangerous goods	s_2	Low	0.10	0.30
	Graneles sólidos	Dangerous goods 1)	s_3	High	0.01	0.15
		No dangerous goods		Low	0.10	0.30
	General goods		s_2	Low	0.10	0.30
	Passengers		s_2	Low	0.10	0.30
FISHING			s_2	Low	0.10	0.30
NAUTICAL-SPORTS			s_2	Low	0.10	0.30
INDUSTRIAL		Dangerous goods 1)	s_3	High	0.01	0.15
		No dangerous goods	s_2	Low	0.10	0.30
MILITARY			s_3	High	0.01	0.15

(1) Dangerous foods wil be considered the following ones: Groups of prority substances included in Annex X of Water Framework Directive (Decision 2455/2001/CEE), in the european pollutant emssion register (EPER: Decision 2000/479/CE) and in the National Regulation od admission, Handling and Storage of Dangerous Goods (Royal Decree 145/1989).
(2) When in or near the berthing structure is foreseen the location og buildings (e.g., maritime stations, fish markets,…) tanks or silos that could be affected in the case of berthing structure's failure, a very high SERI index will be considered (s_4) ($p_{f,\ ULS}$ = 0,0001, $p_{f;\ SLS}$ = 0,07).
(3) In general, the economical optimization studies of the berthing works lead to the convenience of designing much safer works than the minimum thresholds recommended in this table, exting whne the predominant action is waves, wind or earthquake.

Despite the above stated, as indicated in section 3.4.4.1, berthing structure optimization studies usually point to the pragmatism of designing much safer and more functional structures than the minimum thresholds recommended in this table 3.4.2.2, achieving increased levels of reliability and functionality of the Works with very moderate costs, excepting where waves, wind or earthquake are the predominant actions. Therefore, in such cases, when the principal failure modes are assigned low failure probabilities (< 0.05) it is advisable to also verify them using Levels II or III methods, regardless of their ERI and SERI indexes.

In those projects where, multiple verification of the principal failure or stoppage modes should be performed with Level I and other upper rank methods, the calculation will be considered accomplished when both of the verification equation solution procedures employed show that the required reliability, functionality or operational capacity is attained. For this reason, as a Level I method is generally more easily applied, it is recommended that Level I calculation should always be performed, as a reference, allowing the upper rank methods to value the uncertainty associated with Level I methods for each specific case and, resulting in, a much more accurate determination of the probability of failure or stoppage associated with them; which basically corresponds to a more advanced alternative procedure than the performance of a classic parametric sensitivity analysis..

Any of these solution methods may be applied to any verification equation of a failure or stoppage mode. As outlined above, the only differences consist in the way of arranging the Design factors in the verification equation and the acceptance criterion of the achieved result.

3.4. GENERAL PROJECT CRITERIA

The general Project criteria to be defined are the following:

3.4.1 Subsets

As far as the design is concerned, a berthing and mooring structure is subdivided into homogeneous subsets, whenever there are significant differences in some of the design factors (structural and terrain geometry, soil characteristics, environment and materials and values of the agents and forces on the site), as well as the repercussions in case of failure or operational stoppage, regardless of the adoption of different structural typologies.

For those cases where a phased execution is planned, each phase will be treated as a different sub- set if the gap between the commissioning of each phase and the next one is longer than 5 years.

3.4.2 General and Operational Character of each Subset

For each subset into which the berthing structure is subdivided, its general and operational character should be defined.

3.4.3 General Character of the Subset

The general character is an indicator of the importance of that subset, as measured by the economic, social and environmental repercussions generated in case of destruction or irreversible loss of functionality. Therefore, it is indicative of the magnitude of the consequences attendant to the failure of the berthing structure after being put into service.

The general character will be specified by the Developer of the berthing structure, and should not be less demanding than that derived from the economic repercussion index (ERI) and the social and environmental index (SERI) as defined in the ROM 0.0. Also included in that Recommendation are appropriate procedures to determine the principal failure mode, assigned, in general, to ultimate limit states.

