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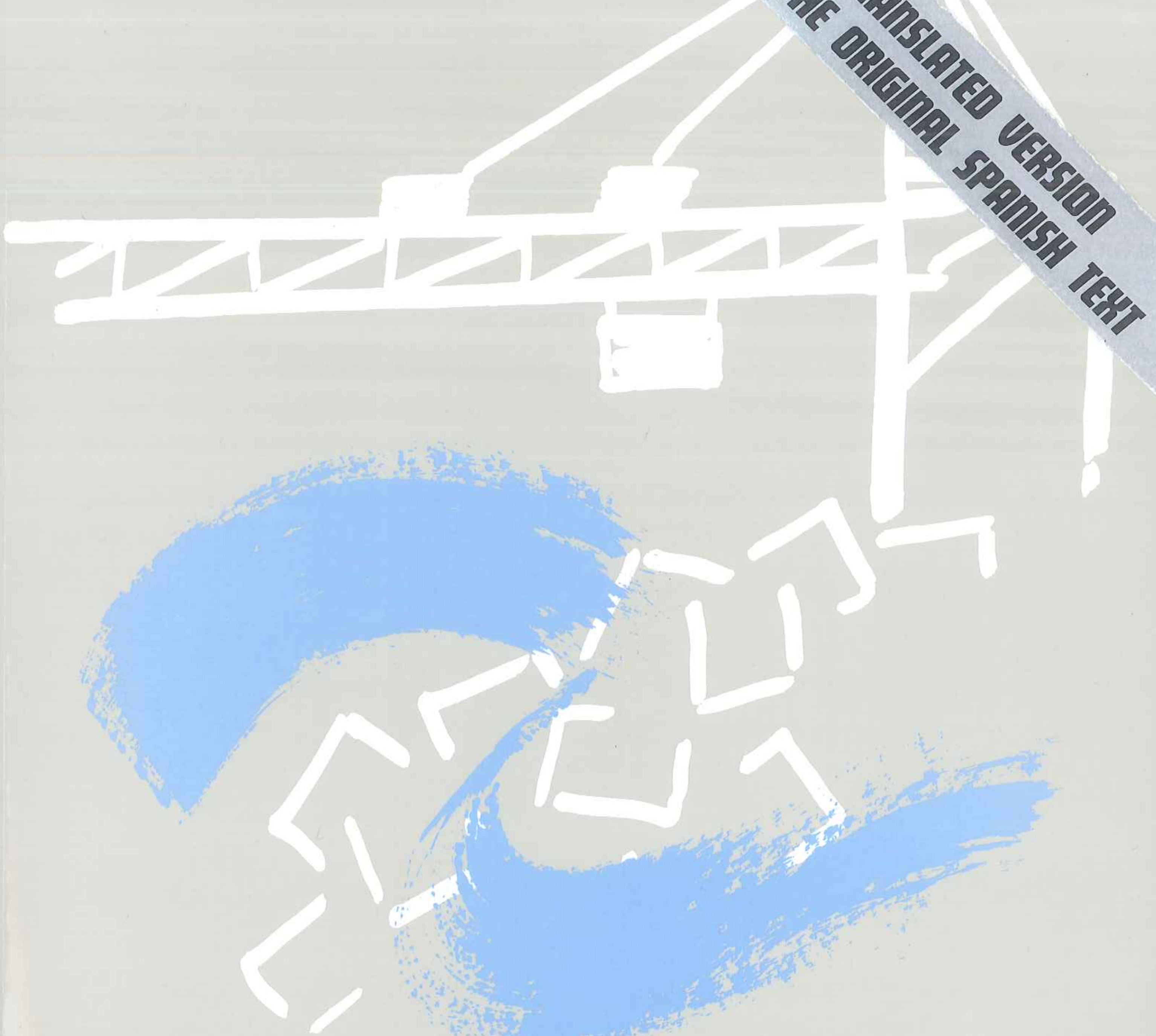

ROM 4.1-94

GUIDELINES FOR THE DESIGN AND CONSTRUCTION OF PORT PAVEMENTS

Puertos del Estado

OBRAS MARITIMAS

TECNOLOGIA

ISBN 84-88975-05-8
9 788488 975058

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GUIDELINES FOR THE DESIGN AND CONSTRUCTION OF PORT PAVEMENTS

GENERAL CONTENTS

INTRODUCTION

These *Guidelines for the design and construction of port pavements* (ROM 4.1) are part of the *Recommendations for Maritime Works* (ROM) Programme undertaken by Puertos del Estado (State Ports Board). This programme, initiated in 1987 with the creation of the first Technical Commission, is intended to constitute the basis for a future set of Spanish Regulations in this field of engineering. The terms of reference for that Commission included drafting a series of guidelines offering the most advanced technology in the field of nautical and port engineering which would serve as a technical tool for designers, supervisors and builders, and provide the various State and private institutions and with competence or interest in maritime engineering with ready access to the specialised information they need to perform their duties.

The first Programme guideline, ROM 0.2-90, titled "Actions for the Design of Maritime and Harbour Works" was published in 1990, and the following have been issued to date:

ROM 2.0-90: Actions for the Design of Maritime and Harbour Works

ROM 0.3-91: Environment Loads I: Waves. Annex I: Wave Climate in the Spanish Coast

ROM 0.5-94: Geotechnical Recommendations for Maritime Works.

ROM 4.1-94: Guidelines for the Design and Construction of Port Pavements.

These GUIDELINES FOR THE DESIGN AND CONSTRUCTION OF PORT PAVEMENTS (ROM 4.1-1994) have been drawn up by the Technical Commission created for this purpose by the President of the Puertos del Estado, under the aegis of the Technical Bureau.

The members of the Commission and their positions are as follows:

— CHAIRMAN:	Juan Muñoz Mitchell	(Puertos del Estado)
— PROGRAMME DIRECTOR:	Francisco Esteban Rodríguez-Sedano	(Puertos del Estado)
— SECRETARIAT:	José Llorca	(Puertos del Estado)
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— MEMBERS:	Alberto Bardesi	(Composan Distribución)
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— REPORT:	Carlos Kraemer	(ETSICCP U. Politécnica de Madrid)
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ROM 4.1 has been drafted taking the following standards, drawn up under the same programme, as a reference: *Actions for the Design of Maritime and Harbour Works* (ROM 0.2), published in 1990, and *Geotechnical Recommendations for Maritime Works* (ROM 0.5), drafted in conjunction with the present document. Other bases for ROM 4.1 are listed below:

- Available experience in Spain on port pavements, assessed by surveying the twenty seven State Port Authorities.
- Recommendations issued by various bodies and institutions, in particular UNCTAD and PIANC.
- The *British Ports Association,* (currently *British Ports Federation*) handbook titled *The structural design of heavy duty pavements for ports and other industries* (1988).

— Spanish standards for highway pavements contained in the *General technical specifications for highway and bridge construction,* the ministerial orders and circulars amending it and *Instruction 6.1 and 2 IC (1989) on pavement structures.*

The aim of the present Guidelines is to cover, in its specific scope, the same purpose as set out for the ROM Programme in general, i.e., to provide designers, builders and port authorities with a tool to help them enhance the quality of their practice in the specific field of port pavements, optimising solutions adopted in each case and establishing uniform design criteria on which such solutions should be based. Standardisation of structural pavement design is meant to cover objectives similar to those established previously for highways, the implementation of which has had considerable benefits:

— there is a limited number of different kind of pavement structures that are designed and built. This facilitates supervision of design, construction quality control, assessment of performance and, in short, maintenance management.
— solutions are selected under a relatively simple process, thus eliminating the complex calculations entailed in some design methods, so the designer can focus on the choice of the most appropriate solution in each specific case on the basis of availability of materials and essentially of cost.

No detailed analysis is included on conditions for the design and construction of reinforced concrete floor slabs, which may be required in special cases for parking and stacking areas depending on the cargo support systems or auxiliary transport facilities (i.e., containers).

In any case, the present document is intended to be a first step towards these objectives, given the paucity of national and international references, and should be considered as such. Moreover, little attention has been paid to this subject in the past, despite the impact of pavements on the various aspects of port operations. From this time on, a process of methodological monitoring will be undertaken in port pavements designed in accordance with these Guidelines, with a view to the ultimate purpose of adjusting such process in later editions according to actual pavement performance.

Consequently, implementation of these Guidelines should lead, in the mid-term, to their improvement. It must be borne in mind in this regard that the purely theoretical approach to the problem is highly complex, on account of the nature and importance of the loads applied to port pavements, the poor quality, in general, of fill materials and the sea bed on which they lie, and the complexity of port operations themselves.

The Guidelines included in this document should be understood to be a "Good Practice" Guide, and entail no exemption from any official Standards or Codes that may be in force.

The Technical Commission will analyze all comments, suggestions and initiatives that may be made with respect to the contents of ROM 4.1 GUIDELINES FOR THE DESIGN AND CONSTRUCTION OF PORT PAVEMENTS, which will be taken into consideration for future versions. Such comments should be addressed to:

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APRIL 1994

PART 1 GENERAL

PART 1 GENERAL

Contents

PART 1 GENERAL

All general questions relating to the proper application and understanding of the Guidelines are discussed.

1.1. SCOPE

ROM 4.1, like the other Recommendations in the ROM series, is generally applicable to the design and construction of all port pavements irrespective of type or purpose. The term port pavements is understood to comprise all surfacing intended to withstand unrestricted roadway traffic within port authority limits, including areas under the aegis of private franchises or specific industrial facilities.

The intent of these Guidelines has been to cover all of the possible different surfacing needs in ports. Some are discussed more fully than others, however, as the emphasis is placed on the various areas of commercial use. The solutions proposed are in keeping with what may be considered to be usual practice in Spain, although in certain cases some rather novel proposals have also been included. Furthermore, in certain special circumstances the designer may take into consideration other different solutions that may be better suited to those circumstances (in view of the nature of the loads, availability of building materials not directly mentioned, etc.).

In principle, the Guidelines discussed in ROM 4.1 preferably address pavements built on a *permanent* basis, i.e., with a design life of 15 years or more. However, *provisional* pavements, with design lives of up to 8 years, are not excluded; such pavements have traditionally been used in ports, where fills are often untreated and settlements occur gradually and virtually without affecting the activities carried out in these areas.

1.2. CONTENTS

These Guidelines contain the information and criteria needed to design and build pavements under what might be considered standard port conditions. Nonetheless, much of what is contained in this paper can be applied directly or by extrapolation to any port, and adjusted to specific local conditions. ROM 4.1 is divided into the following seven parts, plus a catalogue of standard pavement structures:

Part 1: *General.* Discusses all general questions relating to the proper application and understanding of the Guidelines.

Part 2: *Use of land areas in ports.* The various areas that can be distinguished in a port, irrespective of the use to which they are put, are classified from the standpoint of paving; this includes not only those areas directly related to the transfer from sea-borne to land-borne transportation, but to those intended for highway vehicle traffic and parking as well.

Part 3: *Characterisation of loads applied to port surfacing.* The loads carried by each one of the various areas defined in Part 2 are classified. Firstly, they are classified by their effect on the pavement, establishing in every case a design load. Secondly, they are classified by the use rate to which they are subject during the life of each surface, on the basis of management forecasts. The purpose is to establish traffic category as a design parameter; this category is found in each case as a combination of the design load classification, and the use rate for the surface in question.

Part 4: *Fills and subgrades.* Fundamental criteria for characterising pavement foundation are discussed, with particular reference to the capping layer, the upper surface of which is called the subgrade on which the pavement rests, the fill and the natural ground. Finally, subgrade categories are established as a pavement design parameter.

Part 5: *Pavement materials.* The materials most commonly used for the various courses of port pavements are presented, together with a brief description of the fundamental characteristics, advantages and drawbacks for each situation.

Part 6: *Structural design of port pavements.* The procedure to be followed to establish the most appropriate structural design in each case with the aid of the catalogue attached to these Guidelines is discussed. Annex A contains a description of the structural design methods that serve as a basis for the catalogue.

Part 7: *Design and construction specifications.* Guidelines are included for pavement design and construction together with the main specifications that must be met by the materials used in each case. Recommendations are likewise included on the surface characteristics to be held by the different pavements, in particular those required to ensure surface water drainage.

Catalogue of standard pavement structures. A wide range of surfacing solutions, both permanent and provisional, is presented in tabular form for the various port areas in accordance with traffic and subgrade categories.

1.3. DEFINITIONS

The fundamental terms listed below are expressly defined for the purpose of this paper. For other more general terms used only occasionally in ROM 4.1, the reader is referred to the definitions contained in other ROM. For specific terms related to fills or in general to geotechnical questions, see the definitions given in ROM 0.5.

AREA, AUXILIARY: Area in which there is no carriage of cargo, material or supplies. It usually houses office buildings and administrative premises and is landscaped for strolling and recreation.

AREA, NON-CHANNELISED TRAFFIC: Area in which the movements of cargo handling equipment and conventional traffic cannot be pre-determined.

AREA, WORKING: Area intended for the transfer and handling of cargo, material or supplies, but not for the storage of goods for any length of time.

AXLE, TANDEM: Combination of two joint axles on a vehicle that together constitute a single support for the chassis.

BASE: Course in a pavement lying underneath the surfacing.

BULK SOLID: Solid product in the form of loose material that can be continuously and mechanically conveyed. Depending on format these products are classified as ordinary or heavy bulk solids.

BULK SOLID, HEAVY: Bulk solid with high specific gravity, such as minerals.

CARGO, PALLETED GENERAL: General cargo handled by standard size grids or platforms on which cargo is deposited to form a handling and loading unit.

CARGO, GENERAL: Product transported as stacked, wrapped or packaged (in sacks, boxes, barrels, bars, rolls, bales...) material and handled on an individual discontinuous basis (rolls, capital goods...) or pooled as a single unit (in grids, nets...).

CATALOGUE OF PAVEMENT STRUCTURES: Series of entries showing various pavement structure options, grouped by typology, specifying thickness and nature of courses for each one of all the possible combinations of the various design factors.

CEMENT BOUND GRANULAR MATERIAL: Material used in pavement construction composed of a plant mixture of totally or partially crushed aggregates, a small amount of cement, water and sometimes admixtures; it is spread and compacted to make base courses with thicknesses that are 15 to 25 cm thick.

CONCRETE, FIBRE-REINFORCED: Concrete to which wiredrawn steel fibres with hook ends have been added in a homogeneous manner essentially to increase breaking extension and impact strength.

CONCRETE, LEAN: Term used for concrete with a much lower cement content than normal concrete, on the order of one half, for example. In pavements it is used as a base course, with a thickness of at least 15 cm.

CONCRETE, REINFORCED: Concrete that has steel bars or welded mesh to stand tensile stresses and/or to distribute cracks due to hydraulic shrinkage or thermohygrometric action.

CONCRETE, ROLLER COMPACTED: Material used in pavement construction and other civil works composed of a plant mixture of totally or partially crushed aggregates, cement in proportions similar to those used in vibrated cement, water and sometimes admixtures. It is spread and compacted with conventional highway construction equipment, in the case of pavements to constitute a base course or surfacing normally 15 to 35 cm thick.

CONCRETE, VIBRATED: Plant mixture of different sizes of gravel, sand, cement, water and sometimes admixtures, that is spread manually or mechanically in slabs of variable thickness (normally from 15 to 40 cm) and compacted by internal vibrators: after curing and setting it can be used as a pavement. The foremost mechanical characteristic is its bending strength; the denomination of the concrete consists of the initials HP (for paving concrete, in Spanish) followed by the value of the bending strength expressed in kp/cm^2.

CONTAINER: Parallelepiped receptacle of standard dimensions in which cargo is placed and transported from origin to destination.

CRANE: Cargo lifting equipment.

CRANE, PORTAL OR WHARF CRANE: Crane able to move longitudinally on rails parallel to the edge of the wharf; it rests all its legs on the wharf and can turn around completely on a vertical axis.

CRANE, MOBILE: Crane on rubber tyres or caterpillars able to move freely over an entire surface.

DESIGN, PAVEMENT: Process to determine the composition and thickness of each course of a pavement structure.

DESIGN PHASES: Different stages into which design of a structure is usually divided.

DRESSING, SURFACE: Paving technique consisting of the application of a sufficiently fluid bituminous product to a surface followed by the spreading and rolling of uniform size chippings. If such coating is laid only once it is termed single application, and if two are laid, it is termed double application.

FACTOR, SAFETY OR LOAD ENLARGING: Factor by which representative load values are multiplied to find design values.

FACTOR, SAFETY OR MATERIALS PROPERTIES SHORTENING: Coefficient introduced in calculations to decrease the characteristic values of the strength of materials to find design values.

FILLER: In an aggregate, the finest fraction that can be obtained by sieving: in general, the passing fraction in an 80 µm sieve. When a filler other than the one pertaining to a given aggregate is added to an aggregate mix, this is called additional filler.

GRAVEL BED: Area closed off by a concrete kerb, inside which a course about 30 to 40 cm thick of totally crushed single graded aggregates is laid; used exclusively for stacking containers.

LANE, ACCESS: Traffic lane that connects the working or storage areas to off-port areas or serves non-merchandise handling areas. Generally intended for conventional motor vehicle traffic.

LANE, MANOEUVRING: Traffic lane that connects the working areas to storage yards or one storage yard or working area to another, and is mainly intended for merchandise handling equipment traffic.

LANE, TRAFFIC: Area intended exclusively for carrying merchandise, material or supplies from the working areas to the storage yards and from there outside the port area, and *vice-versa*. Areas bearing port facility traffic only are also considered to be traffic lanes.

LIFE, DESIGN: Period of time elapsing between when construction is begun on a structure (or more generally, when it is put into service) until it falls into disuse, is dismantled or given a new use.

LIFT TRUCK, FRONT: Equipment unit able to move freely (unrestricted) with dual wheels on the front axle and single wheels at the rear, sometimes equipped with telescopic jibs used to transport general cargo and containers; sometimes the cargo is raised by means of forklifts.

LIFT TRUCK, SIDE LOADER: Equipment unit able to move freely (unrestricted) and resting on stabilising jacks when loading or unloading; used to move containers.

LIQUID: Product handled in liquid form not being transported in relatively small receptacles.

LOAD: Force that creates stresses, strains or deformations in a structure or structural element, in particular in a course of a pavement or the support on which it rests.

LOAD, CHARACTERISTIC: Value of a load associated with a given probability of surpassing it during the life assigned to each of the phases and design hypotheses.

LOAD, DESIGN: Weighted value of a load found by multiplying the characteristic values of the load by the corresponding safety factors. The effects caused by loads are computed on the basis of their design values.

LOAD, DYNAMIC: Load producing substantial acceleration on the structure or structural elements.

LOAD, IMPACT: Action conveyed to a structure causing a reaction that initially peaks and thereafter declines to a state of rest.

LOAD, INCIDENTAL: Fortuitous or abnormal load that may appear due to accident, misuse, human error or unusual environmental or working conditions.

LOAD, PERMANENT: Load present at all times during the design phase under analysis.

LOAD, STATIC: Load not producing substantial acceleration on the structure or structural elements, in particular in pavement courses. For the purposes of pavement design, and unless otherwise specified, loads are considered to be static.

LOAD, VARIABLE: Load that frequently or continuously changes magnitude and/or position over time.

MACADAM, WET MIX: Aggregate mix comprising several fractions of totally or partially crushed aggregates.

MIX, GRAVEL-ASPHALT EMULSION: Material used in pavement construction composed of a plant mixture of totally or partially crushed aggregates, a small amount of slow-setting bituminous emulsion, water and sometimes filler; it is spread and compacted constituting a base or levelling course 5 to 20 cm thick.

MIX, GRAVEL-SLAG: Material used in pavement construction composed of a plant mixture of totally or partially crushed aggregates, granulated blast-furnace slag, water and a setting agent such as lime; it is spread and compacted constituting a base or levelling course 10 to 30 cm thick.

OPERATIONS INDEX: Index referring to a given magnitude of port operations per year; it provides an indication of port activity and exploitation of a given facility, such as for example the amount of cargo laded or landed per unit of dock length.

PAVEMENT, ASPHALT: Pavement composed of asphalt concrete, a slurry seal or a surface dressing.

PAVEMENT, FLEXIBLE: One that undergoes considerable deflection under loads conveyed by traffic, such as pavements consisting of granular layers or thin asphalt wearing courses.

PAVEMENT, LEACHED: Asphalt pavement composed of an open coated macadam, the voids of which are filled with a slurry made of cement and resins.

PAVEMENT, PERMANENT: One that is designed and built for a design life of at least fifteen years, with a structure such that no substantial deformation is anticipated while in service, as it is laid on a sufficiently consolidated fill.

PAVEMENT, PROVISIONAL: One that is designed and built for a design life of up to eight years, during which time the expected subgrade settlements and deformations should occur.

PAVEMENT, RIGID: One that does not undergo perceptible deflections under loads conveyed by traffic; it usually consists of a concrete (roller compacted or vibrated, plain or reinforced with bars or fibres), pavement laid on other courses or directly on the subgrade.