From the application of these procedures, the typically recommended economic repercussion indices (ERI) and social and environmental indices (SERI) for berthing and mooring structures, are included in tables 3.4.2.1 and 3.4.2.2 respectively.

Basically, regardless of the initial investment, the criterion used to define the ERI index for berthing and mooring structures has been the use of the berthing work, considering that the commercial and industrial uses with respect to fishing and nautical-sports uses have a higher strategic importance to the economic and productive system and, at the same time, a bigger economic domain of the productive system they serve.

The main criterion used to determine the SERI index for berthing and mooring structures is the type of danger of the goods handled at the berthing installation, regardless of the impact to the location of a building on it (fishing market, maritime station, ...), a store, a silo or other installation in or close to the berthing and mooring structure.

3.4.2.2 Operational Character of the Subset

The operational character is an indicator of the economic, social and environmental repercussions created when the subset of the berthing structure in service is no longer operational or its operational capacity level is reduced. Therefore, it is an indicator of the magnitude of those consequences caused by the operational stoppage of the berthing structure.

The operational character will be specified by the Developer of the berthing structure, and should not be less demanding than that derived from the economic repercussion index (ERI) and the social and environmental index (SERI) as defined in the ROM 0.0. Also included in that Recommendation are the appropriate procedures to determine the principal operational stoppage mode.

From the application of these procedures, the typically recommended economic repercussion indices (ERI) and social and environmental indices (SERI) for berthing and mooring structures are included in tables 3.4.2.3 and 3.4.2.4, respectively. Despite the impact of demand intensity, the general criterion basically used to obtain the SERI index is to consider the following demand adaptability to the operational stoppage condition:

- Commercial use
  - For bulk solids and liquids: high adaptability, due to the storage requirements of this type of traffic.
  - For general merchandise with regular traffic and passengers: low adaptability.
  - For general merchandise with occasional (tramp)traffic: medium adaptability.

- Fishing and sporting use
  - Low adaptability, due to the requirement to guarantee the staying of ships and vessels at berth under any climate situation.

- Industrial use
  - High adaptability.

- Military use
  - Low adaptability.

As may be observed, in the majority of berthing and mooring structures, the SERI index will not be significant, as operational stoppage modes will very improbably cause relevant social or environmental impacts. Some operational stoppage modes such as the suspension of the staying of ships at berth due to draught limitations or the paralysis of loading and unloading operations due to an inadequate crest level may cause some environmental impact, although generally it may be considered that they do not reach any significant level. Nevertheless, for fishing and nautical-sporting uses, higher social impacts may occur, because in such cases the impossibility of calling the berth may cause accidental loss of human lives because of the inability of vessels to ride out the stormat the berth.

Table 3.4.2.3. Recommended Operational Indexes of Economic Repercussion (OIER) and minimum operational uptime windows during the useful life ($r_{f,OLS}$) for berthing and mooring structures, depending on use

USE	GOODS TYPE		OIER INDEX		$r_{f,OLS} = 1 - p_{f,OLS}$
COMMERCIAL	Bulk liquids		r_{o1}	Low	0.85
	Bulk solids		r_{o1}	Low	0.85
	General goods	Regular traffics	r_{o3} 1) 2)	High	0.99
		Tramp traffics	r_{o2} 1) 2)	Medium	0.95
	Passengers		r_{o3} 1) 2)	High	0.99
FISHING			r_{o3}	High	0.99
NAUTICAL-SPORTS			r_{o3}	High	0.99
INDUSTRIAL			r_{o1}	Low	0.85
MILITARY			r_{o3}	High	0.99

(1) When traffics occur in summer season only, the achieved indexes will be reduced in one level.
(2) For a demand intensity low intensive (degree of berth occupation $\phi < 40\%$. See section 3.2.1.4) the achieved indexes will be reduced in one level.

Table 3.4.2.4. Recommended Operational Indexes of Social and Environmental Repercussions (OIER) and maximum annual average number of operational stoppages (N_m) for berthing and mooring structures, depending on use

USE	GOODS TYPE	OISER INDEX		N_m
COMMERCIAL	Bulk liquids	s_{o1}	Not significant	10
	Bulk solids	s_{o1}	Not significant	10
	General goods	s_{o1}	Not significant	10
	Passengers	s_{o1}	Not significant	10
FISHING		s_{o2}	Low	5
NAUTICAL-SPORTS		s_{o2}	Low	5
INDUSTRIAL		s_{o1}	Not significant	10
MILITARY		s_{o1}	Not significant	10

3.4.3 Project Phases and their Time Length. Useful Lfe

From the start of the construction of the berthing and mooring structure up to its change of use or dismantling, this and each one of its subsets pass through a continuous sequence of conditions called states or situations characterizing the activity or conditions in which the work is found. In each state the design factors and the structural and functional response of the work may be assumed to be statistically stationary

These states or situations are grouped in project phases, during which the work or its subsets maintain the same principal activity. For the design of berthing and mooring structures, the following project phases will be considered, as a minimum:

- The Construction phase.
- The Service phase.
- The Repair phase.
- The Dismantling phase.

These Project phases should be subdivided into sub-phases only when these will affect the dimensioning of the work or some of its composing elements.

The length of any phase or sub-phase may be imposed by construction, materials behaviour, maintenance, functionality, serviceability or economic and administrative reasons. In the case of the serviceability phase, the length of that phase is called the useful life (V) and, in general, corresponds to that time period when the structure performs the main function for which it was conceived, including in the same the normal maintenance operations.

Depending on the useful life, berthing and mooring structures are divided into:

- Temporary structures: $V \leq 5$ años
- Definitive structures: $V > 5$ años

The length of each project phase will be fixed by the Developer, taking into account the above factors. For definitive structures, it is recommended that the useful life be longer than the minimum values included in the ROM 0.0 depending on the economic repercussion index (ERI) of the work or considered subset of the same.

In table 3.4.2.1 the values normally applicable to berthing and mooring structures are included, obtained as a function of these criteria. As may be observed from that table, in general the minimum useful life for commercial use berthing and mooring structures is 50 years, except for general goods (conventional cargo, containers, Ro-Ro, ...) and cruises, reduced to about 25 years if the initial investment is not very significant. For Fishing and Nautical-Sporting berthing and mooring structures the useful life is generally not less than 15 years.

The execution of a berthing structure will be considered to be done in stages (phases) when the gap between the commissioning of the first stage and that of the last one is longer than 5 years. In these cases, the useful life will be determined for each one of the stages or phases of the work.

At the same time, for those cases where the execution of a stage or subsequent phase could significantly affect the value of some project factors of the last stage, two sub-phases should be considered, whose first one has a useful life limited by the start of the subsequent phase. The project should encompass those adaptations deemed necessary to be performed in case the predicted next stage or phase is eventually not executed.

3.4.4 Safety, Serviceability and Operational Criteria

In every project phase and sub-phase, the work as a whole, or where appropriate, each one of its subsets, as well as the constituent elements should meet the requirements demanded by the regulations and by the Developer regarding safety, service and operation in all states that, in the various solicitation cycles (working conditions), may arise in the phase considered, in order to delimit the occurrence probabilities of a failure or operational stoppage of the berthing structure within acceptable limits, defined according to the consequences of a failure or operational stoppage.

The requirements of safety, service and operation demanded for a specific work or subset of the work will be defined by means of the following parameters (See ROM 0.0):

- **a.** Reliability: The complementary value of the joint failure probability in the considered project phase or sub-phase against the failure modes assigned to ultimate limit states.
- **b.** Service ability or functionality: The complementary value of the joint failure l probability in the considered project phase or sub-phase against the failure modes assigned to serviceability limit states.
- **c.** Operational capacity: The complementary value of the probability of operational stoppage in the project phase or sub-phase considered against the stoppage modes assigned to operational stoppage limit states.

As a measure of the above concepts, the reliability index (β) is also used, having with regard to the corresponding failure probability (p_f) or operational stoppage ($p_{stoppage}$) the following a biunivocal relation: $\beta = -\phi^{-1}(p)$, where ϕ is the normalized accumulated standard probability function.