PAVEMENT, SEMIRIGID: One that undergoes a degree of deflection that is intermediate between deflection in flexible and rigid pavements; this is the case of pavements that have a treated base course.

PAVEMENT STRUCTURE: Structure consisting of one or several courses laid one on top of the other on a subgrade and intended to bear traffic. The most complete model comprises a wearing course, base and subbase.

PAVER (CONCRETE BLOCK PAVING): Precast concrete element that can be laid manually to build pavements.

PORTAINER: Portal crane equipped with a hinged shuttle beam that juts out towards the sea; the cart that moves back and forth on the beam has a container grappling frame hanging from it, making it possible to lade or land containers directly from or to a removal or stacking area. It can move longitudinally on rails in a direction perpendicular to the jig, but cannot turn on a vertical axis.

QUARRY MATERIAL, UNGRADED: Material taken from the excavation face of a quarry and not classified by size; it may be used as a capping layer in port fills, as well as in the backfill of gravity wharves.

ROLL-TRAILER: Platform or open box for transport (if coupled to a tractor) and storage of general cargo or containers, usually 6 or 12 m long; it has rubber tyres on the rear axle, while the front end, when uncoupled, may rest on any one of various kinds of devices: metal wheels, plates or profiles.

SLAB, PRECAST CONCRETE: Factory-made plain or reinforced vibrated concrete slab of relatively small size that can be used to pave some kinds of surfaces.

SLURRY SEAL: Mixture of aggregates with a small maximum size, a slow-setting bituminous emulsion, water and, occasionally, additional filler and admixtures; due to the consistency of this material at room temperature, it can be spread by a rake with a rubber squeegee; it is used as a surface treatment in paving and as an impermeabilisation course.

SOIL-CEMENT: Material used in pavement construction and composed of a plant mix of high quality soil, cement, water and sometimes admixtures; it is spread and compacted to constitute base or subbase courses with thicknesses ranging usually from 15 to 30 cm.

SPRAYING: Manual or automatic application of a sufficiently fluid bituminous product to a surface from a storage tank or other kind of container.

STABILISATION: Process that consists of adding soil or aggregates to another soil or aggregate of a lower quality (mechanical stabilisation). More commonly, some kind of admixture (stabilisation with admixtures) so that the mix (made in place or in plant) once spread and compacted becomes relatively insensitive to water, has a greater bearing capacity and sometimes even becomes a rigid material. There are degrees to this process (simply an *improvement* or actual stabilisation).

STRADDLE CARRIER: Equipment unit able to move freely (unrestricted) equipped with wheels that can turn in all possible directions, or even fully around a vertical axis; used to move general cargo and containers.

SUBBASE: Pavement course lying underneath the base.

SUBGRADE: Support surface for a pavement.

SURFACING: Upper (wearing) course or courses of a pavement.

TEU: *(Transport Equivalent Unit).* Unit equivalent to one 20-foot container.

TRANSTAINER: Equipment unit moving on tracks or tyres (restricted), that handles general cargo and particularly containers.

UNBOUND GRANULAR MATERIAL: Continuously graded mixture of natural gravel and sand found in natural deposits.

USE RATE: Port pavement design parameter established in accordance with the classification of a given operations index; it represents the greater or lesser importance of a surface in relation to port operations, as well as the greater or lesser impact that possible pavement deterioration would have on such operations.

VEHICLE, HEAVY: This term covers lorries with a carrying capacity of over 3 t, more than four wheels and no trailer; lorries with one or several trailers; articulate and special vehicles; and vehicles engaging in passenger transportation with more than 9 seats.

YARD, STORAGE: Area intended for accumulation and mid- or long-term storage of cargo, materials, or supplies.

1.4. UNITS

All of the units used in these Guidelines follow the *International System of Units* (SI), the system of units legally in force in Spain, with the exception of an auxiliary unit for force, known as the tonne-force (t) unit which may also appear, since use of this unit is very common in Spain for measuring loads and forces. Table 1.1 shows the SI units, basic and auxiliary, most often used in civil engineering, as well as some of the most common multiples and submultiples of these units.

The relationship between the tonne-force and the SI auxiliary unit for force is as follows: 1 t = 1 000 kg x 9,8 m/s^2 = 9,8 kN; inversely, 1 kN = 0,102 t. The unit pressure units are related as follows: 1 MPa = 10,2 kp/cm^2; inversely: 1 kp/cm2 = 0,098 MPa, where the kilopond (kp) or kilogram-force is one thousandth of the tonne force.

1.5. NOTATIONS, ABBREVIATIONS AND SYMBOLS

The fundamental conventional notations, abbreviations and symbols and their corresponding units as used in these Guidelines are shown in table 1.2.

TABLE 1.1. INTERNATIONAL SYSTEM MAGNITUDES AND UNITS

MAGNITUDES	UNITS	MULTIPLES AND SUBMULTIPLES
Length	Metre (m)	Kilometre (km) (1 km = 10^3 m) Centimetre (cm) (1 cm = 10^{-2} m) Milimetre (mm) (1 mm = 10^{-3} m)
Mass	Kilogram (kg)	Gramme (g) (1 g = 10^{-3} kg) Tonne (t) (1 t = 10^3 kg)
Time	Second (s)	Hour (h) (1 h = 3600 s)
Temperature	Kelvin degree (°K)	
Force	Newton (N) (1 N = 1 kg.m/s^2)	Kilonewton (kN) (1 kN = 10^3 N)
Pressure	Pascal (Pa) (1 Pa = 1 N/m^2)	Megapascal (MPa) (1 MPa = 10^6 Pa)
Stress	Pascal (Pa) (1 Pa = 1 N/m^2)	Megapascal (MPa) (1 MPa = 10^6 Pa)
Energy	Joule (J) (1 J = 1 N.m)	Kilojoule (kJ) (1 kJ = 10^3 J)
Power	Watt (W) (1 W = 1 J/s)	Kilowatt (kW) (1 kW = 10^3 W)

TABLE 1.2. FUNDAMENTAL CONVENTIONAL NOTATIONS, ABBREVIATIONS AND SYMBOLS USED IN THESE GUIDELINES

I. LATIN LETTERS, UPPER CASE

SYMBOL	DEFINITION	UNIT
A	Designation for very heavy traffic category.	—
B	Designation for heavy traffic category.	—
C	Designation for medium traffic category.	—
D	Designation for light traffic category.	—
E	Elasticity or Young modulus.	MPa
E0	Designation for unsatisfactory subgrade.	—
E1	Designation for satisfactory subgrade.	—
E2	Designation for good subgrade.	—
E3	Designation for very good subgrade.	—
E_1	Compressibility modulus obtained in the first cycle of the plateabearing test.	MPa
E_2	Compressibility modulus obtained in the first cycle of the plateabearing test.	MPa
H_a	Maximum storing or stacking height.	m

TABLE 1.2. (Continued)		
SYMBOL	DEFINITION	UNIT
$I_{1.1}$**	Operations index indicative of use rate in commercial use working areas.	t/m
$I_{1.2}$	Id. in bulk solid storage yards.	t/m^2
$I_{1.3}$	Id. in general cargo storage yards.	t/m^2
$I_{1.4}$	Id. in container stacking bays.	TEU/m^2
$I_{1.5}$	Id. in roll-trailer parking areas.	TEU/m^2
$I_{1.5'}$	Id. in roll-trailer parking areas not used exclusively for this purpose.	t/m^2
$I_{2.1}$	Id. in industrial use working areas.	t/m^2
$I_{2.2}$	Id. in industrial use storage yards.	t/m^2
$I_{3.1}$	Id. in military use working areas.	t/m^2
$I_{3.2}$	Id. in military use storage yards.	t/m^2
$I_{4.1}$	Id. in fishing working areas.	t/m^2
$I_{4.2}$	Id. in areas for classification, preparation and sale of fish.	t/m^2
I_5	Id. in recreational use working or launching areas.	*
IP	Plasticity index.	%
K	Modulus of subgrade reaction.	MPa/m
LL	Liquid limit.	%
Q	Load.	kN
Q_v	Vertical design load.	kN
Q_{v1}	Vertical design per unit area.	kN/m^2

II. LATIN LETTERS, LOWER CASE

SYMBOL	DEFINITION	UNIT
a	Circular load imprint radius .	m
h	Pavement course thickness.	m
k	Proportionality coefficient.	*
l	Concrete slab radius of relative stiffness.	m
p_v	Vertical design pressure.	MPa

TABLE 1.2. (Continued)

III. GREEK LETTERS

SYMBOL	DEFINITION	UNIT
γ	Specific gravity of a material or cargo stacked or stored in the most adverse environmental conditions.	kN/m^3
ν	Poisson coefficient.	*
$\sigma_{máx}$	Maximum tensile stree on a pavement course.	MPa
Ø	Internal friction angle of a bulk solid.	*

IV. ABREVIATIONS

ABREVIATION	MEANING
BC	Good consolidated fill.
BNC	Good unconsolidated fill.
BPA	*British Ports Association.*
BPF	*British Ports Federation.*
CBR	*California Bearing Ratio* (bearing capacity index).
IP	Plasticity index.
LL	Liquid limit.
MC	Poor consolidated fill.
MNC	Poor unconsolidated fill.
RC	Average consolidated fill.
RNC	Average unconsolidated fill.
ROM	Recommendations for Maritime Works.
TEU	*Transport Equivalent Unit.*
UNCTAD	*United Nations Conference for Trade and Development.*

LEGEND:

*: Dimensionless magnitude
**: The meaning of the subscripts corresponding to the Operation Indexes is as follows:
- The first subscript indicates use. Thus, 1 means Commercial Use; 2 Industrial Use; 3 Military Use; 4 Fishing Use and 5 Recreational Use.
- The second subscript indicates area. Thus, 1 means working area; 2, 3 and 4 storage yards; and 5 parking areas.

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PART 2 USE OF LAND AREAS IN PORTS

PART 2 USE OF LAND AREAS IN PORTS

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PART 2 USE OF LAND AREAS IN PORTS

The various areas that can be distinguished in a port, irrespective of the use to which they are put, are classified here from the standpoint of paving; this includes not only those areas directly related to the transfer from sea-borne to land-borne transportation, but to those intended for highway vehicle traffic and parking as well.

2.1. INTRODUCTION

Port pavement design calls for the classification of surfaces based firstly on the use to which they are to be put (commercial, industrial, military, fishing and recreational), and secondly, on the kind of operation involved (working, storage, etc.). Moreover, the auxiliary areas and traffic lanes running between the various areas and between the port and the highway network must be taken into consideration. Table 2.1 contains a summary of land areas in ports classified in accordance with the provisions of ROM 0.2-90.

2.2. COMMERCIAL USE

Commercial use comprises all port activities involved in the interchange between land- and sea-borne transport and merchandise handling and storage where the main purpose is domestic or international trade. In general, a distinction can be made between working and storage areas, as well as between traffic lanes and auxiliary areas. Commercial use is characterised essentially by the kind and nature of merchandise handled:

— Liquids.
— Ordinary bulk solids.
— Heavy bulk solids.
— Conventional general cargo.
— Heavy general cargo.
— Unified general cargo.
  • Containers.
  • Roll-trailers and other roll-on/roll-off cargo.
— Other traffic.

2.2.1. WORKING AREAS

These areas are intended for the transfer and handling of merchandise, material or supplies, but not for the storage of goods for any length of time. This is where the conversion from one kind of transport to the other takes place. Working areas are characterised by the way merchandise is generally handled:

— Haulage.
— Lifting.
— Haulage and lifting.
— Continuous conveyance systems.

For pavement purposes, handling equipment should be considered either to be moving on pre-defined strips (tyres on beam rail and equipment on rails, including railway wagons), or unrestricted (equipment on tyres or caterpillars), the latter case being of particular concern.

Where no prior design or specific client or Port Authority criteria are available, the site chosen for the working area should be a strip parallel to the edge of the dock, extending from this area to 5 m beyond the axis of the roadway of the interior leg of the inland-most rail moun-

TABLE 2.1. USE OF LAND AREAS IN PORTS

USE	AREA	FEATURES
COMMERCIAL Liquids Ordinary bulk solids Heavy bulk solids Conventional general cargo Heavy general cargo Pooled general cargo • Containers • Roll-trailers and roll-on/roll-off Other traffic	WORKING	Haulage
		Lifting
		Continuous conveyance systems
		Storage
	STORAGE YARD	Equipment traffic - moving freely around the yard
		Equipment traffic - moving on pre-defined strips
	TRAFFIC LANES	Manoeuvering lanes
		Acess lanes
	AUXILIARY	Traffic
		Parking lots
INDUSTRIAL	Similar to commercial use for heavy general cargo	
MILITARY	Similar to commercial use for conventional general cargo and roll-on/roll-off cargo	
FISHING	WORKING	Off-shore fishing
		Long-distance fishing
	CLASSIFICATION, PREPARATION AND SALE	Classification and preparation
		Storage areas
		Market areas
	TRAFFIC LANES	Manouvering lanes
		Access lanes
	AUXILIARY	Traffic
		Parking lots
RECREATIONAL	WORKING OR LAUNCHING	Large vessels
		Small vessels
	AUXILIARY	Traffic
		Parking lots

ted yard crane; in any case, this strip should be at least 15 m wide. The existence of this area depends upon the need for a place intended exclusively for temporary stowage during the merchandise transfer process; otherwise, no distinction should be drawn between the working area and storage yard.

2.2.2. STORAGE AREAS

These areas are intended to hold merchandise or supplies for several days and are designed to accommodate large stocks of goods. These are areas not included in the working areas. Storage yards may be sub-divided depending upon the various uses to which the surface is to be put - for storage *per se* or for (freely moving or railed) equipment traffic, although this distinction may often not be made.

Moreover, the different storage yard areas can be classified on the basis of other considerations:

— Roofed or unroofed; roofed areas in turn may be enclosed or unenclosed.
— Height of stacks.
— Merchandise storage time.
— Nature of merchandise (mineral, coils, scrap metal, etc.)
— Type of merchandise (general merchandise, solid bulk, containers, etc.)

On the basis of this latter criterion, the storage areas considered here in greater detail from the surfacing standpoint are as follows:

2.2.2.1. LIQUID STORAGE

These materials are conveyed continuously by means of specific facilities and stored in tanks of different kinds. Problems which may arise with regard to the foundations of these tanks are beyond the scope of the present Guidelines.

Nonetheless, there may be paved areas to accommodate tanker traffic and parking; since these are highway vehicles, the approach should be the same as indicated below for access lanes, with the exception of surface protection against possible spilling of fuel, oil or other substances.

For surfacing purposes, powdery bulk solids handled by continuous conveyance systems and stored in silos should be treated like liquids.

2.2.2.2. BULK SOLID STORAGE

These are areas where both ordinary bulk solids (low and average specific gravity, foremost among which are grain and other food products, given the large volume of such goods shipped by sea) and heavy bulk solids (such as, for example, iron ore, scrap metal, etc.) are stored outside. The pavement load due to stockpiling, usually conical or step-tapered, is relatively low, while handling equipment (loaders and shovels may entail substantial loads and cause surface erosion.

2.2.2.3. GENERAL CARGO STORAGE

A distinction must be drawn between conventional and heavy general merchandise. In the former, stack heights (sacks, barrels, bales, crates, grids etc.) are relatively low, with running lanes between them, so loadings are moderate, although the handling equipment (carriers, for example) may cause heavier loads. Heavy general merchandise includes stone blocks, logs, steel profiles, steel coils etc. The pavement loads may be greater where merchandise is placed on support materials sleepers.

2.2.2.4. CONTAINER STACKING

These are open areas where containers are set directly on the pavement or stacked on other containers. The maximum stack heights are usually from 3 to 5 units (7,5 to 12 m), depending on the available space, the layout and the handling equipment used. Containers may be arranged singly, or in single or multiple rows (blocks); in the first two cases, minimum widths of 10 to 15 m are needed, depending on the kind of container and handling system used. These areas carry highly concentrated and very heavy loads.

2.2.2.5. ROLL-TRAILER PARKING LOTS

For the purpose of pavement design, the areas intended exclusively for highway vehicle parking are not included under this item, but rather only the parking areas for large trailers imposing loads as analyzed in part 3. In these areas, loads from trailers and tractors are computed separately because the trailer (holding a drop-box or one or several containers; or, at times, with the box open, other kinds of elements such as coils) is often uncoupled and parked, so the tractor can be used to bring others to the lot. This kind of carriage may call for no further handling equipment, so the only specific facilities involved would be ramps between the vessel and land or between the dock and the railroad.

Trailers are 2,5 m wide and 20 feet (6 m) or 40 feet (12 m) long. They are angle parked in spaces measuring 3.5 x 15 m^2 with through-lanes measuring 6 or 16,50 m (the latter is needed to turn at a right angle when entering or exiting).

These areas may be treated in two different ways. The first consists of treating the entire surface in a homogeneous way, which places no restriction whatsoever on use. The second consists of treating these areas in the same way as the auxiliary parking lots except in (1 m wide) strips specifically designed to carry the front end of the roll-trailers after they are uncoupled from the tractors.

2.2.3. TRAFFIC LANES

These are intended exclusively for carrying merchandise, material or supplies from the working areas to the storage yards and from there outside the port area, and *vice-versa*. Likewise, they channel port works traffic and connect the port to the road network. A distinction may be drawn between manoeuvering lanes, on the one hand, and access lanes on the other.

Manoeuvering lanes connect the working areas to storage yards or one storage yard or working area to another, and are mainly intended for merchandise handling equipment traffic. The access lanes, in turn, connect the working or storage areas to off-port areas or serve non-merchandise handling areas, and are intended in general and preferably for conventional motor vehicle traffic. For pavement purposes, access lanes should be treated like general highways, whereby Instruction 6.1 and 2 IC on pavement structures may be applied directly to such areas.

2.2.4. AUXILIARY AREAS

There is no merchandise, material or supply carriage in these areas, which are usually developed, with buildings and administrative premises, or landscaped for strolling. Auxiliary areas also include the parking lots for light and heavy vehicles.

Although the surfaces intended for traffic or parking carry loads from highway vehicles only, the special nature of these areas makes it unadvisable to apply Instruction 6.1 and 2 IC on pavement structure to them directly. These Guidelines contain specific solutions, although other routine options used for city streets may be employed.

2.3. OTHER USES

2.3.1. INDUSTRIAL

Industrial use is understood to mean that an area is intended exclusively for an industry or for an industrial zone (shipyards, power plants, steel mills, refineries, petrochemical plants, ...). Unless specific criteria are available, surfaces for industrial use should be treated in a way similar to the areas intended for heavy general cargo.

2.3.2. MILITARY

These are areas directly related to military vessels. Military areas may be subject to particularly aggressive conditions, such as crawl tread vehicle traffic. Unless specific criteria are available, military area surfaces should be treated like conventional general and roll-on/roll-off cargo areas.

2.3.3. FISHING

These areas, directly related to this industry, are used not only for carriage of fish, but likewise for vessels docking and stocking up. Further, they are fish contracting areas, points of departure for distribution networks and sites for secondary or auxiliary industries. Most of these facilities call for no special pavement, but some of them must meet special health and hygiene requirements. The following sub-areas can be defined:

2.3.3.1. WORKING AREAS

This is where fish is handled and sea-borne gives way to land-borne transport. The characteristics differ depending on whether off-shore or long-distance fishing is involved, and the action affecting pavements differ in each case.

2.3.3.2. CLASSIFICATION, PREPARATION AND SELLING AREAS

This is where fish is classified, prepared and sold (markets), stored for export (warehouses) and where fish is loaded on to lorries for land-based distribution.

2.3.3.3. TRAFFIC LANES

As in the case of commercial use, a distinction should be drawn between manoeuvering and access lanes.

2.3.3.4. AUXILIARY AREAS

As in the case of commercial use, the areas intended mainly for traffic should be distinguished from those intended primarily for parking.

2.3.4. RECREATIONAL

Recreational use comprises all in- and outdoor facilities specifically designed for sport or recreation, including the so-called marine sports, nautical-residential complexes, recreational ports, island-ports), etc. The in-port land surfaces may be classified on the basis of:

2.3.4.1. WORKING OR LAUNCHING AREAS

These areas include access lanes to piers and those adjacent to launching ramps, as well as boat workshops and storehouses.

2.3.4.2. AUXILIARY AREAS

These areas include marinas, shopping centres, etc., as well as parking lots and buildings directly involved in port operations.

PART 3 CHARACTERISATION OF LOADS APPLIED TO PORT SURFACING

PART 3 CHARACTERISATION OF LOADS APPLIED TO PORT SURFACING

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PART 3 CHARATERISATION OF LOADS APPLIED TO PORT SURFACING

The loads carried by each one of the various areas defined in Part 2 are classified. Firstly, they are classified by their effect on the pavement, establishing a design load in each case. Secondly, they are classified by the use rate to which they are subject during the life of each surface, on the basis of management forecasts. The purpose is to establish traffic category as a design parameter; this category is found in each case as a combination of the design load classification, and the use rate for the surface in question.