3.4.4.1 Reliability against Failure Modes Assigned to Ultimate Limit States

The minimum safety demanded of a berthing structure (or to a subset of the same) against the full set of failure modes assigned to ultimate limit states that may occur in each project phase is a function of the consequences resulting from the failure or destruction of the same.

For the serviceability phase, these consequences may be globally evaluated by means of the general character of the work, the value of which cannot be less demanding than that achieved through the corresponding economic repercussion (ERI) and social and environmental repercussion (SERI). indexes (See section 3.4.2.1). Accordingly, safety levels should be greater when the social and environmental consequences of failure are more serious.

It is recommended that the maximum failure probability accepted for a berthing structure against the full set of failure modes assigned to ultimate limit states be lower than the maximum values included in the ROM 0.0, depending on the social and environmental repercussion index (SERI). The appropriate values for berthing and mooring structures, achieved as a function of these criteria. are included in table 3.4.2.2 of this Recommendation.

According to the above-mentioned table, during the useful life of berthing and mooring structures, those joint failure probabilities associated with low social and environmental repercussion indexes ($\max p_f = 0.10$) may be considered typical, except when dangerous goods are handled therein, when it is recommended to consider failure probabilities associated with high social and environmental repercussion indexes ($\max p_f = 0.01$).

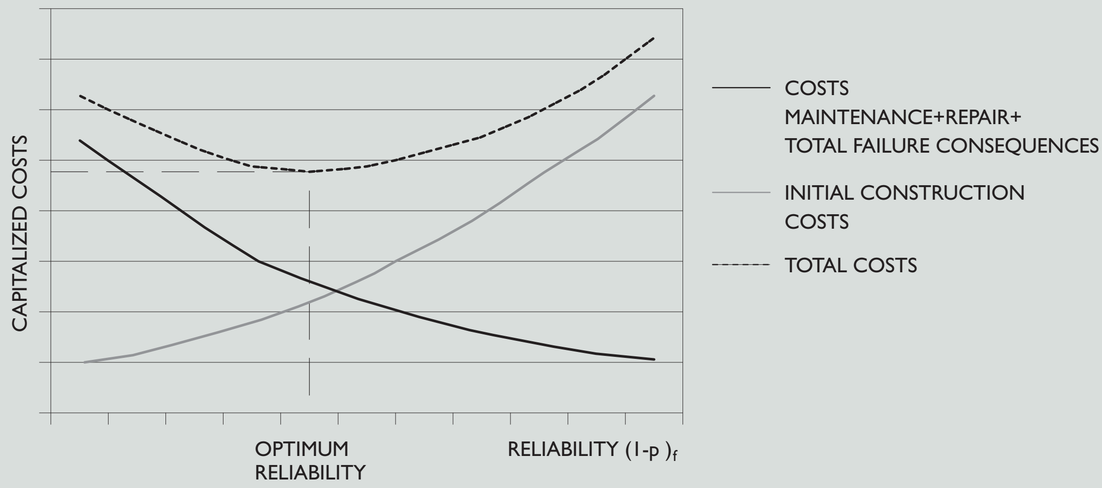
Excepting the latter cases, the decision on the reliability to be assigned to a berthing structure for design purposes should be the object of economic optimization calculations. One of these economic optimization methods is to match the optimum reliability to be adopted with the minimum value of the generalized cost function (expected total costs) of the structure in the analysed phase (See figure 3.4.4.1), achieved considering the optimum distribution of the joint failure probability between the principal failure modes; although in any case this should be lower than the minimum assigned to that structure in figure 3.4.2.2 of this Recommendation. In general, for berthing and mooring structures with a low SERI index it will be acceptable, simplifying, to consider in the generalized cost function only those terms corresponding to initial construction costs plus those for conservation, minor repairs, major repairs and reconstruction; that is, without assigning the costs associated with economic and human losses or the environmental consequences of the total collapse of the structure, because for these structures with low SERI indexes it may be assumed that its influence on the generalized cost function is very minimal.