3.1. LOAD ASSESSMENT

A distinction is drawn between the loads applied to the pavement by cargo stacked or stored on a given surface (load from parking or storage) and the loads imposed by equipment used in handling such merchandise (load from handling). Finally, consideration must be given to the loads applied by heavy conventional traffic (highway vehicles). In the present Guidelines loads and stresses are considered more simply than in ROM 0.2-90, although this should not prevent the designer from proceeding in accordance with the latter approach if there is sufficient information to do so.

3.1.1. LOAD FROM PARKING OR STORAGE

These loads tend to vary, depending mainly on the weight of the merchandise stored or stacked directly on the surface or inside auxiliary carriage and handling facilities (containers, roll-trailers, etc.). The effect and distribution of such loads are usually constant over a given period of time.

The value of the effect of such loads is determined on the basis of the use for which the surface is intended, the area of the surface affected and the kind of stress placed on the pavement, taking the following factors into consideration:

- Nature of merchandise stored or stacked, including physical characteristics such as specific weight or friction angle.
- Type of merchandise (general cargo, bulk solids, containers, roll-trailers, etc.).
- Layout and dimensions of stocks and stacks.
- Maximum handling capacity.
- Handling methods and equipment.

Loads are taken to be vertical, distributed or point loads, depending on the kind of material stacked or stored and how it affects the surface; these loads entail no significant accelerations on the pavement. When designing the pavements, loads applied by bulk solids and, with some exceptions, general cargo, are considered to be distributed loads; loads imposed by containers and roll-trailers, on the contrary, as well as those due to manufactured goods set up on sleepers, are considered to be point loads.

3.1.1.1. LOAD FROM BULK SOLID STORAGE

The value used is the maximum weight per unit area of materials temporarily stowed in the working area or stored in the storage yard under anticipated storage or stacking conditions.

For each material:

$$Q_1 = \gamma \cdot H_a \ (kN/m^2)$$

where:

Q_1 Load per unit area

γ Specific gravity of the material stored or stacked in the most adverse environmental conditions in kN/m^3. The values of these specific weights can be found in table 3.4.2.3-1.1 of ROM 0.2-90.

H_a Maximum temporary storage or stacking height of material, given in m.

The maximum height depends essentially on:

— Area and use
— Nature and type of material
— Handling facilities and methods
— Storage place

The natural slope of bulk solids (tg , where is the internal friction angle of the material), which determines the area which will carry the load deriving from maximum height, is given in the table referred above, in ROM 0.2-90.

The most common values of H_a, in turn, are given in table 3.4.2.3.1.2 of ROM 0.2-90.

Unless specific design or operating criteria are available, the following contact pressures will be taken for bulk solid storage:

— In working areas:

Ordinary bulk solids:	0,04 MPa
Heavy bulk solids:	0,07 MPa

— In storage yards or parking lots:

Ordinary bulk solids:	0,08 MPa
Heavy bulk solids:	0,15 MPa

Finally, it should be pointed out that all these fixed overload values for storage or parking are only applicable to the operational phase of the pavement under consideration at any given time.

3.1.1.2. LOAD FROM GENERAL CARGO STORAGE

The value used is the maximum weight per unit area of materials temporarily parked in the working area or stored in the storage yard under estimated stowing conditions. These loads are to be taken into account not only in the corresponding commercial use areas (heavy or conventional general cargo) but also, unless specific design criteria are available, in the industrial (heavy general cargo) and military (conventional general cargo) use areas.

For each material:

$$Q_1 = \gamma \cdot H_a \ (kN/m^2)$$

where:

Q_1 Load per unit area

γ Specific gravity of the material stored or stacked in the most adverse environmental conditions in kN/m^3. These values can be found in table 3.4.2.3-1.1 of ROM 0.2-90.

H_a Maximum temporary storage or stacking height of material, given in m.

The maximum height depends essentially on:

— Area and use
— Nature and type of material
— Handling facilities and methods
— Storage place

The usual values for H_a are given in table 3.4.2.3.1.2 of ROM 0.2-90.

Moreover, point loads may be imposed by manufactured goods (steel, precast concrete, etc.) set on sleepers, with contact pressures of up to 2,5 MPa. Unless specific design or operating criteria are available, the following loads and contact pressures should be used for general cargo:

— In working areas:

  Conventional general cargo: 400 kN and 0,8 MPa
  Heavy general cargo: 900 kN and 1,8 MPa

— In storage yards or parking lots:

  Conventional general cargo: 700 kN and 1,5 MPa
  Heavy general cargo: 1200 kN and 2,0 MPa

Finally it should be pointed out that all these fixed values for storage or parking overloads are only applicable to the operational phase of the pavement under consideration at any given time.

3.1.1.3. LOADING IN CONTAINER STACKING BAYS

Containers convey loads to the pavement through 0,178 x 0,162 m^2 corner castings, which protrude 0,0125 m and are intended to isolate the container from the ground and facilitate handling.

At times, when several containers are stacked one on top of the other and especially when they are supported by a flexible surface, contact is possible with the pavement in places other than the corners, called *off-carrier positions* (this does not occur, however, where refrigerated containers are involved, since their underbeams are more rigid).

The measurement unit for container transport is the TEU *(Transport Equivalent Unit)* or the equivalent to a 20-foot container. The containers most commonly used today are 20 feet (1 TEU) or 40 feet (2 TEU) long. There are also 10-foot (0,5 TEU) and 30-foot (1,5 TEU) containers, and 50-foot (2,5 TEU) containers are beginning to be used. The TEU is also used as a unit of measure for roll-trailer drop-boxes (see item 3.1.1.4).

The total loading applied by containers varies widely. The maximum load for a 20-foot container is about 200 kN, but it may be assumed that the mean load will not be in excess of 130 kN. The maximum load for a 40-foot container, in turn, is about 300 kN, with an assumed mean load not in excess of 200 kN.

Pavement contact pressures depend on the loading, the container storage layout (singly, in single rows or blocks), the heights (from one to five containers high), the flexibility of the pavement itself, and on whether or not there are *off-carrier positions.*

Stacking arrangements (layout and height) depend directly on the logistic and operating criteria of the facility and on the handling equipment used. Where no specific criteria are available, the layouts and maximum heights that should be considered for each kind of handling equipment are given in Table 3.1. In the event of single-row or block stacking, the running lane or distance between two adjacent containers may vary from practically nil (normally the case for empty containers) to 0,40 - 0,80 m to make it possible to read the code numbers they bear on their sides (usually the case for full containers).

The probability for all containers to be stacked as high as allowed is, in principle, relatively small and depends on the specific operating criteria of the facility in question. For this reason, to estimate the applied loads some authors (BPA) apply gross weight reductions depending on the stacking height (up to 40 % for 5-container stacks). Nonetheless, there are operating systems that group containers by the kind of cargo they hold, in which case there may indeed be stacks with five fully loaded containers.

Unless there are specific design data or port authority criteria to follow, the loads to be considered for pavement design in container stacking bays should be those corresponding to 40-foot block, five-container stacks: i.e., 1 524 kN applied to an area of 0,356 x 0,324 m^2 (which entails a pavement pressure of 13,2 MPa), even though maximum heights of three-container stacks are generally found (the load carried by each inner bearing of the block would be, in that case, 914 kN and the pressure would be 7,9 MPa).

TABLE 3.1. LAYOUTS AND MAXIMUM HEIGHTS FOR CONTAINER STACKING		
HANDLING EQUIPMENT	LAYOUT	MAXIMUM HEIGHT N.º OF CONTAINERS
Front loader	Single or double rows	4
Side loader	Single or double rows	4
Straddle carrier	Single rows	3
Mobile crane	Small block	4
Transtainer (medium-sized span, < 30 m)	Medium-sized block	4
Transtainer (large span, > 30 m)	Large block	5

Only three kinds of pavements are able to carry such extremely high loading and pressures and thus guarantee that the container stacking bay will suffer no damage whatsoever: gravel beds, precast concrete blocks and reinforced concrete.

Should other kinds of pavements be used (unreinforced cement concrete or bituminous concrete) there may be some degree of damage (cracking or permanent deformation under the castings, respectively), which is acceptable providing that it is compatible with the kind of operation (which means in general that these areas must be used for that exclusive purpose) and surface water drainage. In any case, design should be adapted to the handling equipment used (item 3.1.2).

3.1.1.4. LOAD FROM ROLL-TRAILER PARKING

A common port management scheme is roll-trailer storage (general cargo pooled in containers or drop-boxes; or sometimes, open boxes containing very large items such as coils), which entails parking the trailers until a tractor comes to transport them. The rear axles of these roll-trailers (single, tandem or tridem) cause no particular damage to pavements, since they meet highway traffic requirements. However, the various devices with which these roll-trailers are equipped to rest their front ends on the ground when uncoupled can cause great damage. Roll-trailers are classified into three categories, depending on the kind of such device:

— Those equipped in the front with two pairs of dolly wheels 0,088 m wide and 0,225 m in diameter each; when the roll-trailer is fully loaded (loads of 140 kN at the front end), the pressure contact may go as high as 40 MPa, with a theoretical contact area of 0,088 x 0,010 m^2

— Those equipped in the front with two steel plates measuring 0,225 x 0,150 m^2, that bring to bear a contact pressure on the order of 2 MPa for a total load of 140 kN at the front end

— Those that have a font resting device consisting of a beam with a bearing area of 0,130 x 2,145 m^2, that makes for a pavement pressure contact of 0,5 MPa for loads of 140 kN at the front end

In short, with the exception of the last of the types described, very high pressure contacts are applied. Although these may be smaller on relatively flexible bearing surfaces, certain kinds of pavements are not advisable, such as bituminous concrete, for example, in which on warm days, the roll-trailers could sink several centimetres into the pavement. Nonetheless, it is possible to use a conjunctive system with a given strip (concrete, blocks, etc.) intended to accommodate the front ends and pave the rest of the area in the same way as the access lanes (using bituminous paving throughout, except on the said strips).

Unless specific design or operating data are available, the following loads and pressures should be used in pavement design for roll-trailer parking areas: 70 kN and 40 MPa, respectively.

These loads from roll-trailer parking must be taken into account not only in commercial areas, but in military areas as well.

3.1.2. LOADING FROM CARGO HANDLING EQUIPMENT AND FACILITIES

This variable loading is applied to the pavement by the cargo, materials or supplies handling equipment and systems.

In conjunction with pre-defined port planning criteria as well as others provided by the client or the port authority, the designer should consider the characteristics of the merchandise handling equipment operating in the area, location thereof and the kind of loads it places on the pavement. The designer should receive all relevant data on the specific handling equipment that is going to be operated in the area from equipment manufacturers. In this regard, if such specific information is not available, the designer may refer to the data corresponding to equipment most commonly used in port areas given in tables 3.4.3.2.1 and 3.4.3.2.2 and in particular table 3.4.3.2.3, all of ROM 0.2-90, which, in addition to load values, include information on load distribution for such equipment.

For the effects and purposes of how loads are applied and their effect on pavement design, handling equipment can be classified on the basis of mobility:

— estricted mobility, on rails or girder rails;
— unrestricted mobility, on tyres or caterpillars.

Table 3.2 gives a summary of the fundamental characteristics of the various kinds of handling equipment for pavement design purposes.

The possibility that maximum loads from bearing points or maximum contact pressures may be greater than those indicated (1 100 kN and 2,6 MPa, respectively) should be borne in mind and be subject to special analysis.

Moreover, the existence of substantial horizontal stresses (due to cornering, accelerating and braking, etc.) is not taken into account for the structural design of pavements, but such factors should be considered when establishing the pavement surface characteristics.

3.1.2.1. PORTAL CRANES

This equipment is used on the dock: it is found in the working area and engages in the conversion from sea- to land-borne transport. It may use hooks for general cargo (and exceptionally, for containers) or scoops for bulk goods. These revolving cranes are able to travel parallel to the edge. They have restricted mobility, on rails that are in turn mounted on beams or piles. For this reason, the loads they convey do not affect the pavement.

3.1.2.2. PORTAINERS

This kind of equipment is specially designed for moving containers from one kind of transport to another and it is likewise located in the working area. It is provided with a hinged jib that constitutes a long cantilever. This kind of crane is not a revolving crane, the truck moves perpendicular to the ledge and, like portal cranes, can travel all along the dock. Mobility is also restricted, as portainers travel on rails like the ones described in the preceding item.

3.1.2.3. TRANSTAINERS

This equipment, used to handle containers in stacking bays, may stack them up to 5 containers high in the case of transtainers with spans of over 30 m. Transtainers travel on tyres or rails and can have a highly damaging effect as they convey wheel loads on the order of 450 kN and contact pressures of 1,1 MPa. However, their movement is restricted to predefined roadways usually designed in beam form; and, given that the intersection between two beams is where tyre-equipped transtainers turn, these points are usually reinforced with 1,5 x 1,5 m^2 steel plates 0,020 m thick. In short, the roadway should be built on a floating beam, so pavement design is independent of the characteristics of this kind of equipment.

TABLE 3.2.	LOAD AND PRESSURE FROM HANDLING EQUIPMENT UNDER THE WORST POSSIBLE WORKING CONDITIONS	
HANDLING EQUIPMENT	MAXIMUM LOAD ON EACH BEARING POINT(kN)	MAXIMUM CONTACT PRESSURE (MPa)
Transtainers	450	1,1
Straddle carriers	130	1,1
5 t front lift trucks	30	0,8
20 t front lift trucks	110	0,7
40 t front lift trucks	220	0,6
Side lift truck	230	0,6
10 t mobile crane	150	0,4
30 t mobile crane	400	0,9
50 t mobile crane	550	1,3
70 t mobile crane	750	1,8
140 t mobile crane	1.100	2,6
Tractor with 40 t roll-trailer	35	2,2
Tractor with 80 t roll-trailer450	70	2,2

3.1.2.4. STRADDLE CARRIERS

These are load vehicles that travel throughout the entire manoeuvring area and storage yard with no restrictions; they are container handlers, and can stack them up to three high. Their wheels can turn in all possible directions, so the great horizontal stress involved when they turn at a right angle in a very short distance, or even when completely stopped, can cause substantial damage to the pavement. Under the worst conditions they may convey up to 260 kN per pair of dual wheels and exert contact pressures of up to 1,1 MPa.

3.1.2.5. FRONT LIFT TRUCKS (FLT)

This equipment likewise travels freely, and of all the port operation equipment used, it is the most harmful to pavements. It is used in handling containers, which it can stack up to four high, and for general cargo, in which case the FLTs are much smaller and less powerful. They all have dual wheels on the front axle and single wheels at the rear. There are two kinds engaging in container handling: those that handle 20-foot containers only, and those that can handle 40-foot containers. In the latter case, they can load up to 720 kN on the front axle, which entails a wheel load of 120 kN, and up to 150 kN if the vehicle is equipped with a telescopic jib. Forklifts can apply wheel loads of up to 220 kN when handling 40-foot containers.

3.1.2.6. SIDE LOADER LIFT TRUCKS

These vehicles travel freely, and are used sometimes for general cargo handling, but mostly for containers, which they can stack up to four high. These vehicles cause most damage not when they are moving, but when they are load or unload, since they are set on stabilising jacks that absorb from 70 to 95 % of the combined weight of the vehicle and the container.

The number of jacks varies from 2 for the smaller vehicles to 4 for the larger ones, that handle 40-foot containers. In the latter case the contact pressures can reach 0,6 MPa, the load from each base being 230 kN.

3.1.2.7. MOBILE CRANES

These cranes are used basically for handling general cargo. When handling containers, they can stack them up to four high. Their lifting capacity, in short radii, ranges from 10 to 140 t, although jib length can reach up to 12 m or more. The worst operating conditions occur when they work sideways or backwards on stabilising jacks. In these circumstances, the load from each base in 140-t cranes is 1 100 kN, with a pressure of 2,6 MPa.

3.1.2.8. ROLL-TRAILERS

These are used both for moving and for storing (in the latter case, uncoupled from the tractor) general cargo and containers (see item 3.1.1.4).

3.1.3. LOADING FROM VESSEL LIFTING EQUIPMENT

These are variable loads applied to the pavement by mobile lifting systems and equipment for off-shore, usually recreational vessels. This equipment is normally found in the working or dry-dock areas of recreational ports or docks, where they travel freely. They are usually employed to dock or launch boats with displacements ranging from 200 to 2000 kN. They are usually called travelifts.

The most common kind of equipment travel on four pneumatic tyres, conveying vertical wheel loads on the order of 90 kN for lifts with a capacity of 200 kN and up to 600 kN for lifts able to handle 1 500 kN, with maximum contact pressures of up to 1,1 MPa. In travelifts with greater capacity the wheel loads reach around 400 kN, for a total of eight wheels.

In accordance with pre-defined port planning criteria as well as others provided by the client or the port authority, the designer should consider the specifications of travelifts operating in the area, their location and the kind of loads they place on the pavement. The designer should receive all relevant data on the specific handling equipment that is going to be operated in the area from equipment manufacturers.

The horizontal stresses due to cornering, accelerating and braking (from 7 to 75 kN depending on equipment lifting capacity) are not taken into account for the structural design of pavements, but such factors should be considered when establishing the pavement surface characteristics.

3.1.4. LOADING FROM HEAVY CONVENTIONAL TRAFFIC

Heavy conventional traffic comprises vehicles that can circulate freely on the highway network. This kind of traffic can be found in all port areas, but it is characteristic of access lanes; it should also be borne in mind when designing pavements for auxiliary areas.

In Spain the category "heavy vehicles" covers lorries with a carrying capacity of over 3 t, more than four wheels and no trailer; lorries with one or several trailers; articulate and special vehicles; and vehicles engaging in passenger transportation with more than 9 seats. Moreover, in order to travel freely on Spanish roads, heavy vehicles may not exceed the following maximum loads:

- Load per single axle: 130 kN
- Load per dual or tandem axle: 210 kN
- Total load (carrying capacity plus own weight) for two-axle rigid vehicles: 200 kN
- Total load for rigid vehicles with 4 or more axles, articulate vehicles (roll-trailers) and vehicle combinations: 380 kN

Depending on tyre specifications, the maximum contact pressures range from approximately 0,6 to 0,9 MPa, although pressures of 1,5 MPa may be reached due to the dynamic effect.

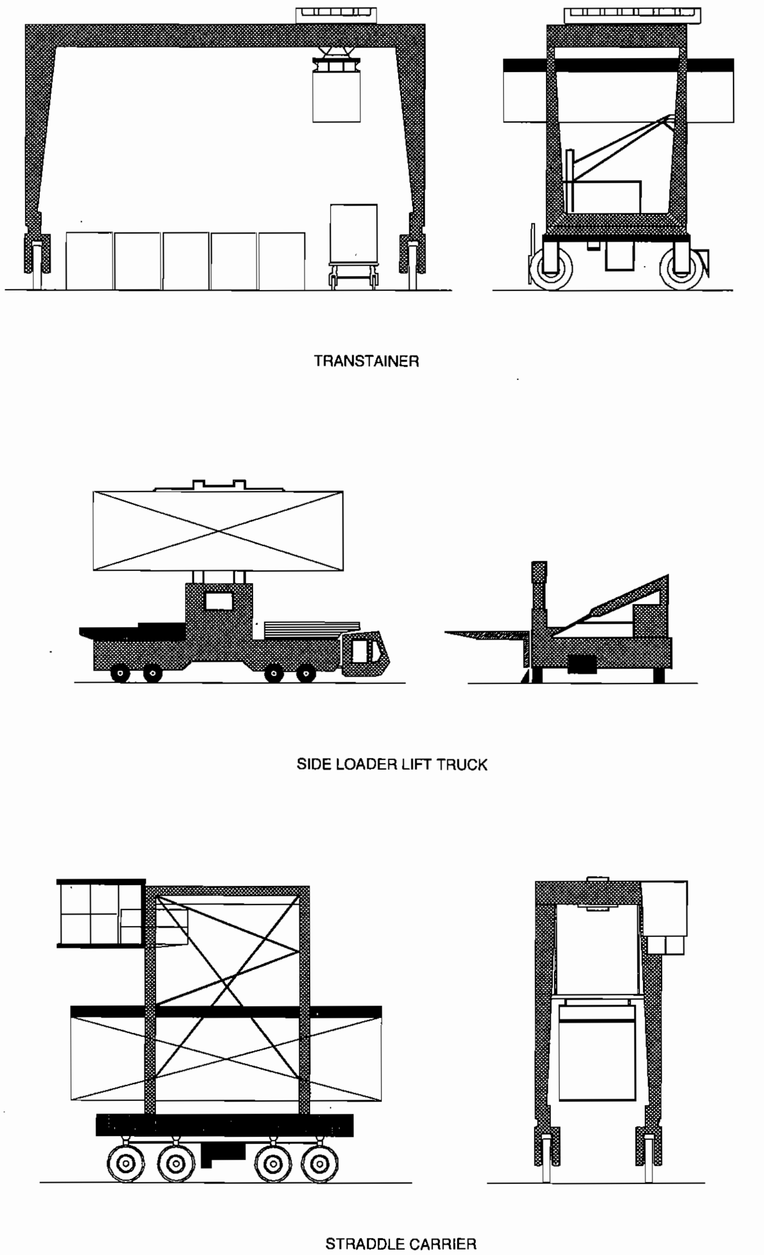
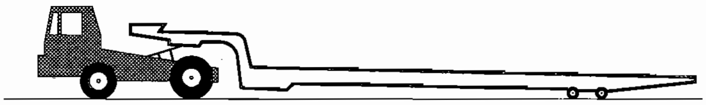
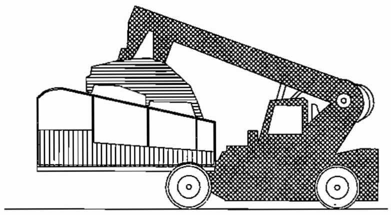


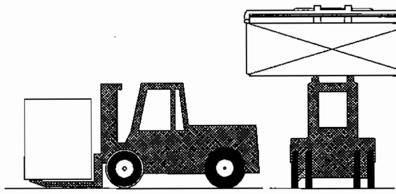
FIGURE 3.1. Cargo handling and vessel lifting equipments.



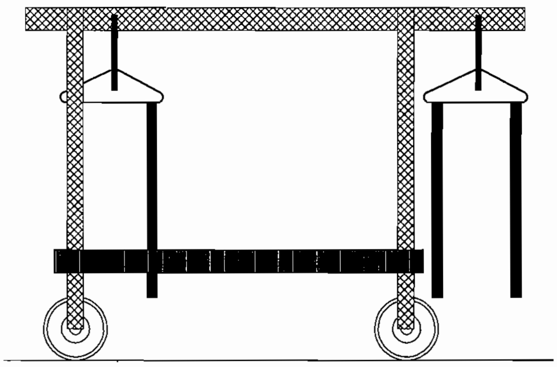
ROLL - TRAILER



MOBILE CRANE



FRONT LIFT TRUCK OR FLT



TRAVELIFT

FIGURE 3.1. (Continued)

3.2. PORT SURFACE USE RATES

As indicated at the beginning of the present item, use rate is, together with applied loads, fundamental to defining the traffic category for a port surface. Use rate, according to the definitions given below for each case, provides an indication, on one hand, of the number of times that a given kind of load is applied to a surface during its life; but above all it is indicative of the relative importance of the surface in port operations and, therefore, the relative effect that possible damage to the pavement in this area would have on such operations.

A series of *port operation indexes* is employed to evaluate the use rate, and must be estimated by the designer or port authority in question. Such indexes refer to a given magnitude of operations per year and are established for the mean year of design life, i.e., the said magnitude is summed for the entire design life and is divided by the number of years. In the case of access lanes, the parameter used is the average daily traffic of heavy vehicles in the mean year of design life.

Estimating port operation indexes is no easy matter (establishing them for a facility in operation would be quite something else), and the reliability of this estimate may be called into question. Nonetheless, it must be borne in mind that it is a way to relate the importance of surfaces to expected port activity (even though maximum possible port efficiency should always be pursued). Moreover, when, for the purposes of these Guidelines the various use rates were classified in item 3.4 on the basis of the values of these indexes, an attempt was made to establish very wide ranges so as to minimise the effects of possible estimation errors.

Use rate of port surfaces is directly linked to the kind of land transport used to transfer merchandise, particularly in working areas. For example, where railed transport is the major system in a terminal, even though use rate is high, the effect on pavements is probably less than in a terminal with a lower use rate but relying heavily on equipment on tyres for transport.

Two different situations can be distinguished in storage yards:

— equipment traffic surfaces are not differentiated physically and permanently from merchandise storage surfaces (the usual case);

— equipment traffic surfaces are differentiated physically and permanently from merchandise storage surfaces. This would be the case, for example, where containers are stored on gravel beds (part 5), or in some bulk solid and liquid storage areas.

In the latter case, like in item 3.3 for the classification of design load, two different operating indexes could be established, one for each kind of surface, thus defining two different use rates.

3.2.1. COMMERCIAL USE

3.2.1.1. OPERATING AREAS

Cargo and material handled by haulage per berth unit length in the mean year of design life: $I_{1.1}$ (t/m).

Unless more precise data are available, the amount of cargo hauled is found by multiplying the total amount of cargo (loaded and unloaded) by the values listed below, for each kind of handling:

Haulage	1,00
Lifting	0,30
Haulage and lifting	0,70
Continuous conveyance	0,10

For the effects and purposes of determining this index, where incoming and outgoing cargo is transported essentially by rail, a coefficient of 0,10 should also be applied.

Where no design or operating data are available, it should be assumed that all cargo is handled by haulage.

3.2.1.2. BULK SOLID STORAGE AREAS

Materials stored per surface unit in the mean year of design life: $I_{1.2}$ (t/m^2).

3.2.1.3. GENERAL CARGO STORAGE AREAS

Cargo stored per surface unit in the mean year of design life: $I_{1.3}$ (t/m^2).

3.2.1.4. CONTAINER STACKING BAYS

Containers stacked per surface unit in the mean year of design life: $I_{1.4}$ (TEU/m^2).

3.2.1.5. ROLL-TRAILER PARKING AREAS

Containers and drop-boxes transported on roll-trailers per unit of surface in the mean year of design life: $I_{1.5}$ (TEU/m^2).

In the event that elements other than drop-boxes or containers (coils for example) are transported on a considerable number of roll-trailers, the following equivalence may be used, for the sole purpose of estimating use rate:

One 40-foot (12 m) roll-trailer <—> 2 TEU
One 20-foot (6 m) roll-trailer <—> 1 TEU

Where operating indexes in these areas can be estimated only in tonnes of transported load, and the corresponding equivalences are not available, the following equivalence may be used (for the sole purpose of estimating operating index):

10 t <—> 1 TEU

Where the roll-trailer parking area is not used exclusively for this purpose, but for mixed or multi-purpose docking, for example, and as a result other kinds of storage takes place there, the operating index to be used, adopting the equivalences referred, should be expressed in tonnes per surface unit in the mean year of design life: $I_{1.5'}$ (t/m^2)

3.2.1.6. MANOEUVRING LANES

The same indexes as found for the areas connected by the manoeuvring lane in question should be used.

3.2.1.7. ACCESS LANES

Similarly, but not identically, to the provisions of *Instruction 6.1 and 2 IC on pavement structures*, the average daily traffic of heavy vehicles in the design lane in the mean year of design life should be taken into account (the said Instruction refers, to the contrary, to the first year of service).

3.2.1.8. AUXILIARY AREAS. TRAFFIC

Following a criterion similar to the one discussed in the preceding paragraph, the average daily traffic (total vehicles) for the lane in question should be considered.

3.2.1.9. AUXILIARY AREAS. PARKING

The total number of parking spaces available in the area should be considered.

3.2.2. INDUSTRIAL USE

3.2.2.1. WORKING AREAS

Merchandise and material handled by haulage per berth unit length in the mean year of design life: $I_{2.1}$ (t/m), following the same criteria as indicated in item 3.2.1.1.

3.2.2.2. STORAGE YARDS

Materials and merchandise stored per unit area in the mean year of design life: $I_{2.2}$ (t/m²).

3.2.3. MILITARY USE

3.2.3.1. WORKING AREAS

Merchandise and material handled by haulage per berth unit length in the mean year of design life: $I_{3.1}$ (t/m), following the same criteria as indicated in item 3.2.1.1.

3.2.3.2. STORAGE YARDS

Materials and merchandise stored per unit area in the mean year of design life: $I_{3.2}$ (t/m²).

3.2.4. FISHING USE

3.2.4.1. WORKING AREAS

Fish landings in the area per berth unit length in the mean year of design life: $I_{4.1}$ (t/m).

3.2.4.2. CLASSIFICATION, PREPARATION AND SELLING AREAS

Amount of fish handled in these areas per surface unit in the mean year of design life: $I_{4.2}$ (t/m²).

3.2.4.3. MANOEUVRING LANES

See item 3.2.1.6.

3.2.4.4. ACCESS LANES

See item 3.2.1.7.

3.2.4.5. AUXILIARY AREAS. TRAFFIC

See item 3.2.1.8.

3.2.4.6. AUXILIARY AREAS. PARKING

See item 3.2.1.9.

3.2.5. RECREATIONAL USE

3.2.5.1. WORKING OR LAUNCHING AREAS

Number of docking plus launching operations for recreational vessels with an overall length of 6 m or more in the mean year of design life: I_5 (No.).

3.2.5.2. AUXILIARY AREAS. TRAFFIC

See item 3.2.1.8.

3.2.5.3. AUXILIARY AREAS. PARKING

See item 3.2.1.9.

3.3. DESIGN LOADS BY PORT SURFACING USE

This item contains an analysis and classification of applied load values intended to enable the designer to determine the load-use rate combination for each surface and thus define the corresponding traffic category. Design loads are classified as low, medium or high for the various possible situations, attention being drawn to the fact that design loads classified in the same manner for different situations are not necessarily equivalent. Therefore the design load classification and as a result the traffic category (item 3.5) cannot be extricated from surface usage.

A distinction is drawn, for each port area, between loads from storage, that refer to loads from parking and storage (as defined in item 3.1.1) and loads from handling, that refer to loads imposed by merchandise handling equipment or vehicles (as defined in item 3.1.2). In order to relate this to use rate and thus find the traffic category, in general the design load classification to be finally used for each area should be the highest of the two so determined.

In storage areas, however, two different situations can be distinguished (see item 3.2). Where the equipment traffic and merchandise storage areas are physically and permanently differentiated, the two design loads are to be considered separately, and consequently a separate traffic category for each surface is to be determined.

The essentially qualitative classification of design loads given below for the various possible situations should be interpreted as an acceptable simplification for pavement design purposes. Therefore, where the designer has access to more precise quantitative data he/she may opt to draw up his/her own load characterisation and classification, providing he/she respects the general principles set out both in the present item and in Part 6.

3.3.1. COMMERCIAL USE

3.3.1.1. WORKING AREAS

3.3.1.1.1. DESIGN LOAD - STORAGE

Except in specialised terminals and providing no specific design or operating criteria are available, it will be considered HIGH for port operational reasons or taking into account future operational changes, as well as for load impact and suitability of pavement to dock structure considerations. In specialised terminals, and where specific criteria are likewise lacking, the following classification should be employed:

Bulk liquids:	LOW
Bulk solids:	MEDIUM
General cargo:	HIGH
Containers:	HIGH
Roll-on/roll-off cargo:	MEDIUM

If precise data are available, design loads may be classified on the basis of the loads Q_v and pressures p_v applied to the pavement in each case:

LOW: $Q_v < 120$ kN and $p_v < 0,7$ MPa, simultaneously.
MEDIUM: $120 \text{ kN} \leq Q_v \leq 500$ kN, or $0,7 \text{ MPa} \leq p_v \leq 1,0$ MPa.
HIGH: $Q_v > 500$ kN and $p_v > 1,0$ MPa, simultaneously.

3.3.1.1.2 DESIGN LOAD - HANDLING

This depends on the kind of equipment to be used and therefore on the loads Q_v and pressures p_v applied to the pavement by each wheel, each pair of dual wheels or in general each bearing point:

LOW: $Q_v < 120$ kN and $p_v < 1,1$ MPa, simultaneously.
(includes situations where merchandise is handled exclusively by vehicles on beams or rails, or by a continuous conveyance system).
MEDIUM: $120 \text{ kN} \leq Q_v \leq 700$ kN or $1,1 \text{ MPa} \leq p_v \leq 1,5$ MPa.
HIGH: $Q_v > 700$ kN and $p_v > 1,5$ MPa, simultaneously.

Irrespective of this classification, the designer should consider the advisability of considering a HIGH design load, to provide for the possibility that very heavy mobile cranes may be needed to handle special merchandise or in the event of dock equipment failure.

3.3.1.2. BULK SOLID STORAGE AREAS

3.3.1.2.1. DESIGN LOAD - STORAGE

This depends on the contact pressure p_v exerted by the maximum storage heights (tables 3.4.2.3.1.1 and 3.4.2.3.1.2 of ROM 0.2-90):

LOW: $0{,}15 \text{ MPa} > p_v$.
MEDIUM: $0{,}15 \text{ MPa} \leq p_v$.

Where precise data are not available, ordinary bulk solids should be considered to apply a LOW load and heavy bulk solids a MEDIUM load.

3.3.1.2.2. DESIGN LOAD - HANDLING

This depends on the kind of equipment to be used and therefore on loads Q_v and pressures p_v applied to the pavement by each wheel, each pair of dual wheels or in general each bearing point:

LOW: $Q_v < 120$ kN and $p_v < 1{,}1$ MPa, simultaneously.
(includes situations where handling is performed exclusively by a continuous conveyance system).
MEDIUM: $120 \text{ kN} \leq Q_v$ or $1{,}1 \text{ MPa} \leq p_v$.

3.3.1.3. GENERAL CARGO STORAGE YARDS

3.3.1.3.1. DESIGN LOAD - STORAGE

This depends on the contact pressure p_v exerted by the maximum storage heights (tables 3.4.2.3.1.1 and 3.4.2.3.1.2 of ROM 0.2-90):

LOW: $0{,}15 \text{ MPa} > p_v$.
MEDIUM: $0{,}15 \text{ MPa} \leq P_v < 1{,}5 \text{ MPa}$.
HIGH: $1{,}5 \text{ MPa} \leq p_v$.

Where more precise data are not available, conventional general cargo should be considered to apply a MEDIUM load and heavy general cargo a HIGH load.

3.3.1.3.2. DESIGN LOAD - HANDLING

This depends on the kind of equipment to be used and therefore on the loads Q_v and pressures p_v applied to the pavement by each wheel, each pair of dual wheels or in general each bearing point:

LOW: $Q_v < 120$ kN and $p_v < 1{,}1$ MPa, simultaneously.
(includes situations where merchandise is handled exclusively by vehicles on girders or rails).
MEDIUM: $120 \text{ kN} \leq Q_v \leq 700 \text{ kN}$ or $1{,}1 \text{ MPa} \leq p_v \leq 1{,}5 \text{ MPa}$.
HIGH: $Q_v > 700$ kN and $p_v > 1{,}5$ MPa, simultaneously.

3.3.1.4. CONTAINER STACKING BAYS

3.3.1.4.1. DESIGN LOAD - STORAGE

This depends on the stacking layout and consequently on the loads Q_v and pressures p_v applied to the pavement at each bearing point:

LOW: $Q_v < 100$ kN and $p_v < 4$ MPa, simultaneously.
(only for containers stacked singly and or 20-foot containers stacked two high).
MEDIUM: $100 \text{ kN} \leq Q_v \leq 1200 \text{ kN}$ or $4 \text{ MPa} \leq p_v \leq 10 \text{ MPa}$.
(all stacking layouts, with the exception of those indicated for LOW and HIGH loads).
HIGH: $Q_v > 1200$ kN and $p_v > 10$ MPa, simultaneously.
(only where containers are block-stacked or singly stacked, four or five containers high).

Where no design data are available, the load should be considered to be HIGH. If pavements are to be guaranteed absolutely against any possibility of damage from these loads and pressures, solutions such as gravel beds, concrete pavers or reinforced concrete slabs must be considered. Where unreinforced concrete is used, a certain amount of damage (cracking) may be expected and is acceptable providing it is compatible with operating requirements and surface water drainage; in such cases, design should be based on the design loads for handling.

3.3.1.4.2 DESIGN LOAD - HANDLING

This depends on the kind of equipment to be used and therefore on the loads Q_v and pressures p_v applied to the pavement by each wheel, each pair of dual wheels or in general each bearing point:

LOW: $Q_v < 120$ kN and $p_v < 1{,}1$ MPa, simultaneously.
(includes situations where merchandise is handled exclusively by portal cranes on beams or rails).
MEDIUM: $120 \text{ kN} \leq Q_v \leq 700 \text{ kN}$ or $1{,}1 \text{ MPa} \leq p_v \leq 1{,}5 \text{ MPa}$.
HIGH: $Q_v > 700$ kN and $p_v > 1{,}5$ MPa, simultaneously.

3.3.1.5. ROLL-TRAILER PARKING AREAS

3.3.1.5.1. DESIGN LOAD - STORAGE

This load would depend in principle on the kind of roll-trailer used; as this may vary, the load should always be considered HIGH (i.e., $Q_v = 70$ kN and $p_v = 40$ MPa at each bearing point).

The above refers to the front end of the trailer once uncoupled from the tractor, so that where it is decided to pave a strip specifically for this purpose, it is in this strip only that a high design load must be considered; the rest of the area may be treated like all other access lanes.

3.3.1.5.2. DESIGN LOAD - HANDLING

Where there is handling equipment other than the roll-trailers themselves, the design loads for handling depend on the nature of such equipment and therefore on the loads Q_v and pressures p_v applied to the pavement by each wheel, each pair of dual wheels or in general each bearing point:

LOW: $Q_v < 120$ kN and $p_v < 1{,}1$ MPa, simultaneously.

MEDIUM: $120 \text{ kN} \leq Q_v \leq 700 \text{ kN}$ or $1{,}1 \text{ MPa} \leq p_v \leq 1{,}5 \text{ MPa}$.

HIGH: $Q_v > 700$ kN and $p_v > 1{,}5$ MPa, simultaneously.

In strict application of the Guidelines, this classification does not affect the determination of the traffic category, since the design load from storage is always HIGH.

3.3.1.6. MANOEUVRING LANES

Manoeuvring lanes should be assigned the highest design load classification found when analyzing the design loads for handling in the various areas connected by the manoeuvring lanes in question.

3.3.1.7. ACCESS LANES

The design load to be used is the one corresponding to heavy highway vehicles, in the sense indicated in *Instruction 6.1 and 2 IC on pavement structures* (see the definition of heavy vehicle in item 1.3): half-axles with dual wheels with loads of 65 kN and pressures, in general, of not over 0,9 MPa. Given the way the traffic category is determined in the said Instruction (on the basis of average daily traffic of heavy vehicles), the design load classification is irrelevant in this case.

3.3.1.8. AUXILIARY AREAS. TRAFFIC

The criterion is identical to the one discussed in item 3.3.1.7.

3.3.1.9. AUXILIARY AREAS. PARKING

The purpose for which the parking spaces are intended should be considered:

LOW: Parking lot for light vehicles only
MEDIUM: Parking lot for heavy and light vehicles
HIGH: Parking lot for heavy vehicles only

3.3.2. INDUSTRIAL USE

3.3.2.1. WORKING AREAS

Classification criteria identical to those discussed in item 3.3.1.1 (commercial working areas) should be considered.

3.3.2.2. STORAGE YARDS

Unless specific criteria are available, design loads should be classified in a manner similar to that recommended for general cargo (item 3.3.1.3).

3.3.2.2.1. DESIGN LOAD - STORAGE

This depends on the contact pressure p_v exerted by the maximum storage heights (tables 3.4.2.3.1.1 and 3.4.2.3.1.2 of ROM 0.2-90):

LOW: $0{,}15\ MPa > p_v$.
MEDIUM: $0{,}15\ MPa \leq P_v < 1{,}5\ MPa$.
HIGH: $1{,}5\ MPa \leq p_v$.

Where no data are available, the load should be considered to be HIGH (heavy general cargo).

3.3.2.2.2. DESIGN LOAD - HANDLING

This depends on the kind of equipment to be used and therefore on the loads Q_v and pressures p_v, applied to the pavement by each wheel, each pair of dual wheels or in general each bearing point:

LOW: $Q_v < 120$ kN and $p_v < 1{,}1$ MPa, simultaneously.
(includes situations where merchandise is handled exclusively by vehicles on beams or rails).
MEDIUM: $120\ kN \leq Q_v \leq 700\ kN$ or $1{,}1\ MPa \leq p_v \leq 1{,}5\ MPa$.
HIGH: $Q_v > 700$ kN and $p_v > 1{,}5$ MPa, simultaneously.

3.3.3. MILITARY USE

3.3.3.1. WORKING AREAS

The same general classification criteria as discussed under item 3.3.1.1 (commercial working areas) should be considered.

3.3.3.2. STORAGE YARDS

Unless specific criteria are available, design loads should be classified in a manner similar to that applied for general cargo storage yards (item 3.3.1.3) and roll-trailer parking areas (item 3.3.1.5).

3.3.3.2.1. DESIGN LOAD - STORAGE

Here only the most adverse case discussed under roll-trailer storage is considered, i.e., the load is always considered to be HIGH (hence, where $Q_v = 70$ kN and $p_v = 40$ MPa at each bearing point).

3.3.3.2.2. DESIGN LOAD - HANDLING

This depends on the kind of equipment to be used and therefore on loads Q_v and pressures p_v applied to the pavement by each wheel, each pair of dual wheels or in general each bearing point:

LOW: $Q_v < 120$ kN and $p_v < 1{,}1$ MPa, simultaneously.
MEDIUM: $120 \text{ kN} \leq Q_v \leq 700$ kN or $1{,}1 \text{ MPa} \leq p_v \leq 1{,}5$ MPa.
HIGH: $Q_v > 700$ kN and $p_v > 1{,}5$ MPa, simultaneously.