Berthing structure economic optimization studies generally point to the pragmatism designing much safer structures than the minimum recommended thresholds, achieving structural reliability increases with very moderate economic costs, excepting those cases where the predominant forces triggering some failure mode are:

- waves (berthing and mooring structures located in non-sheltered areas or with significant turbulence).
- wind (very flexible berthing and mooring structures).
- earthquake (berthing and mooring structures located in areas with high or medium seismicity).

Once the optimum joint failure probability is determined, the assignment of the occurrence probability corresponding to each failure mode will be performed from top to bottom in the failures diagram, taking into account the safety requirements established by the upper rank regulations for some failure modes (e. g. EHE, Eurocodes, ...), as well as the cost impact of the failure probability assigned to each mode. In this sense, as a general rule the higher probabilities will be assigned to those principal failure modes whose reliability increases contribute most significantly to structural costs, assigning very small failure probabilities (unconditional non-failure

Figure 3.4.4.1. Optimum reliability of a berthing and mooring structure associated with the minimum value of the generalized costs function



$$\textit{Optimum reliability}: \min C\left(p_f\right) =$$

$$\min\left\{ C_I\left(p_f\right) + \sum_{t=1}^{V}\left[C_{main}\left(p_f\right)\cdot P_{main}\left(p_f\right) + C_{repair}\left(p_f\right)\cdot P_{\text{repair}}\left(p_f,t\right) + C_{Failure}\left(p_f\right) P_{Failure}\left(p_f,t\right)\right]\cdot \frac{1}{(1+r)^t}\right\}$$

Where:

$C\ (p_f)$: Capitalized costs function at starting moment, as a function of the adopted probability of failure to the work.
$C_1\ (p_f)$: Initial investment, as a function of the adopted probability of failure to the work.
$C_{main}\ (p_f)$) : Maintenance and minor repair costs, as a function of the adopted probability of failure to the work.
$C_{repair}\ (p_f)$: Major repairs costs, as a function of the adopted probability of failure to the work.
$C_{Failure}\ (p_f)$: Costs of failure consequences of the work, as a function of the adopted probability of failure to the work.
$P_{main}\ (p_f, t)$: Probability of a possible maintenance or minor repairs in the year t, as a function of the adopted probability of failure to the work.
$P_{repair}\ (p_f, t)$: Probability of possible major repairs in the year t, as a function of the adopted probability of failure to the work.
$P_{Failure}\ (p_f, t)$: Probability of work's failure in the year t, as a function of the adopted probability of failure to the work.
V : Useful life.
r : Annual interest rate.

probabilities where, $p_f < 10^{-4}$) to the non-principal failure modes. The joint probability distribution is not associated with one unique solution. Previous experience and the degree of incertitude of calculation models used to verify each failure mode should be taken into consideration accordingly. Nevertheless, the joint probability distribution among the principal failure modes will be fundamentally performed bearing in mind Project investment economic optimization criteria and its socio-environmental consequences during its useful life, to avoid over-dimensioning [34]. In general, for this purpose, for berthing and mooring structures with a low SERI index it may be sufficient to analyse the total annual cost of the work for different distribution situations, one of which should be the assignment of all the joint failure probabilities to a single failure mode.

The Failure diagrams for each berthing structure typology. corresponding to the different structural typologies of berthing and mooring structures are included in the subsequent series 2 Recommendations, as well as the appropriate recommendations to assign occurrence probabilities to each of the failure modes.

(34) The recommended methods for project investment economic optimization and its socio-environmental consequences are more widely developed in section 2.5.4.2. of the ROM 1.0-09.

In berthing structures where dangerous goods are handled, necessary precautions should be taken to avoid any possible damage. The failure probability included in table 3.4.2.2 (10^{-2}) is only a formal maximum reference, and it is recommended for these cases to adopt the probabilities which are typically used in civil engineering for each and every one of the failure modes, which have served as the basis for the consistent development of rigorous project guidelines.

The construction, repair and dismantling phases, the joint failure probability is delimited as a function of the corresponding SERI index during those phases, performing the joint probability distribution for these phases with criteria identical to those established for the serviceability phase. In general, for berthing and mooring structures construction phases it may be assumed that the social and environmental repercussions in case of failure are not significant, so that the adopted reliability need only meet economic optimization criteria. In any case, the failure probability for these phases should not be greater than 0.20.