3.3.4. FISHING USE

3.3.4.1. WORKING AREAS

3.3.4.1.1. DESIGN LOAD - STORAGE

If specific data are available, design loads may be classified on the basis of the loads Q_v and pressures p_v applied to the pavement in each case:

LOW: $Q_v < 120$ kN and $p_v < 0{,}7$ MPa, simultaneously.
MEDIUM: $120 \text{ kN} \leq Q_v \leq 500$ kN, or $0{,}7 \text{ MPa} \leq p_v \leq 1{,}0$ MPa.
HIGH: $Q_v > 500$ kN and $p_v > 1{,}0$ MPa, simultaneously.

Where there are no data, classification should be based on the kind of vessels serviced at the dock:

LOW: Vessels engaging in off-shore fishing only.
MEDIUM: Vessels engaging in both off-shore and long-distance fishing.

3.3.4.1.2. DESIGN LOAD - HANDLING

The criteria discussed for commercial working areas (item 3.3.1.1.2) should be followed.

3.3.4.2. CLASSIFICATION, PREPARATION AND SELLING AREAS

The same general classification principles as established for general cargo in item 3.3.1.3 should be followed. Where no data are available, the load from storage should be considered to be MEDIUM.

3.3.4.3. MANOEUVRING LANES

See item 3.3.1.6.

3.3.4.4. ACCESS LANES

See item 3.3.1.7.

3.3.4.5. AUXILIARY AREAS. TRAFFIC

See item 3.3.1.8.

3.3.4.6. AUXILIARY AREAS. PARKING

See item 3.3.1.9.

3.3.5. RECREATIONAL USE

3.3.5.1. WORKING OR LAUNCHING AREAS

3.3.5.1.1. DESIGN LOAD - STORAGE

If specific data are available, design loads may be classified on the basis of the loads Q_v and pressures p_v applied to the pavement in each case:

LOW: Q_v < 120 kN and p_v < 0,7 MPa, simultaneously.
MEDIUM: 120 kN ≤ Q_v ≤ 500 kN, or 0,7 MPa ≤ p_v ≤ 1,0 MPa.
HIGH: Q_v > 500 kN and p_v > 1,0 MPa, simultaneously.

Where there are no data, classification should be based on the kind of vessels serviced at the dock:

LOW: Vessels with an overall length under 6 m only.
MEDIUM: Vessels with any other overall length.

3.3.5.1.2. DESIGN LOAD - HANDLING OR LIFTING VESSELS

The criteria discussed under commercial working areas (item 3.3.1.1.2) should be followed.

3.3.5.2. AUXILIARY AREAS. TRAFFIC

See item 3.3.1.8.

3.3.5.3. AUXILIARY AREAS. PARKING

See item 3.3.1.9.

3.4. USE RATES BY PORT SURFACING USE

This item contains an analysis and classification of port operation indexes representing use rate intended to enable the designer to determine the design load-use rate combination for each surface and hence define the corresponding traffic category.

Use rates are classified as low, medium or high depending on the values of the indexes defined in item 3.2 (referring in all cases to the mean year of design life). The intention of these recommendations, however, is for the medium use rate to cover most of the situations that may arise in a port. Where no data are available, the use rate should, in any case, be classified as MEDIUM.

3.4.1. COMMERCIAL USE

3.4.1.1. WORKING AREAS

LOW: $I_{1.1}$ < 300 t/m.
MEDIUM: 300 ≤ $I_{1.1}$ ≤ 3 000 t/m.
HIGH: $I_{1.1}$ > 3 000 t/m.

3.4.1.2. BULK SOLID STORAGE AREAS

LOW: $I_{1.2}$ < 6 t/m^2.
MEDIUM: 6 ≤ $I_{1.2}$ ≤ 60 t/m^2.
HIGH: $I_{1.2}$ > 60 t/m^2.

3.4.1.3. GENERAL CARGO STORAGE YARDS

LOW: $I_{1.3}$ < 2 t/m^2.
MEDIUM: 2 ≤ $I_{1.3}$ ≤ 20 t/m^2.
HIGH: $I_{1.3}$ > 20 t/m^2.

3.4.1.4. CONTAINER STACKING BAYS

LOW: $I_{1.4}$ < 0,2 TEU/m^2.
MEDIUM: 0,2 ≤ $I_{1.4}$ ≤ 2 TEU/m^2.
HIGH: $I_{1.4}$ > 2 TEU/m^2.

3.4.1.5. ROLL-TRAILER PARKING AREAS

One of the operation indexes defined in item 3.2.1.5 should be considered, depending upon available estimates.

— Where the operating index is based on the number of containers and drop-boxes per unit area in the mean year of design life:

LOW: $I_{1.5} < 0{,}2$ TEU/m².
MEDIUM: $0{,}2 \leq I_{1.5} \leq 2$ TEU/m².
HIGH: $I_{1.5} > 2$ TEU/m².

— Where the operation index is based on the number of tonnes per unit area in the mean year of design life:

LOW: $I_{1.5} < 2$ t/m².
MEDIUM: $2 \leq I_{1.5} \leq 20$ t/m².
HIGH: $I_{1.5} > 20$ t/m².

3.4.1.6. MANOEUVRING LANES

The highest use rate classification found for the areas connected by the manoeuvring lane in question should be applied.

3.4.1.7. ACCESS LANES

The mean daily use rate classification for heavy vehicles is established in *Instruction 6.1 and 2 IC on pavement structures,* except that where the instruction refers to the first year of service the reference for the present purposes is the mean year.

3.4.1.8. AUXILIARY AREAS. TRAFFIC

The criterion discussed in 3.4.1.7 should be followed.

3.4.1.9. AUXILIARY AREAS. PARKING

LOW: Less than 10 parking spaces in all.
MEDIUM: From 10 to 100 parking spaces in all.
HIGH: More than 100 parking spaces in all.

3.4.2. INDUSTRIAL USE

3.4.2.1. WORKING AREAS

LOW: $I_{2.1} < 300$ t/m.
MEDIUM: $300 \leq I_{2.1}$ 3 000 t/m.
HIGH: $I_{2.1} > 3\,000$ t/m.

3.4.2.2 STORAGE AREAS

LOW: $I_{2.2} < 2$ t/m².
MEDIUM: $2 \leq I_{2.2} \leq 20$ t/m².
HIGH: $I_{2.2} > 20$ t/m².

3.4.3. MILITARY USE

3.4.3.1. WORKING AREAS

LOW: $I_{3.1} < 300$ t/m.
MEDIUM: $300 \leq I_{3.1} \leq 3\,000$ t/m.
HIGH: $I_{3.1} > 3\,000$ t/m.

3.4.3.2. STORAGE AREAS

LOW: $I_{3.2} < 2$ t/m².
MEDIUM: $2 \leq I_{3.2} \leq 20$ t/m².
HIGH: $I_{3.2} > 20$ t/m².

3.4.4. FISHING USE

3.4.4.1. WORKING AREAS

LOW: $I_{4.1} < 10$ t/m.
MEDIUM: $10 \leq I_{4.1} \leq 100$ t/m.
HIGH: $I_{4.1} > 100$ t/m.

3.4.4.2. CLASSIFICATION, PREPARATION AND SELLING AREAS

LOW: $I_{4.2} < 0{,}4$ t/m².
MEDIUM: $0{,}4 \leq I_{4.2} \leq 4$ t/m².
HIGH: $I_{4.2} > 4$ t/m².

3.4.4.3. MANOEUVRING LANES

The criterion indicated for commercial use under item 3.4.1.6 should be followed.

3.4.4.4. ACCESS LANES

The criterion indicated for commercial use under item 3.4.1.7 should be followed.

3.4.4.5. AUXILIARY AREAS. TRAFFIC

The criterion indicated for commercial use under item 3.4.1.8 should be followed.

3.4.4.6. AUXILIARY AREAS. PARKING

The criterion indicated for commercial use under item 3.4.1.9 should be followed.

3.4.5. RECREATIONAL USE

3.4.5.1. WORKING OR LAUNCHING AREAS

LOW: $I_5 < 100$.
MEDIUM: $10 \leq I_5 \leq 1\,000$.
HIGH: $I_5 > 1\,000$.

3.4.5.2. AUXILIARY AREAS. TRAFFIC

The criterion indicated for commercial use under item 3.4.1.8 should be followed.

3.4.5.3. AUXILIARY AREAS. PARKING

The criterion indicated for commercial use under item 3.4.1.9 should be followed.

3.5. TRAFFIC CATEGORIES

Four traffic categories are defined on the basis of design load and use rate of the surface in question.

Very heavy traffic: A
Heavy traffic: B
Medium traffic: C
Light traffic: D

These traffic categories are valid for all kinds of surfaces, except for access lanes and auxiliary traffic areas, where the traffic categories to be applied are as defined in *Instruction 6.1 and 2 IC on pavement structures.* Table 3.3 shows the traffic categories as a combination of surface design load and use rate. In each case, the category to be applied is the highest one found in all the analyses run for a given surface. Likewise, in the event of doubt between two categories, the higher of the two should always prevail.

TABLA 3.3. TRAFFIC CATEGORIES

USE RATE	DESIGN LOAD		
	LOW	MEDIUM	HIGH
LOW	D	C	B
MEDIUM	D	B	A
HIGH	C	B	A

PART 4 FILLS AND SUBGRADES

PART 4 FILLS AND SUBGRADES

Contents

PART 4 FILLS AND SUBGRADES

Fundamental criteria for characterising pavement foundations are discussed, with particular reference to the capping layer, the upper surface of which is called the subgrade, on which the pavement rests, fill and the natural ground. Finally, subgrade categories are established as a pavement design parameter.

4.1. INTRODUCTION

One of the major determinants in the structural behaviour of a pavement is the bearing capacity of the underlying material. Not only the upper material, but even the characteristics of the materials several metres underground, affect this behaviour. In highways and other land transport infrastructures the pavement is laid on a suitably compacted embankment or on the bed of a clearing in land or rock. However, in ports, the foundation consists, in general, of a fill placed totally or partially under sea level, which cannot, therefore, be compacted following usual mechanical procedures. Such fills are laid in turn on sea beds of varying quality. However, on occasion the situation may be very similar to what might be expected in highway construction, where fills are built and compacted by layers, which procedure is only viable at elevations above sea level.

Similarly to the distinction made in embankments between foundation, core and capping layer, in port pavements a distinction is likewise drawn between ground, fill and capping layer. As in highway usage, in these Guidelines the term *subgrade* is used to mean only the surface on which the pavement is laid, and subgrade category refers to the overall bearing capacity of everything underlying the said surface.

Ground lying under port fills generally consist of existing material, which in most cases cannot be replaced even where it is composed of loam with a very low bearing capacity. With regard to fills, far from the usual requirements for highways and railways, the nearest available material is used, which may consist of dredgings; further, it is practically impossible to compact such material, and even today consolidating techniques are less common than might be desired. Finally, the capping layer is often non-existent, although this document advocates the use of rather thick, duly compacted high quality materials as indispensable to ensure an acceptable pavement support.

4.2. FILLS

This section discusses the minimum information on port fills required for pavement design. For further information on fill project and construction requirements, see *Geotechnical recommendations for maritime works* (ROM 0.5), included in the ROM programme.

4.2.1. CLASSIFICATION

Fills may be classified into two major groups: hydraulic and direct landfill (table 4.1).

4.2.1.1. HYDRAULIC FILLS

These fills are obtained by sedimentation of solid particles contained in dredged effluents, which are, in turn, characterised mainly by outflow and suspended solids content.

In general, the procedure consists of pouring a stream of water with suspended solids in a relatively water-tight enclosure. The water is drained off through a spillway placed at one end of the enclosure as far away from the inflow point as possible, so that in between, the suspended solids sediment out. The fine particles accumulate near the spillway, from where they are extracted providing there are no restrictions (e.g., environmental).

TABLE 4.1. CLASSIFICATION OF PORT FILLS

KIND OF FILL	CLASSIFICATION
HYDRAULIC	Fines under 10 %
	Fines from 10 to 35 %
	Fines over 35 %
DIRECT LANDFILL	With land materials
	Granular fills
	Cohesive fills
	Clean rockfills
	Dirty rockfills
	Anthropic and unconventional

Hydraulic fills are possibly the most cost-effective in most cases. As in all port fills, the high settlement consolidation and low bearing capacity are due more to the foundation (where composed of thick layers of loam) than to the fill itself.

Depending on fines, i.e., material passing the 80 µm sieve (approximately No. 200 ASTM) hydraulic fills can be classified as follows:

— Fines under 10 %: They constitute good fills if the surface is kept relatively smooth to avoid the accumulation of lime and clay.

— Fines between 10 and 35 %: Very compressible fills, but consolidation can be expedited by building alternating layers of the material and sand.

— Fines over 35 %: Very compressible and soft fills, in which consolidation is slow and difficult.

4.2.1.2. DIRECT LANDFILL FILLS

This name refers to the way the fill is built, either with barges or from land. One variation of this system is the use of hinged barges for the landfill. In this case, although the capping layer is not reached and the fill may contain a large portion of fines, it is possible to reach a height 3 to 4 m below high tide.

Depending on the materials used, the following types can be distinguished:

— Land material fills: This type covers products obtained from land borrow pits such as clearing excavations, underground works or foundations. They may be classified as follows:

- Granular fills: Comprising gravel or sand, or a mixture of the two, taken from land borrow pits and with fines not over 35 %.
- Cohesive fills: Cohesive fills, strictly speaking (clays, clayed silt) are never desirable, but they may sometimes be inevitable due to the absence of other materials. However, the reference here is, in particular, to material with limited plasticity, such as the kind which can be used in highway embankment cores.
- Clean or open-graded rockfills: Consisting of rock blocks with a small fines content. They are not usually found in fills, but are used for dikes, foundation banks for gravity docks and in various kinds of enclosures, and as such may form part of a fill.

- Dirty rockfills: Consisting of high quality rock blocks with high fines content (for example, unclassified quarry material) or of low quality rock blocks that would not be acceptable for exterior rockfills. They are often used in pile dock back fills. Depending on their quality, they may or may not be protected by filter layers.

— Unconventional anthropic fills. Anthropic fills are made by waste materials, essentially refuse and solid urban waste. The great heterogeneity of these materials makes their use unadvisable in principle, but they constitute a far from negligible alternative when other fills are not available at reasonable cost. Organic waste should, however, be banned altogether.

Foremost among unconventional fills are those made up of industrial subproducts or waste, particularly slag and fly ash. The most common slag comes from the steel industry, either from blast furnaces (crystallised slag, as granulated slag is used for other purposes) or steelworks. The fly ash, in turn, comes from coal-powered thermal power plants. Both kind of material provide excellent fills, which improve with time due to the presence of puzzolanic compounds. Where slag is used, the capping layer may even be eliminated, providing that the free lime content is controlled in materials that are to be placed above sea level.

Certain problems may arise, in particular in connection with anthropic fills, but with unconventional fills as well, such as:

- physical, chemical and/or biological pollution of the marine environment due to leakage of uncontrolled elements and accumulation of such elements in undesired places. Solutions that prevent pollution of the physical environment should be considered in these cases;
- important changes in volume due to expansivity of certain subproducts (steel slag, for instance);
- excessive deformability, since the landfill compaction is usually not monitored, except above sea level; this problem, which is common to any kind of marine fill, is all the more serious when anthropic materials are involved, because they tend to be more deformable than other conventional materials with an analogous grain size;
- heterogenous behaviour leading to heterogeneity of applicable solutions.

4.2.2. CONSOLIDATION TREATMENTS

In most cases, the quality of recently built fills is not sufficient for use as the foundation for a permanent pavement. Port fills, given their varying nature, generally low bearing capacity and extension over relatively large areas, call for land improvement techniques where a permanent pavement is to be built in any reasonable period of time. However, it must be stressed that expected settlements are due as much to the nature of the fill foundation as to the fill itself. In any case, such settlements, when they occur unevenly, cause not only unacceptable pavement deformation, but also sudden changes of level in docks, which in turn cause problems in the fill.

The most suitable techniques in each case depend on the type and characteristics of the fill. The designer must, then, know the nature of the fill and estimate the grade of compaction or consistency to be expected after the fill has been built, so as to be able to determine whether or not it is actually necessary to improve its characteristics, and to what extent. One of the most important facts to know is the depth of the fill, which is a determining factor in the effectiveness of the method to be used.

When considering granular fills, relative density is of utmost importance, as the strength, deformability, compressibility and susceptibility to liquefaction of such fills depend almost exclusively on that parameter. The idea, in these cases, is to increase the relative density as much as necessary.

For cohesive fills, the parameters to be determined are plasticity and state conditions (dry density and water content). Other information of interest is their undrained shear strength, oedometer modulus and consolidation coefficient.

It is important to bear in mind the effect of fill treatment on the consolidation of the fill foundation. Likewise, a comparative study should be run on the costs of the different treatments and on their cost-effectiveness. The decision to use a given kind of treatment should be based on such analyses.

4.2.2.1. KINDS OF TREATMENT

A first possibility is to wait and do nothing with the fill until settlement reaches the desired values. This may be a very long process.

A second alternative is to use a provisional pavement and carry out the port operations for which it is designed. This would improve the fill and expedite settlement due to the effect of these operations.

Thirdly, some techniques may be employed which, while not consolidation techniques *per se*, help to equalize fill characteristics, leading to more even settlement; this would be the case of passive, traditionally wood, pile sinking.

The possible alternatives for the cases where it is decided to accelerate fill consolidation are discussed briefly below and dealt with in greater detail in ROM 0.5.

4.2.2.1.1. PRELOADING

If it is felt that the fill is going to be excessively deformed due to service loads, it is possible to cause such deformation in advance with elements that will not be damaged thereby, normally earth, steel plates, etc. Thus, fill deformability under future loads will be much reduced. Preloading can be shortened by using vertical drainage.

Preloading is definitely the most common consolidation treatment, since it is highly cost-effective and has a consolidating effect on the fill foundation.

4.2.2.1.2. DYNAMIC COMPACTION AND REPLACEMENT

Dynamic systems are based on subjecting fills to a large number of stress-shear cycles or to densification by introducing certain volumes of supplementary material. This increases fill rigidity and strength. Dynamic compaction consists of dropping a weight from a given height: each impact produces a compression wave which is transmitted through the fill at the speed of sound generating compression and tension; in replacement processes, in addition, material is removed at certain points and replaced by other, high quality material.

4.2.2.1.3. VIBROFLOTATION

This method consists of pushing a cylindric vibrator, that generates horizontal vibrations, down into the fill mass. Penetration is aided by injecting water and air. Once the desired depth is reached, vibroflotation *per se* is carried out in consecutive layers from the bottom up while supplementary material is piled around the mouth of the hole so that as much of it can be absorbed as needed. This material enters the hole via the ring formed between the pipe and the hole walls. Grids with one point every 4 to 12 m^2 are usually employed and the variables to be considered are the speed of descent and vibration time and frequency. The major advantages to this method are:

— It is feasible in standard practice to depths of approximately 15 m.
— It ensures even compaction throughout the entire depth.
— In addition to vibratory compaction, the fill is improved due to the addition of better quality material.

The various types of vibroflotation are:

— Vibrocompaction: This method is recommended for clean and loose granular fills. It is generally accepted that the maximum fines content compatible with the process is 18 %. For higher contents, a uniform stone fill several centimetres in size must be added. Spacing between vibrocompaction points usually ranges from 1,8 to 3 m, and the relative density achieved is on the order of 70-80 %.

— Vibrosubstitution: Used to form stone columns in soft cohesive fills, where fill is removed by a flow of water and replaced by the supplementary material.

— Vibrodisplacement: Used to form stone columns in moderately soft cohesive fills in which the vibrator bores a stable hole. Generally a cohesion value of at least 20 kN/m^2 is required to ensure stability of the upper part of the walls of the stone columns.

— Dynamic compaction with gravel columns: this system performs the double function of compressing the fill and draining any existing water.

— Vibratory penetration: This method consists of sinking a metallic profile (sheet piles) hung from the vibrator into the fill. The profile is pushed down to the desired depth, kept there for a given amount of time and then withdrawn, while vibrating at all times.

4.2.2.1.4. CONSOLIDATION THROUGH BLASTING

This is done by blasting inside the fill so the waves affect its structure or surface, increasing its consistency. It is used for fine silty cohesive sand.

There are essentially three ways to proceed in this kind of consolidation:

— Planting the charges on the seabed (when the fill is under water).
— Placing the charges in holes drilled in the fill.
— Placing the charges at a given depth under the fill surface.

4.2.2.1.5. JET-GROUTING

This is an injection technique involving in-depth treatment of fill material to form columns of improved material or to replace such material with other products. The treatment is performed from the bottom up, injecting cement grout. The procedure is fast and versatile and is particularly recommended for granular materials.