3.4.4.2 Functionality against Failure Modes Assigned to Serviceability Limit States

The minimum functionality required of a berthing structure (or to each one of its subsets) against the full set of failure modes assigned to serviceability limit states present at each Project phase, is a function of the consequences attendant to the serviceability failure.

For the serviceability phase, these consequences may be globally evaluated by means of the general character of the work, established in a way similar to that of reliability, given that some of the failure modes assigned to serviceability limit states may equally lead to the practical collapse of the structure. Similar to that outlined for reliability, the functionality should be greater when the social and environmental consequences of functional failure are more significant. The recommended maximum acceptable failure probability for a berthing structure against the full set of all the possible failure modes assigned to serviceability limit states should be less than the maximum values included in table 3.4.2.2 depending on the social and environmental repercussion index (SERI) of the same.

Similar to that previously outlined regarding reliability, the decision on the functionality to be assigned to the berthing structure should be the object of economic optimization processes, considering the possibility and the cost of repair in case of a functional failure, but should not be less than that specified in table 3.4.2.2 (failure probability ≤ 0.15 for berthing and mooring structures handling dangerous goods and ≤ 0.30 for the rest). In general, berthing and mooring structure economic optimization studies point to the pragmatism of designing structures with much more functionality than the recommended minimum thresholds, excepting very easily repaired structures.

Once the joint probability of functional failure is determined, the assignment of occurrence probabilities to each functional failure mode will be performed in the corresponding failure tree with similar criteria to those outlined for the failure modes assigned to ultimate limit states. As a general rule, higher probabilities will be assigned to those principal functional failure modes whose functionality increases most significantly contribute to the costs of the structure.

Functional failure diagrams for each typology of berthing structure, corresponding to the different structural typologies of berthing and mooring structures are included in the subsequent series 2 Recommendations, as well as the appropriate recommendations to assign occurrence probabilities to each of the functional failure modes.

For construction, repair and dismantling phases, the joint probability of functional failure is delimited as a function of the corresponding SERI index during those phases, performing the joint probability distribution in these phases with criteria identical to those established for the serviceability phase. In general, for the construction phases of berthing and mooring structures it may be assumed that the social and environmental repercussions in case of functional failure are not significant, so that the adopted reliability need only meet economic optimization criteria. In any case, the probability of functional failure for these phases should not be greater than 0.20.

3.4.4.3 Operational Capacity against Failure Modes Assigned to Operational Limit States

The minimum operational capacity required of a berthing structure (or to each one of its subsets) against the full set of stoppage modes assigned to operational stoppage limit states at each project phase, is a function of the consequences attendant to operational stoppage.

For the serviceability phase, these consequences may be globally evaluated by means of the operational character of the work, whose value cannot be less requiring than that achieved through the operational index of economic repercussion (OIER) and operational index of social and environmental repercussion (OISER) corresponding to it (See section 3.3.2.2). Accordingly, the operational capacity should be greater when the economic consequences of operational stoppage are more significant.

The recommended minimum admissible operational capacity for a berthing and mooring structure against the full set of possible operational stoppage modes should be greater than the minimum values included in the ROM 0.0 as a function of the operational index of economic repercussion (OIER). The appropriate values for berthing and mooring structures, achieved as a function of these criteria are included in Table 3.4.2.3.

According to the above-mentioned table, the most important factor conditioning the categorization of the berthing and mooring structures to operational effects is the regularity of traffic. Accordingly, commercial uses fundamentally associated with regular traffic (containers, passengers, etc.) with a high degree of berth occupation, as well as fishing, nautical-sporting and military uses have a higher operational economic repercussion index. Conversely, in general, those uses associated with non-regular (Tramp)traffic, have the lowest indexes. Respecting the corresponding lower limits according to this table, the most convenient operational capacity for each case should be deduced from economic optimization studies.