4.2.2.2. FILTERS AND ANTIPOLLUTION LAYERS

Filters are used to prevent the removal of fine particles when water passes through the fill: the gradients caused by tidal range or currents may be high and may carry fines away with them, thus weakening the structure and causing surface undermining.

Fills only rarely meet self-filtering requirements that ensure stability, since the intermediate sizes, needed to ensure such self-filtering, are generally lacking. This can be verified by dividing the fill grading into two parts, arbitrarily: larger and smaller than a given size (1 mm, for instance). The coarser particles should be able to filter the finer ones. If the material does not meet this requirement it must be protected with filter or at least transition layers, as in standard practice in protecting breakwater cores.

Installation of filters inside fills is difficult and its effectiveness is seldom guaranteed. In fills with a high fine content these layers can be replaced by geotextiles that make for good filters, although installation is likewise difficult at times. In any case, geotextiles should not be used where there are stones over 20 cm in size, unless they have a puncture-proof geogrid web.

Moreover, it is advisable to include antipollution layers between the fill and the capping layer in order to prevent fines from seeping up and eventually eliminating the capping layer.

4.3. SUBGRADES

4.3.1. DEFINITION

The use of dredging material to build a fill leads, especially in the consolidation phase, to an accumulation of fines on the surface. These fine particles are very difficult to eliminate and severely hinder travel of construction equipment. Capping with high quality material that is gradually pushed over the top of that surface makes for a suitable working platform. Some of the capping materials seep into the fill, facilitating load support. Moreover, the capping layer is often the only element that is always above sea level.

The subgrade is, by definition, the surface of the capping layer on which the pavement lies. This capping layer should be at least 1 m thick (difference between subgrade elevation and fill elevation before the construction process is begun), and spread in layers no more than 40 cm thick; in any case, the thickness of these layers should decrease with the quality of the material used.

The quality of the subgrade, in terms of bearing capacity, depends largely on the materials used for the capping layer and the degree of compaction achieved when laid, although it also depends, as indicated with respect to fill specifications, mainly on the degree of fill consolidation and homogeneity achieved.

4.3.2. MATERIALS

The materials used for capping layers should be soils of an average quality (such as embankments used for instance in highway construction) or ungraded quarry material. Materials of lesser quality may also be used, although they have to be stabilised or improved.

4.3.2.1. ADEQUATE SOILS

Such soils contain no particles over ten centimetres (10 cm) in size, and less than 35 %, by weight, passes the 0,080 mm sieve. It liquid limit is under forty (LL<40). Maximum standard Proctor density should not be under one tonne seven hundred fifty kilogrammes per cubic metre (1,750 t/m^3). The CBR index should be over five (5) with swelling under two per cent (2 %). The organic content is less than one per cent (1 %).

4.3.2.2. SELECTED SOILS

Such soils have no particles over eight centimetres (8 cm) in size, and less than 25 %, by weight, passes the 0,080 mm sieve. Its liquid limit is under thirty (LL<30) and plasticity index less than ten (PI<10). The CBR index should be under ten (10) and no swelling should occur during the test. They should be free of any organic material.

4.3.2.3. UNGRADED QUARRY MATERIAL

This material consists of an unclassified mix of coarse and fine materials from quarry operations from which particles larger than 50 % of the thickness of the layer (and in any case, those over 20 cm) have been removed. They provide important advantages deriving from their structure: they constitute an excellent work platform, transmit loads to the fill effectively and have antipollution qualities.

4.3.2.4. SELECTED SOILS WITH CBR>20

These are soils that meet the specifications for selected soils and have a CBR of over twenty (20).

4.3.3. IMPROVEMENT OR STABILISATION TECHNIQUES

Where material of a given quality is not available (at least adequate soils), others of a poorer quality may be used for the capping layer, providing they are subject to improvement or stabilisation processes, usually with lime or cement.

Improvement or stabilisation of a soil with lime or cement is the in place mix, duly compacted, of soil, lime or cement, water and occasionally other additives, which must meet certain requirements regarding insusceptibility to water, strength and durability.

Improvement and stabilisation differ only in the degree of change achieved with respect to the original material. Normally, in improvement processes the amount of binder used is around 2-3 % of the dry weight of the soil; in stabilisation processes, a much larger percentage may be necessary, although it is usually on the order of 3-5 % for reasons of economy.

Lime is more appropriate when the soil has a high plasticity index and especially if it has a high water content, greater than that needed for compaction, since one of the major effects of lime is that it increases optimum compaction water content. In soils with a low plasticity index, on the contrary, the use of cement is much more effective. On occasion, both binders are used: lime is added in a first stage, which reduces plasticity and causes soil granulation. Some time later, cement is added as a second stage.

4.3.4. SUBGRADE CATEGORIES

Several aspects must be considered when determining the category of a subgrade as a pavement foundation: nature of the fill, degree of consolidation, and material used in the capping layer.

Six fill categories are established:

— Poor unconsolidated fills (PU): Hydraulic fills with high fines content (> 35 %) or anthropic fills not subject to any kind of consolidation treatment.

— Poor consolidated fills (PC): Ditto, but subject to some kind of consolidation treatment.

— Average unconsolidated fills (AU): Hydraulic fills with fines content between 10 and 35 % or unconventional fills, not subject to any kind of consolidation treatment.

— Average consolidated fills (AC): Ditto, but subject to some kind of consolidation treatment.

— Good unconsolidated fills (GU): Hydraulic fills with low fines content (< 10 %) or fills with land materials, not subject to any kind of consolidation treatment.

— Good consolidated fills (GC): Ditto, but subject to some kind of consolidation treatment.

A fill is considered to be unconsolidated when the estimated settlement (following one of the procedures indicated in ROM 0.5) in the ten years following construction of the capping layer reaches a total of 0,10 m or more. Only provisional pavements are to be allowed on unconsolidated fills. Therefore, before a permanent pavement may be laid, total settlement in the next ten years must be shown to be less than the said 0,10 m.

Another factor which should be taken into account is fill homogeneity. It may be said that a fill is homogeneous when the estimated differential settlement is under 0,05 m over a distance of 10 m. However, as a first approximation, this parameter was not considered in the subgrade classification shown in table 4.2, which, following a more conservative criterion, takes fills to be non-homogeneous as this is usually the case.

The various possible circumstances with regard to the capping layer are:

— No capping layer. Not at all recommended (not even viable in most cases); acceptable for provisional pavements only, in which case it is advisable to use filter or geotextile layers between the subgrade and the lower layer of pavement.

— Capping layer with adequate soils (or others with poorer characteristics but improved with lime or cement so that the mix meets standard soil requirements).

— Capping layer with selected soils (or with adequate soils or soils with characteristics poorer than adequate soils stabilised with cement so that the mix meets selected soils requirements).

— Capping layer with selected soils with CBR > 20 (or with adequate soils or soils with characteristics poorer than adequate soils stabilised with cement so that the mix meets requirements for selected soils with CBR > 20).

— Capping layer with ungraded quarry material

A combination of the different kinds of fills and capping layers circumstances leads to the classification of port subgrades in four categories:

— Unsatisfactory subgrade	E0
— Satisfactory subgrade	E1
— Good subgrade	E2
— Very good subgrade	E3

Classification of subgrades for port pavement design is based, in principle, on the contents of table 4.2, which is meant to be used as a general guideline only. Ultimately, subgrade classification should be based on the results of plate-bearing tests.

Table 4.3 shows the minimum values required for the compressibility modulus E2 obtained during the second load cycle of the plate test, as well as the maximum values for the E_2/E_1 ratio, where E_1 is the compressibility modulus obtained during the first load cycle (while E_2 can be used to assess bearing capacity at the depth affected by the bulb of pressure under the plate, the E_2/E_1 ratio provides an indication of the degree of compaction reached in the capping layer).

If the minimum compressibility modulus indicated for the pre-established subgrade category is not obtained, measures should be taken to reach that objective Otherwise, the subgrade should be assigned the category corresponding to the modulus value actually found.

An attempt should be made in any case to reach the highest possible subgrade category, consolidating fills and, as appropriate, subjecting the capping layer to improvement or stabilisation treatments. The higher the traffic category, the more important these measures and procedures are.

TABLE 4.2. SUBGRADE CATEGORIES

CAPPING LAYER	(*) PU	(*) AU	(*) GU	PC	AC	GC
Adequate soils	E0	E0	E0	E1	E1	E1
Selected soils	E1	E1	E1	E1	E2	E2
Ungraded quarry material	E1	E1	E1	E2	E2	E3
Selected soils with CBR > 20	E1	E1	E2	E2	E3	E3

NOTA:

(*) In these cases, only provisional pavements may be laid.

TABLE 4.3. SUBGRADE CATEGORIES. BASED ON PLATE-BEARING TEST RESULTS

CATEGORY	MIN. E_2 (MPa)	MAX. E_2/E_1
E1	25	2,0
E2	35	2,0
E3	55	2,0

PART 5 PAVEMENT MATERIALS

PART 5 PAVEMENT MATERIALS

Contents

PART 5 PAVEMENT MATERIALS

The materials most commonly used for the various courses of port pavements are presented, together with a brief description of their fundamental characteristics, advantages and drawbacks for each situation.

5.1. MATERIALS FOR SUBBASES AND BASES

The following is a brief discussion of the characteristics of the various materials that may be used as subbases (laid directly on the subgrade when the quality of the latter is insufficient) and bases (laid underneath the surfacing). This discussion attempts to include all possible options, although only some of them are directly considered in the catalogue of pavement structures.

5.1.1. GRANULAR SUBBASES

This course, located between the pavement base and the subgrade, is not always present. In port pavements the subbase is usually a continuous grading granular course made of materials taken from gravel pits and used as is *(ungraded)* or after slight modification of the grading, eliminating the coarsest particles or some of the finest ones (unbound granular material).

Wherever possible, the use of industrial by-products or waste should be considered; crystallised blast furnace and steel slag are particularly advisable, in the latter case after the lime has been slackened after storage.

5.1.2. GRANULAR BASES

The base is the course on which the surfacing rests and is located above the subgrade or subbase where there is one. There are two kinds of bases, depending on the materials used: granular bases and bases treated with bituminous, hydraulic or puzzolanic binders.

Granular bases are composed of totally or partially crushed aggregates with continuous (wet mix macadam) or uniform (dry bound macadam) grading. Today wet mix macadams are more commonly used, although this does not mean that the traditional dry bound macadam technique should be disregarded.

The use of slag and other waste materials should also be considered here, as in the case of subbases, in this case after grinding to ensure the proper particle angularity.

5.1.3. CEMENT STABILISED SOIL

This material is a plant mix of selected soils, cement, water and in some cases additives.

Contrary to the materials discussed below, which are used almost exclusively in bases, cement stabilised soil can be used either in the base or subbase course.

5.1.4. CEMENT BOUND GRANULAR MATERIAL

This material is a plant mix of good quality aggregates, cement, water and in some cases, additives. The aggregates are wholly or partially crushed and have a continuous grading. The maximum size of the aggregate should not be over 25 mm to prevent segregation and the percentage of non-plastic fines passing the 0,080 mm sieve should be small. The aggregate matrix of a cement bound granular material is actually a wet mix macadam. The cement content usually ranges between 3,5 and 5 % of the aggregate weight; the water content, in turn, usually varies from 4,5 and 6,5 %, to allow for rolling.

5.1.5. GRAVEL-SLAG MIX

This mix is based on the same principle as cement bound granular material. The binder is granulated blast-furnace slag in doses, depending on reactivity, from 10 to 20 % of aggregate weight. As this is a puzzolanic binder, a setting agent must be added (normally lime, 1 % of aggregate weight). There is a special kind of gravel-slag mix composed of a crystallised blast furnace slag aggregate *(slag-slag mix)*.

Although this material has several advantages over cement bound granular material (due essentially to its much longer workability period, its spreadability in various thicknesses, and a closer relationship between flexural strength and stiffness modulus), it can only be used as an alternative within distances of about 100 km from the plants producing slag.

5.1.6. GRAVEL-ASPHALT EMULSION MIX

In this case a slow ageing bituminous emulsion, usually with under 3 % of asphalt binder, is used. Cationic or anionic emulsions are used depending on the kind of aggregate. Although its strength is lower than for cement bound granular material, it has advantages over such material, such as the fact that it does not crack due to shrinkage and it can be spread in a wide range of thicknesses.

5.1.7. LEAN CONCRETE

There are two techniques in connection with this material, differing basically with respect to placing procedures and hence to the water content required for each. The first technique considers it to be a cement bound granular material with a higher than normal cement content and it is consequently rolled into place. The second considers it to be a concrete with a lower than normal cement content (about 150 kg/m^3, as opposed to the 300 kg/m^3 or more in traditional concrete), and it is applied on site by vibration.

5.2. MATERIALS FOR SURFACING

The following is a brief discussion of the various materials that can be used for surfacing. They vary widely with regard to utility in ports, since while some of them - vibrated concrete, for example - can be considered to be of great importance for port pavements, others, such as leached pavements, for instance, can only be applied in certain special circumstances. Nonetheless, all possible options have been included, even though only some of them are directly considered in the catalogue of standard pavement structures.

5.2.1. VIBRATED CONCRETE

These pavements are composed of slabs of varying thickness, that may range from approximately 0,15 to 0,40 m. Their surface area is about 5 x 5 m^2, and although the thickest ones may be built somewhat larger, the area should never be more than 25 times the thickness. It is deemed in these Guidelines that slabs less than 0,20 m thick should not be used, because smaller thicknesses prove to be very critical under heavy loads.

Concrete composed of suitable aggregates, a minimum of 300 kg/m^3 of cement, a relatively low water/cement ratio (under 0,5) and additives as required, is mixed, spread, vibrated and cured to achieve a homogeneous, flexurally strong and wear-resistant material.

Flexural strength, as opposed to compressive strength, is the main characteristic of pavement concrete than compressive strength, although approximate correlations may be established between the two. Except in access lanes, which should follow the recommendations contained in Instruction 6.1 and 2 IC on pavement structure, designers should tend to use HP 40 type concrete, i.e., with a 28-day characteristic flexural strength of 4 MPa. Where HP 35 type concrete is used (that is to say, with a characteristic flexural strength of 3,5 MPa), the decline in strength should be compensated by increasing thickness by 0,03 m.

Nonetheless, it must be made clear that it is not only a matter of ensuring sufficient slab flexural strength, but rather that a higher characteristic concrete strength is the only guarantee against deterioration due to punching (in container bay areas, for example) and surface disintegration (due for instance to caterpillar vehicle traffic).

Where flexural strength can not be determined, and from the standpoint of information only (not to be taken as an assumption on actual equivalences), HP 40 concrete can be replaced by an H 300 concrete (28-day compressive strength of 30 MPa) and HP 35 concrete by H 250 (28-day compressive strength of 25 MPa).

On highways and lanes intended for heavy, high-volume and channelised traffic, the concrete slabs must be laid on a non-erosionable base to prevent pumping of fines at the joints. In port surfaces the support may consist of a granular course or even the subgrade itself if it meets quality standards (E3). Naturally, this calls for good support levelling and evenness, so where this cannot be guaranteed a levelling course must be added, which would also act as a filter.

Placing may be carried out using relatively manual procedures, spreading the concrete between planks or other kinds of formwork and compacting it first with internal vibrators and later with vibrating beams. A higher quality is nonetheless attained if mechanised methods are used, such as slip-form pavers. Where concrete is laid by strips, a few hours after laying (normally 6 to 18) when the concrete is hard enough, the transverse contraction joints (and the longitudinal joints where the concrete strips are over 5 m wide) are sawn.

The major advantages to these pavements are as follows:

- They resist high contact pressures.
- They offer an excellent surface for port vehicle traffic.
- They are skid-resistant.
- They do not usually suffer permanent deformation, making them very suitable for heavy vehicle traffic.
- The surface is not weakened by spills of oil, gasoil or other similar products, nor by high temperatures.

5.2.2. ROLLER-COMPACTED CONCRETE

These are plain concrete pavements with low water content (the water/cement ratio is 0,35 - 0,40) which, like cement bound granular material, must be vigorously compacted with vibrating and rubber-tyre rollers. The cement content, however, is similar to the cement content in vibrated concrete for pavements (300 kg/m^3, at least), and normally type V cement with high fly ash content is used.

Possibly the most important feature of this kind of pavement is that special machinery is not needed for construction and, due essentially to its aggregate structure which is in itself sufficiently resistant (using totally or partially crushed material), it can be open to traffic immediately, thus avoiding the usual period required for vibrated concrete. However, the surface of this pavement may be less even than vibrated concrete surfaces.

If it is feared that traffic may induce surface disintegration, roller-compacted concrete may be protected with some kind of surface dressing; in port pavements where vehicles circulate at relatively low speeds a float finish may suffice. However, such pavements require a support with sufficient bearing capacity so the concrete may be effectively compacted.

5.2.3. REINFORCED CONCRETE

The purpose of the reinforcing bars in pavements is normally to tie the shrinkage cracks together. A particular case is the heavily reinforced concrete (floor slabs) that may be employed for container stacking bays where a full guarantee against failure is desired.

5.2.3.1. JOINTED REINFORCED CONCRETE PAVEMENTS

The fundamental purpose of the reinforcing bars in these pavements is to tie the transverse cracks that inevitably appear in long slabs (8 to 30 m). This ensures transmission of loads in cracks, reduces water and fines seepage and prevents widening of cracks under traffic. It may be considered to be an old-fashioned technique with more drawbacks than advantages, which in no way compensate for the higher cost involved. With rare exceptions, it should not be considered as a pavement alternative.

5.2.3.2. CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

Transverse contraction joints are eliminated in these pavements, thanks to the increase - to values up to 0,7 % - in steel to total section by longitudinal reinforcement bars of high yield strength steel. Many cracks smaller than 0,5 mm wide appear, usually at 1- to 3-m intervals, which are practically imperceptible and which do not deteriorate under traffic. In port pavements this kind of paving may be of interest for heavier traffic because the reinforcement substantially reduces maintenance. Further, slab thickness can be somewhat smaller (4 to 5 cm), although this does not offset the cost of the reinforcement bars.

5.2.3.3. REINFORCED CONCRETE FLOOR SLABS

In this case, reinforcement bars are arranged to resist bending stresses caused by loads. Design should follow the criteria set out in EH-91.

5.2.4. FIBRE-REINFORCED CONCRETE

Appropriate proportions of steel fibre are added to the concrete to improve the physical and mechanical features of traditional concrete pavements. The most effective kind of fibre for this kind of pavements is made from wiredrawn steel, with hook ends configured to ensure better anchorage to the concrete. The fibres should be comb-tied to prevent lumping in the concrete mix. Fibre-concrete workability declines with length/diameter ratio; when the fibres are comb-tied the equivalent diameter is greater and as a result, workability increases. Fibre tensile strength should be approximately 1 200 MPa and the dosage should not be under 30-40 kg/m^3.

The major advantages to this kind of pavements with respect to plain concrete are:

- Greater strength, especially bending strength, and greater dynamic fatigue resistance, so the slab thickness can be reduced.
- Greater impact strength, so it is especially recommended for scrap metal handling areas.
- Greater surface fretting resistance.
- Shrinkage stresses are absorbed and distributed better, so joint spacing can be increased by 50 %.
- Enhanced durability thanks to a smaller degree of cracking.

5.2.5. PRECAST CONCRETE SLABS

These square or rectangular slabs have high compressive strength (on the order of 40 MPa). They are often reinforced and may even be equipped with a protective angle surround; their size ranges from 1,5-3 m per side and 0,16-0,18 m thick. In general, the results obtained have been frankly poor, due particularly to the fact that the surrounds tend to come loose, causing damage to vehicles. Plain concrete blocks 0,25 m thick with an area of 2 m^2 (1,41 per side) have shown better performance.

The major features of this material (in addition to the general characteristics of all concrete surfaces) are as follows:

- It adapts to possible settlements.
- Access to underground services is relatively straightforward.
- Relative ease of repair and rehabilitation.
- The elements can be theoretically be re-used, although in practice this is not such an easy matter.

As in the case of pavers, surfaces paved with precast slabs may, if bevel-edged, have a substantial megatexture, and therefore riding on them at moderate to high speeds may be uncomfortable. Moreover, in some cases deformation of the edges may aggravate the situation, and even more so where the angle surrounds come loose.

In any case, for a successful precast slab pavement, the thickness chosen must be sufficient (never smaller than recommended), and the concrete must be sufficiently strong (never under H-300).

5.2.6. CONCRETE BLOCK PAVING

Concrete blocks are precast elements of a size that enables them to be laid manually. They vary in shape, while usually simply rectangular. They can adapt to possible settlements. Transmission of vertical loads among the blocks is essential to ensure proper behaviour and is achieved by means of the sand that fills the joints. To ensure the response to horizontal stress, the paving must be laterally contained by rigid elements. The sand in the joints and paving layout also have an effect on this response.

With regard to the cross-section, the pavers are usually laid on granular bases with a low fines content (sometimes on cement-treated courses: cement-stabilised soil, lean or low-strength concrete), with an intermediate levelling course of clean compacted sand 3 cm thick. In any case, measures must be taken to prevent weak spots (and in general excessive surface deformation), by ensuring the drainability of the underlying courses and using water-resistant material.

This kind of pavement shares many of the same characteristics of concrete surfaces, with the exception of resistance to deformability, which is much higher in block-paved surfaces. It has, in addition, other characteristics, such as:

- Surface drainability
- Direct access to existing services.
- Ability to carry static and dynamic loads, withstand impacts and very heavy point loads without major deformation or failure.
- Ability to adapt to fill settlement where this occurs.

A disadvantage to pavers, due to the fact that they have close joints, is their high megatexture, making them very noisy under traffic at high speed. On port surfaces this is of relatively little importance, since traffic is usually quite slow; furthermore, the noise level drops where high quality blocks with an excellent surface are used and properly laid.

A possible drawback to block-paved surfaces is that underground water currents may undermine the support provoking localised subsidences. A possible solution may consist of substituting a low-strength concrete (H-175, for example) slab with a minimum feasible thickness, on the order of 15 cm, for the granular base or cement-treated course. This, however, entails greater expense and forfeiting the great advantage that such supports offer with respect to accommodation to ground movement. If such subsidence due to undermining is expected to occur, a good alternative would be to use granular bases with a low fines content.

Due to probable accumulation of filth in the joints of block-paved surfaces, such pavements are not recommendable in bulk solid storage areas.

Irrespective of the above, the high cost of pavers is usually considered to be their major drawback. It should be borne in mind that this situation is tending to change, as has already occurred in other European countries, as the number of paver manufacturers complying with strict quality standards increases. Moreover, laying methods have been developed that increase construction efficiency and reduce labour costs.

5.2.7. PAVING STONES

Paving stones are the predecessors to concrete pavers. Today they constitute a very costly pavement offering very few technical advantages. They may only be considered for aesthetic reasons for use in pedestrian walkways and certain auxiliary areas. In any case, a high quality, carefully cut stone must be used, since otherwise the megatexture is uncomfortable even for pedestrians.

5.2.8. ASPHALT PAVEMENTS

The basic types of this kind of pavement are as follows:

- Surface dressings, consisting of either spread chippings (normally with bituminous emulsions) or slurries (by definition, always with bituminous emulsions). While the former are often used on granular courses in provisional pavements, the slurries can also be used in permanent pavements to achieve certain surface characteristics.

— Open cold-mixed materials (made with bituminous emulsions), in relatively small thicknesses: 4-8 cm. Used either as provisional pavements or as permanent pavements carrying light traffic.

— Dense hot-mixed materials (made with penetration bitumens), such as asphalt concrete. In pavements intended for heavy traffic, due to their strength characteristics, the overall thickness should not be under 15 cm, and in some cases may even reach 35 to 40 cm.

Should it be decided, in certain port areas, to use asphalt pavements for permanent surfacing, the limitations to this kind of material should be borne in mind:

— Plastic deformation may occur where slow speeds and heavy loads are involved.
— Low resistance to high contact pressures (making them highly unrecommendable for container stacking and roll-trailer storage areas).
— Where oil, gasoil or other similar products are spilled, the bituminous binder slowly dissolves, and the pavement disintegrates and may be carried away.

On the contrary, asphalt pavements offer certain advantages: they are versatile, easily laid, adaptable to support settlement and in the case of surface dressings and thin layer mixes, they are easily rehabilitated and reinforced, etc. In any case, they should be considered as a basic alternative in access lanes, where the conditions indicated in the preceding paragraph do not usually occur.

5.2.9. LEACHED PAVEMENTS

These pavements comprise a compacted, roller-vibrated course, approximately 40 cm thick, of coated macadam without fines, to which a slurry, usually cement with resins, is added and roller vibrated; after rolling it must be let lay until it reaches the required strength.

Leached pavements are used where a pavement is needed that is more flexible than concrete and yet resistant to temperature changes, oil spills and/or punching. They are, however, susceptible to tensile stress that may appear on the underside of the course. Pavements of this kind, because of their anti-absorbent and skid-resistant qualities, can be used in fishing areas (particularly in fish markets).

5.2.10. GRAVEL BEDS

These areas, limited by a concrete kerb, are intended exclusively for container stacking, so the handling equipment travels outside the bed (therefore, on some other kind of pavement or on the corresponding beam rails in the case of portal cranes). Inside, the beds are composed of a course of single graded crushed gravel, 0,35-0,40 m thick, laid on a support course and duly levelled and compacted. The maximum nominal size of the aggregate should not be more than 50 mm, with a Los Angeles coefficient not greater than 30.

The strength of these pavements lies in the angularity and abrasion resistance of the aggregates used and in the lateral containment imposed by the concrete kerb. These surfaces have excellent drainability and, due to their unevenness, excellent distribution of the loads applied by the containers. The major drawback is that they are highly inflexible from the operations standpoint, as they are practically unfeasible for any other kind of use.

Steps should be taken to ensure that fine particles from the pavement foundation or surrounding areas do not contaminate the gravel bed. Consequently, they must be checked for compliance with filtering requirements; if they do not meet them, a geotextile fabric should be placed in between these two layers. Moreover, when the ground is not sufficiently permeable, underground drainage systems are indispensable to drain off the water filtering in through the gravel bed.

The only maintenance required, depending on use rate, is re-levelling after several months of use. Such activities should be strictly scheduled, to ensure that disturbance of port operations is kept to a minimum.

5.3. FINAL COMMENT

The choice of one or another material for pavements should be based on the analysis of technical characteristics, weighing advantages against drawbacks. In this regard, it should be borne in mind that the various port surfaces have different requirements, and therefore, the solution for one may differ widely from the solution for another. Furthermore, it is important not to lose sight of the fact that in the final analysis, the actual durability and overall cost of the pavement structure in question should be decisive; i.e., in addition to an analysis of building costs, some estimate should be made of maintenance and rehabilitation costs.

PART 6 STRUCTURAL DESIGN OF PORT PAVEMENTS

PART 6 STRUCTURAL DESIGN OF PORT PAVEMENTS

Contents

PART 6 STRUCTURAL DESIGN OF PORT PAVEMENTS

The procedure to be followed to establish the most appropriate structural design in each case with the aid of the catalogue attached to these Guidelines is discussed here. Annex A contains a description of the structural design methods that serve as a basis for the catalogue.

6.1. INTRODUCTION

In some port pavement projects, the selection of handling equipment is considered separately from the selection of the pavements themselves, so that even though the main objective is to ensure that such pavements stand up under the effect of the selected port equipment used without becoming seriously deteriorated, such damage may in fact occur only a short time after the pavement is in operation. It is, therefore, advisable to consider jointly the selection of equipment and pavement, but this should nevertheless be done in such a way that changes in the kind of equipment used, within a given reasonable range of variation, should not necessarily entail re-paving. Therefore, pavement and handling equipment should be considered together as inter-related parts of the port operation.

In selecting a complete system the designer should bear the following aspects in mind:

— Handling equipment to be used.
— General characteristics of such equipment.
— Loads applied by each kind of equipment under working conditions.
— Use of each kind of equipment during design life.
— Possible pavement structures.
— Adaptation of pavement to working conditions.
— Surface characteristics required.
— Available funding.

Under this approach the result is a series of combined systems of equipment and pavement which should be analyzed on the basis of overall economic cost and resources available. This evidently requires a knowledge of both engineering and port operational aspects. In short, this process calls for joint consideration of pavement selection and port operation parameters: handling equipment, storage of the various kinds of merchandise, etc.

Pavements are dimensioned to withstand a design load applied at a given use rate, so both parameters must necessarily be evaluated. It should be stressed that the largest design load is not necessarily the one that inflicts the greatest damage; rather it is the combination of heavy load and high use rate that leads to critical situations. This is what should be evaluated in the process.

6.2. STRUCTURAL DESIGN FACTORS FOR PORT PAVEMENTS

6.2.1. USE OF PORT SURFACE

The designer should be aware of the uses intended for the surface to be paved, since depending on such use, different kinds of handling equipment will be employed, and the surface will be subject to one or another kind of specific operation plan. Where such information is not available, the designer should consider the most unfavourable circumstances possible.

6.2.2. HANDLING EQUIPMENT

The following characteristics of the handling equipment to be used in port operations are needed.

- Total weight of each equipment type
- Total load it can handle
- Number of wheels and wheel load
- Tyre pressure
- Load applied to pavement
- Turning system
- Average speed of traffic
- Operational method

6.2.3. FILL CHARACTERISTICS

The kind of fill that has been used, as well as the characteristics of the fill foundation and the capping layer, essential to the choice of the pavement and in particular to decide whether a base or a subbase course should be laid.

6.2.4. CHARACTERISTICS OF AVAILABLE MATERIALS

The possibility of selecting a material on the basis of both availability and cost leads ultimately to the structural solution for the pavement.

6.2.5. DESIGN LIFE

The concept of design life is used here in accordance with the definition set out in ROM 0.2. It is equivalent to the definition used in the Spanish Highway Department's *Pavement Design Guidelines.*

Design life of port pavements is linked to the very concept of port development. It determines the number of operations which the pavement is expected to withstand while in service. The design life of permanent pavements is set at between 15 and 25 years, as this kind of infrastructure only needs to meet security level 1 standards (small risk to human lives or of environmental damage in the event of breakage) (See ROM 0.2).

In these Guidelines a design life of 25 years has been adopted as a working hypothesis for calculations and in general for permanent port pavements, as they are considered to be infrastructures of a general nature. According to ROM 0.2-90, where the pavement can be earmarked for a specific industrial use, the designer may reduce the design life to 15 years. For provisional pavements, in turn, a design life of 8 years has been adopted in general as a working hypothesis for calculations. Where the designer can foresee that the surface use will change or that the permanent pavement will be laid in less time, a design life of 3 years may be adopted.

6.3. CATALOGUE PRINCIPLES

6.3.1. INTRODUCTION

The main objective of port pavement structural design is to ensure that the pavement will remain in service during its entire design life, under a given load regime and use rate.

The specifics of port pavement structural design depends, firstly, on the quality of the fills and sea beds, and secondly on the following characteristics of port traffic:

- The wheel loads applied by merchandise handling and transport equipment are very heavy.
- The range of types and sizes of equipment and therefore of applied loads, wheel separation and pressure is very wide.
- Additional stresses due to impact, cornering, braking, surface unevenness, etc., may be very high, although this affects surface characteristics more than structural design.

— Often traffic areas are not delimited or channelled.

— Advance information on traffic composition and future trends is not readily available.

— The loads transmitted to the pavement by stored and stacked cargo are very heavy, as are those transmitted by some of the equipment that handles such merchandise.

The loads considered in port pavement design depend on the use to which the areas in question are put, since this determines the kind of cargo handling and transport vehicles that will be employed, as well as whether the merchandise will be stored in these areas, and ultimately the loads that may be applied and the total number of load applications.

Consequently, port pavement structural design requires that each project makes provision for the cargo handling and transport equipment that will affect the pavement to be laid (main characteristics and loads transmitted to the pavement by each type of equipment under the various working conditions). Furthermore, account must be taken of the way the various kinds of merchandise is stored or stacked. Finally, specific studies must be run to determine the use rate during the stage of the project subject to analysis.

6.3.2. DESIGN MODELS AND PARAMETERS

A computer program based on Burmister's hypotheses (see Annex A) has been used in all cases to determine, albeit in a preliminary manner, stresses, strains and displacements affecting critical points of the pavement structure under design conditions. Concrete pavements have also been checked with the aid of nomograms and simplified formulae based on Westergaards' hypotheses (likewise described in Annex A).

In all these calculations, the design conditions considered are as defined in Part 3, modelled according to the corresponding hypotheses, while the specifications of the materials are as shown in Annex A in keeping with the provisions of Part 7.

6.3.3. DESIGN CRITERIA

In the case of flexible materials (asphalt concrete and granular courses or subgrades), the analytical reference criterion used was the corresponding fatigue law. In cement concrete the reference criterion was that the flexural stress should not be greater than two thirds of the characteristic flexural strength. In some cases (container bays), punching resistance was also tested, following the method described in Instruction EH-91. Finally, in both cases the results obtained from analytical calculations were adjusted on the basis of existing experience and empirical criteria.

The solution proposed for container stacking bays, i.e., cement concrete pavement, is likewise based on empirical criteria, but it does not meet the theoretical requirements of the design model, so cracks may indeed be expected to appear in the pavement. However, such cracking may be considered to be an acceptable type of deterioration, compatible with operations, providing it occurs in areas reserved for container stacking only, and the Clients or Owners concur. In order to fully guarantee these concrete surfaces against all kinds of deterioration, reinforced concrete floor slabs must be employed following the criteria and procedures set out in Instruction EH-91; nonetheless, this solution is not generally recommended.

6.4. DESCRIPTION OF THE STRUCTURAL DESIGN PROCEDURE USING THE CATALOGUE

The structural design procedure proposed here is in keeping with the methodology discussed below.

6.4.1. SELECTION OF PORT SURFACE USAGE

The uses here considered are: commercial, industrial, military, fishing and recreational.

6.4.2. SELECTION OF AREA WITHIN THE USAGE CONSIDERED

The pavement should be specifically designed for a given area under the use in question. For example, under commercial use a distinction is made between the operations area, storage area, access lanes and auxiliary areas (table 2.1).

6.4.3. DISTINCTION BETWEEN STORAGE AND HANDLING LOADS

Once the use and port area for which the pavement is to be designed are determined, the storage loads (bulk solids, general cargo, etc.) and handling loads (due to handling equipment in port operations) (items 3.1.1 and 3.1.2, respectively), should be analyzed separately. Where both kinds of loads are transmitted to the pavement in the port area in question, a study is run for each and the one causing the most unfavourable situation (highest traffic category) is used for calculations. Where there is a permanent physical separation between the storage and traffic surfaces, the two situations are to be analyzed separately.

For provisional pavements, no differences are established between the various uses and areas, in principle at least, the only criterion considered being the compatibility between expected deformation and operation requirements.

6.4.4. DETERMINING THE DESIGN LOAD

In accordance with the criteria discussed in Part 3, the designer should classify the design load as low, medium or high (item 3.3).

6.4.5. DETERMINING THE USE RATE

The use rate should be classified as low, medium or high (item 3.4) in accordance with the port operation criteria defined in Part 3.

6.4.6. DETERMINING THE TRAFFIC CATEGORY

The traffic category is defined for each of the different areas studied under the use considered (table 3.3), on the basis of the use rate and design load classifications. Four traffic categories have been established:

Very heavy traffic	A
Heavy traffic	B
Medium traffic	C
Light traffic	D

6.4.7. DETERMINING THE SUBGRADE CATEGORY

The subgrade category to be considered in the design is chosen on the basis of the characteristics of the fill and capping layer on which the pavement is to be laid.

Four subgrade categories have been defined on the basis of bearing capacity, which is a result of the fill and capping layer characteristics:

Unsatisfactory subgrade	E0
Satisfactory subgrade	E1
Good subgrade	E2
Very good subgrade	E3

The subgrade category is determined in accordance with the methodology discussed in Part 4; it should be borne in mind that category E0 is only acceptable for provisional pavements.

6.4.8. SUBBASE AND BASE COURSES

The decision to lay a base or a subbase course depends on the subgrade category found. Thus, the following four possibilities may be considered:

E0 subgrade: a 0,40-m subbase consisting of a course of unbound granular material as well as a 0,25-m base consisting of a course of wet mix macadam, must be laid over these subgrades.

E1 subgrade: a 0,25-m subbase consisting of a course of unbound granular material, as well as a 0,25-m base consisting of a course of wet mix macadam, must be laid over these subgrades.

E2 subgrade: in these conditions, a base course of wet mix macadam 0,25 m thick should be laid.

E3 subgrade: this kind of subgrade calls for no base or subbase course, unless otherwise indicated for the pavement in question in the corresponding catalogue entry. Nonetheless, a course of wet mix macadam, at least 0,15 m thick, may be used to even out the surface where necessary.

In all cases, where unbound granular material is not available, wet mix macadam may be used in its place, in which case the thickness may be reduced by 0,05 m.

Where the pavement is to be laid on an existing provisional pavement, the condition and in particular the surface evenness of the existing pavement must be evaluated. If no substantial strain is noted, the permanent pavement may be laid directly on the provisional pavement as if it were an E3 subgrade, unless the new pavement consists of pavers or asphalt concrete, in which case the designer should take into account the bearing capacity of the existing pavement.

Otherwise, the surface should be levelled before the new pavement is laid. In this case, if the existing pavement consists only of granular courses, granular courses and a seal coat or granular courses with a thin and deteriorated layer of asphalt concrete, the surface should be scarificated and evened out with a course of wet mix macadam at least 0,15 m thick. In all other cases, the existing pavement should be removed or evened out by laying an asphalt concrete layer at least 0,05 m thick.

6.4.9. SELECTING THE PAVEMENT

One of the pavement types defined in the catalogue for the use and area considered (see Catalogue) is chosen on the basis of the subgrade and traffic categories found. The selection should be essentially based on a comparative economic analysis of the various options, considering both construction and maintenance costs in each case.

PART 7 DESIGN AND CONSTRUCTION SPECIFICATIONS

PART 7

DESIGN AND CONSTRUCTION SPECIFICATIONS

Contents

PART 7 DESING AND CONSTRUCTION SPECIFICATIONS

Guidelines are included for pavement design and construction, together with the main specifications that must be met by the materials used in each case. Recommendations are likewise included on the surface characteristics to be held by the different pavements, in particular those required to ensure surface water drainage.

7.1. INTRODUCTION

This chapter intends to be a guide for drafting the technical specifications for a given project. Although this document is meant to be independent in nature, it is inevitable under this item to recur by way of reference to the general specifications drafted by the Division of Highways (Dirección General de Carreteras) (Ministerio de Obras Públicas, Transporte y Medio Ambiente - Ministry of Public Works, Transportation and Environmental Affairs). The said specifications are contained in the *Standard Technical Specifications for Highway and Bridge Construction*, approved by Ministerial Order (O.M.) on January 21, 1988 (*B.O.E.* or Government Gazette of February 3), under the abbreviated title "PG-4/88". However, no fully revised version has ever been published, so for all practical purposes they may be considered to consist of *Standard Technical Specifications* PG-3/75 (approved by O.M. on February 6,1976, *B.O.E.* or Government Gazette of July 7) and by successive amendments to some of its articles approved by O.M. or Circular issued by the Division of Highways.

7.2. SPECIFICATIONS FOR FILL CAPPING LAYERS

7.2.1. GENERAL

On the one hand, port fill capping layers may be made of materials specific to this use, such as ungraded quarry material, but on the other, the same materials as used for highway embankment capping layers may be employed.

7.2.2. SOILS

These materials are subject to the provisions of article 330 of PG-3/75. The soils in question, classified from lower to higher category and following the terminology used in the reference are: adequate soils, selected soils or selected soils with CBR > 20.

7.2.3. UNGRADED QUARRY MATERIAL

This material consists of an unclassified mix of coarse and fine quarry materials from which particles larger than 50 % of the thickness of the layer (and in any case, those over 20 cm) have been removed. With the exception of grading characteristics, the materials must meet the same specifications as for unbound granular material (item 7.3.2).

7.3. SPECIFICATIONS FOR PAVEMENT MATERIALS

7.3.1. GENERAL

Pavement performance depends essentially on the quality of the materials used in the various courses, so that defective materials can only sometimes, and then only partially, be compensated by over-designing course thickness. In this regard, and although ports are singular in nature, the specifications normally followed in highway construction should be considered to be the best possible reference. However, possible restrictions in construction procedures in ports should be observed and every attempt should be made to use available materials as far as possible. This latter rule should not, however, be an excuse for accepting lower quality materials, but rather a decisive criterion in the choice of the available materials and therefore of the most technically and economically feasible pavement design.

7.3.2. UNBOUND GRANULAR MATERIAL

The provisions of annex 3 of the O.M. of July 31, 1986 (*B.O.E.* or Government Gazette of September 5) are applicable to this material, in accordance with the stipulations of Division of Highways O.C. 311/90.

The materials used are natural uncrushed aggregates from gravel pits or natural deposits. Stone-like industrial by-products (slag, for example) may also be used, providing that there is no risk of chemical or physical alteration when they come into contact with water or other substances.

The grading curve should preferably fall within the ZN (25) gradation limits. Efforts should be made to use the aggregate with the smallest possible maximum size, so as to prevent segregation as far as possible.

Unbound granular material should have a CBR of at least 20 as determined on an optimum moisture (determined by the modified Proctor test) compacted sample with 97 % of the maximum dry density. The material should, also, meet the liquid limit (under 25) and plasticity index (under 6) requirements.

A single layer of aggregate is to be laid when the course is under 0,30 m thick and two layers of approximately the same thickness should be laid when the total thickness is greater than 0,30 m. A motor grader or paver should be used for spreading.

The material should be compacted with a rubber-tyre and/or vibrating roller and compaction should continue until a density not less than 95 % of the modified Proctor test maximum is reached.