Similar to that previously outlined for reliability and functionality, once the joint operational capacity is determined, the assignment of occurrence probabilities to each operational stoppage mode will be performed in the corresponding operational failure tree with equivalent criteria. That is, greater stoppage occurrence probabilities (minimum operational capacity) will be assigned to those operational stoppage modes whose operational capacity increases most significantly contribute to the costs of the work, to the access channels and manoeuvring areas necessary for the same or to the operational costs and productivity of the berthing installation (principal stoppage modes). The non-principal stoppage modes will be assigned very low stoppage probabilities ($\leq 10^{-3}$).

Considering the synchronicity produced between suspension or paralysis causes assigned to the different groups of operational stoppages, generally the stoppage modes (causes of suspension or paralysis of the operations) to which the highest stoppage probabilities should be assigned, are some of the operational modes corresponding to the paralysis of loading and unloading operations, because it is not desirable for a ship to suspend its staying at berth without first having a cause of stoppage of the loading and unloading operations. Also, a ship should be able to stay at berth whenever it may enter and berth in it. In particular, among those stoppage causes related to loading and unloading operations or passenger boarding and disembarking it is convenient to assign the highest stoppage probabilities to paralysis due to incompatible motions of the berthed ship with respect to loading and unloading operations or passenger boarding and disembarking and to paralysis due to safety reasons pertaining to the handling equipment or passenger boarding and disembarking, as well as to the operation of same, associated with stubborn functional or environmental issues, depending in the last case on the local climate conditions at the site, particularly on the occurrence probabilities of operational capacity limits for the equipment associated with the wind speed.

Despite the above mentioned, in some cases, economic optimization criteria may recommend the separation of the suspension of staying of the ship at berth from the suspension of maritime accessibility. In such cases, it may be convenient to assign stoppage probabilities of the same order of magnitude as the joint stoppage probability to some of the stoppage modes of the group corresponding to the suspension of maritime accessibility.

The criteria used to define the operational stoppage diagrams, as well as the appropriate recommendations to assign occurrence probabilities to each of the stoppage modes are included in sections 4.1and 3.2 of this Recommendation. Plan and elevation layout, in section 4.6.4.2. Definition of the operational capacity limit conditions for the handling of goods and passenger boarding and disembarking, in section 4.6.4.4.3. Definition of the operational capacity limit conditions for the performance of berthing operations, in section 4.6.4.4.7. Definition of the operational capacity limits for the ship at berth, as well as those for the definition of operational capacity limits for maritime accessibility, together with the criteria used to assign occurrence probabilities to each of the stoppage modes are included in the ROM 3.1.

Complementarily, other operational capacity indicators are the annual average number of operational stoppages and the maximum duration of each one. Since operational failures of berthing and mooring structures have little or no significant social and environmental repercussions , the maximum admissible average annual number of operational stoppages will range between 5 and 10. The applicable values according to the use of the berthing and mooring structure, are included in Table 3.4.2.4, with lesser values for fishing and nautical-sporting use berths because, in such cases, operational stoppage due to limitation of accessibility to berth may cause the loss of human lives, because the type of vessels using these installations are not able to ride out storms. Additionally, the maximum prospective durations of operational stoppage recommended not to be exceeded are included in Table 3.4.4. 1.

For the repair phase, the Developer will decide if the operational capacity conditions of the berthing structure in that phase should be totally or partially restricted, therefore, in general, the minimum values of operational capacity required for the serviceability phase will not be applicable in these cases.

In the construction and dismantling stages operational capacity scenarios are not usually considered.

Table 3.4.4.1. Maximum probable time lengths of operational stoppage (τ_{max}) for the berthing and mooring structures, not recommended to be exceeded

OIER INDEX	OISER INDEX	
	Not significant	Low
Low	24 hours	12 hours
Medium	12 hours	6 hours
High	6 hours	3 hours

RECOMMENDATIONS FOR MARITIME WORKS SERIES 2

Inner harbor structures

ROM 2.0-11

[Volume I]

Recommendations for the design and construction of Berthing and Mooring Structures

May 2019

INDEX

(VOLUME I)

Puertos del Estado

GOBIERNO DE ESPAÑA

MINISTERIO DE FOMENTO