Compaction may be monitored with isotope techniques, providing that the Engineer has expressly approved, in advance, the correlations established in this regard.

The value of the E_2 module obtained with the plate-bearing test should under no circumstances be less than 55 MPa. The E_2/E_1 ratio should in turn not be over 2.

The finished surface should not differ from the design surface at any point by more than 0,03 m. When this surface is checked with a 3-m ruler, unevenness should not be greater than 0,015 m at any given point.

7.3.3. WET MIX MACADAM

This material is subject to the provisions of annex 4 of the O.M. of July 31 1986 (*B.O.E.* Government Gazette of September 5), as stipulated in Division of Highway Circular 311/90 C and E.

Crushed stones must be used, either from quarries or natural deposits: at least 50 % of the particles retained by the 5 µm sieve should have at least two fracture faces.

The grading curve should preferably fall within the ZA (25) gradation limits.

The Los Angeles abrasion value should be under 35 and the sand equivalent over 30.

Wet mix macadam should be laid in a single layer with a motor grader or paver.

The material should be compacted with rubber-tyre and/or vibrating roller and compaction continued until a density not less than 97 % modified Proctor test maximum is reached.

Compaction may be monitored using isotope techniques, providing that the Engineer has expressly approved, in advance, the correlations established in this regard.

The value of the E_2 module obtained with the plate-bearing test should under no circumstances be less than 80 MPa. The E_2/E_1 ratio should in turn not be over 2.

The finished surface should not differ from the design surface at any point by more than 0,020 m. When this surface is checked with a 3-m ruler, unevenness should not be greater than 0,010 m at any given point.

7.3.4. DRY BOUND MACADAM

The standard specifications corresponding to this material are set out in article 502 of PG-3/75.

Coarse, uniform size aggregates (from 50 to 80 mm) with a Los Angeles abrasion value of 30 or under and at least 75 % of the crushed particles with two or more fracture faces shall be used.

After the aggregate is spread and rolled, it should be filled with sand in which the fines (particles under 80 µm) are not plastic and account for no more than 25 % of the material, by weight.

7.3.5. SOIL-CEMENT

This material is defined in article 512 of PG-3/75 as soil stabilised with cement mixed in plant, and is subject to the additional specifications set out in *Instruction 6.1 and 2 IC on pavement structures.*

The soil should preferably meet the requirements given for selected soils (item 7.2.3). The cement in turn will be of the blended so-called "low strength" type (II-25, III-25, IV-25 and V-25). High alumina cement (type VI) should not be used under any circumstances.

The water content of the mix during compaction should be between the modified Proctor optimum and one point below this value. The cement content should be the minimum amount needed to reach the specified strength.

The manufacturing, transport, spreading, compaction and curing processes are the same as for cement-bound granular material, with the exception of the number of aggregate fractions.

7.3.6. CEMENT-BOUND GRANULAR MATERIAL

This material is as defined in article 513 of PG-3/75, and is subject to the additional specifications set out in *Instruction 6.1 and 2 IC on pavement structures.*

The aggregate mix should adjust, in general, to the GC1 gradation limits and should be made up of a minimum of two and preferably three different fractions. The standards these aggregates must meet are the same as indicated for wet mix macadam (item 7.3.3). The cement will be of the blended "low strength" type (II-25, III-25, IV-25 and V-25). High alumina cement (type VI) should not be used under any circumstances.

The water content of the mix during compaction should be one-half of one per cent below the modified Proctor optimum. The cement content should be the minimum amount needed to reach the specified strength. In warm weather, setting retarders should be added.

The material should always be obtained from continuous batching plants equipped to weight-batch components. It should be transported in open tipping lorries suitably covered with canvas or similar protection. It should always be laid with a finisher and compacted with vibrating and/or rubber-tyre rollers.

7.3.7. GRAVEL-SLAG MIX

This material is as defined in article 515 of PG-3/75.

The aggregates used can be distinguished from those used in cement-bound granular material essentially because of the lower proportion of material smaller than 80 µm. In general, of all the limits specified, gradation GEG 1 should be used.

The binder should be blast furnace granulated slag with a reactivity coefficient of over 20, and the proportion of slag to be added will depend on this value: from 20 % of dry weight where aggregates have low reactivity coefficients, to 10 % where the reactivity coefficients are over 60. Furthermore, 1 % of lime should be added in order to ensure proper setting and hardening.

The manufacturing and spreading process differs from those described for cement-bound granular material in that there are no time restrictions between when the mix is made and compaction is completed. Further, the material may be spread with a motor grader, although the use of finishers is preferable.

7.3.8. GRAVEL-EMULSION MIX

The specifications in force are covered by article 514 of PG-3/75, which stipulates two gradation limits: GEA 1 and GEA 2. The difference between the two lies in the maximum nominal size of the aggregate (20 and 25 mm, respectively), segregation being less likely to occur in the former, which is recommended for this reason.

In all cases, the aggregates should have a Los Angeles abrasion value not greater than 35, a flakiness index not greater than 35 and at least 50 % of coarse material with two or more fracture faces. The plasticity index of the fine aggregate should never be over 10, and the sand equivalent should be at least 30.

Gravel-emulsion mixes should, in principle, be manufactured in continuous plants like the ones for manufacturing cold coated macadam or other treated gravel. Nonetheless, they may also be manufactured in conventional discontinuous asphalt plants.

The mix can be poured directly on a lorry or stocked, in which case suitable bins or other spaces should be prepared to avoid pollution or segregation before transport. As transport calls for no particular precautions, the material may be transported like any other cold mix.

The mix should be spread with a finisher or motor grader and compacted with vibrating and/or rubber-tyre rollers with heavy wheel loads. The mix may be compacted immediately after laying, or several hours later. In any case, it should be compacted before emulsion setting is completed.

A seal coat must be applied where the gravel-emulsion mix course has to be opened to traffic before the corresponding wearing course is laid. This treatment should consist of spraying the course with a rapid-setting emulsion (about 0,5 kg/m^2 of residual bitumen) and a light sanding (about 4 l/m^2).

7.3.9. LEAN CONCRETE

This material is subject to the specifications contained in O.C. 311/90 C and E, of March 20, 1990, amending article 550 (Vibrated cement concrete pavements) of PG-3/75, which should be followed together with the complementary provisions contained in annex 2 of the O.M. of July 31, 1986.

The cement will be of the blended "medium strength" type (II-35, III-35, IV-35 ad V-35). High alumina cement (type VI) must not be used under any circumstances. The cement dosage must be at least 140 kg/m^3. Aggregates of at least three sizes are to be used: 0-5 mm, 5-20 mm and 20-40 mm. The fine aggregate must have a sand equivalent of over 70. At 28 days the compressive strength of the concrete must be at least 10 MPa.

Concrete production at the manufacturing plant must be sufficient to ensure a continuous supply to the paving equipment. This plant must be of the same kind as used for manufacturing pavement concrete.

The granular subbase must be graded before the concrete is laid; the use of an autograde is recommended to meet level tolerance requirements, less than 0,010 m with a 3-m ruler.

Lean concrete should be spread with the same kind of equipment as used for concrete pavements. The same precautions in respect of temperature, humidity of the air and rain shall be observed.

7.3.10. VIBRATED CEMENT CONCRETE PAVEMENTS

This material must meet the specifications of O.C. 311/90 of March 20, 1990, amending article 550 of PG-3/75.

The cement will be of the blended "medium strength" type (II-35, III-35, IV-35 ad V-35). Neither high alumina cement (type VI) nor cement with additives that has not been mixed at the cement plant may be used. Setting should not begin until two hours have elapsed. However, should the concrete be laid when the temperature is over 25 °C, setting should not begin until one hour has elapsed.

The maximum size of the aggregate should not be over 40 mm. Coarse aggregate should be made up of at least three different sizes: 5-12 mm, 12-25 mm and 25-40 mm. The sand equivalent of the fine aggregate should not be under 80. The fine aggregate must have a siliceous particle content of at least 30 % in access lanes and 20 % in all other surfaces.

The concrete admixtures must comply with the requirements established in the following standards:

— UNE 83281: Water reducing and plastifiers.
— UNE 83282: Fast-acting water reducers (superplastifiers).
— UNE 83282: Concrete setting accelerators.
— UNE 83286: Air-entraining agents.

The use of any of these admixtures must be approved by the Engineer. The air-entraining agent should be such that the entrained air bubbles have a diameter of between 10 and 200 µm and are evenly distributed throughout the concrete. If superplastifiers are used to enhance strength, the dose must be limited to 0,4 kg/m^3.

In general, HP 40 concrete should be used for pavements, with a 28-day characteristic blending strength of at least 4 MPa. Concrete slump as measured with Abrams' cone, should not be under 0,02 m nor over 0,06 m. The cement dosage should not be under 300 kg per cubic metre of fresh concrete. The passing fraction content (through a 0,16 mm sieve) should not be greater than 450 kg/m^3 of fresh concrete, including the cement and admixtures. The water/cement ratio by weight should not be over 0,50.

Pavement concrete may be manufactured in discontinuous plants equipped to simultaneously handle the number of aggregate fractions required for the concrete mix.

Concrete placing must be interrupted when it rains hard enough to cause sagging of the slab edges, in the opinion of the Engineer. Should the temperature reach more than 25 °C, the concrete temperature must be continually monitored, and under no circumstances should it exceed 30 °C. The Engineer may enforce complementary precautions to ensure that this does not occur. When the temperature of the air is under 5 °C, the temperature of the concrete must be continually monitored, adopting the necessary measures, including interruption of placing as appropriate.

Once the pavement has been laid and before the concrete begins to set, burlap should be dragged over it to provide a rough, skid resistant surface.

A paraffin-base curing compound for the lean concrete course and a resin-base curing compound for the pavement concrete are recommended. The rate of spray should be determined by laying a test section and should be, at least, 0,230 kg/m^2 for lean concrete and 0,250 kg/m^2 for pavement concrete. The Engineer may modify such rates of spray where weather conditions make it advisable to do so. The sprayers must ensure a continuous and uniform coat over the entire surface and exposed sides of the slabs. They should be equipped with wind guards and a mechanical stirring device in the storage tank which should be in operation throughout. In small, irregular areas, or areas that are inaccessible to mechanical devices, the Engineer may authorize the use of manual sprays.

The slabs should measure approximately 5 x 5 m^2. When placing by strips, once the concrete has begun to harden, transverse contraction joints must be sawn in every 5 m. There should be one more saw on site than needed to keep up with the placing pace, for contingencies.

The Engineer should indicate the measures that must be taken to attain an acceptably even surface on which to pour the concrete and repair damaged areas as appropriate. Horizontal deviations with respect to the design alignment should not be greater than 0,03 m. Unevenness in excess of the specified tolerance, and areas that retain surface water, must be rectified following the Engineer's instructions.

Construction traffic shall not be permitted until three days after paving, or until the concrete has reached eighty per cent of the required bending strength. General traffic shall not be allowed until seven days after the pavement has been laid.

7.3.11. CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

All the specifications listed for vibrated cement concrete pavements (item 7.3.10) must be met, excepting that no provision need be made for contraction joints.

Reinforcement usually consists of deformed steel bars with a yield strength of no less than 510 MPa. Longitudinally, the cross-section should be 0,6 %, using bars with a diameter of at least 0,016 m. Transverse bars with a diameter of 0,008 m should be used as distributed steel. The bars are to be placed in the centre of the slab.

7.3.12. STEEL FIBRE REINFORCED CONCRETE PAVEMENTS

This material must meet all the specifications listed for vibrated cement concrete pavements (item 7.3.10), with the exception of consistency: plastifiers should be used so that slump in Abrams' cone, before the fibre is added, is not under 0,012 m.

The fibre must be made of drawn steel with hooks and tensile strength not under 1 200 MPa. In addition, the fibres should be comb-tied. The fibre diameter should be 800 μm and the minimum length should be 0,050 m.

At least 30 kg/m^3 of fibre should be added to the concrete in any of the batching stages.

7.3.13. ROLLER COMPACTED CONCRETE

The specifications to be met are as outlined in annex 1 to the O.M. of July 31, 1986.

The aggregate mix should adapt to continuous gradation limits, with maximum sizes of 16 to 20 mm, and should be made up of at least two and preferably three different fractions. The specifications that these aggregates must meet are similar to those set out for wet mix macadam (item 7.3.3), and the CBR value of the aggregate mix (without ring surcharge or soaking) must not be less than 65. The cement will be of the blended "medium strength" type (II-35, II-35, IV-35 and V-35).

The water content of the mix during compaction should be the modified Proctor optimum. The cement content should be the minimum amount needed to reach the specified strength, in principle not less than 300 kg/m^3.

The workability time of the mix must be closely monitored. In warm weather, setting retarders should be used.

The concrete should be manufactured in batching plants, such as those used for mixing of soil-cement and cement-bound granular material, or in discontinuous plants such as those used to make vibrated concrete. In any case, the plants must be equipped with devices for weight-batching components.

The concrete should, in general, be transported in open tipping lorries suitably covered with canvas or similar protection. It should always be laid with finishers. The concrete should be compacted with vibrating and/or rubber-tyre rollers, and periodically checked for specified density.

When placing by strips, measures must be taken to ensure that each strip is spread while the concrete in the previously laid strip is still workable.

In order to prevent surface over-drying, a light, continuous flow of water should be sprinkled over the concrete before the end of compaction and until curing is applied.

Once the pavement is placed, and while the concrete is still workable, the surface must be finished in some way: burlap dragged, float finished, etc.

Once the concrete is hard enough, transverse contraction joints should be sawed into it, so as to form slabs approximately 5 x 5 m^2. There should be one more saw on site than needed to keep up with the placing pace, for contingencies. The joints should not be sealed.

7.3.14. CONCRETE PAVERS

The concrete used in pavers should have a 28-day characteristic compressive strength (found on cut cubic specimens) of at least 50 MPa. It concrete should be made with type I-45 cement, an aggregate with a Los Angeles abrasion value not over 20 and sand with a siliceous particle content of at least 30 %.

The geometric tolerance allowed in pavers is ± 0,002 m in any horizontal direction and tolerance for thickness is ± 0,003 m.

The sand for the levelling course must not be over 5 mm in size, with 15 % of particles, at most, larger than 2,5 mm and 5 % of particles smaller than 80 µm. The sand used in joint filling must be no larger than 2,5 mm with at least 15 % of particles smaller than 80 µm.

Pavers are initially vibratory compacted, after which the joints should be filled and a second compaction applied. The excess sand should be removed.

7.3.15. SURFACE DRESSINGS

This material is subject to the specifications contained in O.C. 297/88 T, of March 29, 1988.

Rapid-setting emulsions are to be used as binders for the chippings.

Crushed (more than 50 % of the particles with two or more fracture faces), clean, well-shaped (flakiness index under 30), wear resistant (Los Angeles abrasion value under 30) and non-polishable (accelerated polishing coefficient at least 0,40) uniform aggregates should be used; where there is little or no traffic, however, they need not necessarily be non-polishable.

The binder and aggregate rates can be established with the so-called rule of one-tenth. In single application, or in each course of double application:

- Chippings rate (D+d)/2 l/m^2
- Residual bitumen rate: [(D+d)/2]/10 kg/m^2

where D and d are the maximum and minimum sizes (in mm), respectively, of the chipping used. The rates thus computed should be considered as merely indicative and should be rectified on the basis of factors such as the mean size of the aggregate, absorption, shape, permeability of the surface on which the chippings are laid, kind of binder used, etc. In double application, while the total amount of residual binder should remain unchanged, it is advisable to reduce the rate in the first spray somewhat and increase the rate in the second proportionally.

The only binder spraying technique allowed is tank spraying. For the spreading of chippings, in turn, which should be as homogeneous as possible, several kinds of spreaders may be used: with the draw-gate attached to the tipping lorry, with a lorry-driven hopper or with a self-propelled spreader.

In single applications, the chippings should be rolled with high pressure rubber-tyre rollers. In double applications, before the second spray is applied, it is advisable to roll the chippings with a light smooth roller. The second layer of aggregate should be rolled in the same way as for a single application. In all cases, as little time as possible should elapse between the various stages of the operation.

7.3.16. SLURRY SEAL

This material is subject to the specifications contained in O.C. 297/88 T, of March 29, 1988.

The various kinds of slurry seal surfacing are distinguished on the basis of the maximum aggregate size (normally from 2,5 to 10 mm) and the rate of spread, usually between 5 and 20 kg/m^2. Where the rate of spread is very high, two successive courses are laid.

Crushed, hard and very clean sand is used as aggregate. Its grading should adapt to one of the specified gradation limits. The binder should be a slow-setting, preferably controlled, bituminous emulsion, chosen on the basis of the characteristics of the aggregate, the weather conditions when laying takes place, and the characteristics of the available paving equipment.

Slurry seal characteristics should depend on the purpose of use. The following points should be considered: kind of slurry, composition, rate of spread and number of layers.

Proportioning should be established in the laboratory. Consistency and mechanical abrasion tests (as well, sometimes, as bleeding tests) should be run. Water content may vary from 8 to 20 % of aggregate weight (in addition to the water from the emulsion itself), while the water content in the bituminous emulsion ranges from 10 % to - occasionally - over 20 %.

Slurry seals are manufactured and poured by lorry mixers. The equipment consists, essentially, of a series of tanks for the various components and a continuous type mixer. The slurry is poured from the mixer to a distribution box or rake through an adjustable draw-gate. This rake, which is towed over the surface to be treated, has a height-adjustable rubber squeegee at the end.

7.3.17. ASPHALT CONCRETE

This material is subject to the provisions of Division of Highways O.C. 299/89 T, of February 23, 1989, amending article 542 of PG-3/75.

Bitumen type b 60/70 should normally be used as a binder.

The proportion of coarse aggregate particles with two or more fracture faces should be at least 95 % in wearing courses and at least 75 % in the other layers. The maximum coarse aggregate Los Angeles abrasion value should be 30 in the lower layers and 25 in the wearing courses. The coarse particle accelerated polishing coefficient should be at least 0,40 in wearing courses, although this requirement may be disregarded where there will be little or no traffic. The maximum flakiness index of the various coarse aggregate fractions should not be over 30.

Should all or part of the fine aggregate come from natural sand beds, the maximum proportion of natural sand in the mix (percentage by mass of all aggregates, including filler) should not be over 15 %.

The proportion of additional filler, excluding the dust that inevitably adheres to the aggregate, should be at least 100 % in the wearing courses and 50 % in the base layer. In all cases, cement should be used as the additional filler, unless otherwise authorized by the Engineer.

The grading curves for the mixes must be adapted to the following gradation limits:

— Wearing courses	S20
— Courses immediately under the wearing courses:	S20
— Courses under the preceding courses:	G25

The ratio, by weight, of the filler and binder contents should be approximately 1.3 for wearing courses, 1.2 in the courses immediately under the wearing courses and 1.0 in the courses under the latter.

The batching criteria for asphalt concrete using the Marshall device are as follows:

— Number of blows per side	75
— Stability	> 10 kN
— Flow	2-3 mm
— Air voids	4-5 % in wearing course
	5-7 % in courses underneath wearing course
	6-8 % in courses underneath the preceding courses
— Voids in mineral aggregate:	≥ 14 % in S 20 mixes
	≥ 13 % in G 25 mixes

To avoid rutting, the maximum slope of the deformation curve in the wheel-tracking test in the 105 to 120-minute interval should not be over 15 μm/min for mixes in wearing courses and those directly underneath such courses.

In any case, the dose of minimum asphaltic bitumen should not be under the following values (% of aggregate dry weight):

— Wearing courses	4,50 %
— Courses immediately underneath wearing courses:	4,25 %
— Courses underneath the preceding courses:	3,75 %

Surface unevenness limits for asphalt concrete courses must not be greater than those listed below (expressed as maximum unevenness under a 3-m ruler):

— Wearing courses 0,005 m
— Lower layers 0,007 m

7.3.18. COLD ASPHALT

This material is subject to the provisions of article 541 of PG-3/75, except as regards gradation limits, which must be one of the two indicated in table 7.1.

TABLE 7.1. GRADATION LIMITS FOR COLD ASPHALT

ROUND HOLE SCREENS AND SIEVES (mm)	PERCENT PASSING BY WEIGHT (%)	
	AF 12	AF 20
25		100
20	100	70-90
12,5	60-80	50-70
10	45-65	35-55
5	10-35	5-30
2,5	0-5	0-5
0,080	0-2	0-2

Gradation AF1 12 should be used when the course is under 0,06 m thick; for courses 0,06 m thick or thicker, gradation AF 20 should be used.

The aggregates must meet the same requirements as specified for asphalt concrete (item 7.3.17), except as regards polishing, for which no requirement exists. The binders, in turn, should be slow-setting emulsions (ECM or EAM) Proportioning is to be determined on the basis of specific surface criteria.

The cold asphalt should be made in continuous plants; finishers are recommended for spreading, although motor graders may also be employed.

At least two weeks after the cold asphalt is laid (four weeks if the weather is cold or humid), the surface should be sealed with a single course of LB 3 type slurry seal at a rate of spread of 10 kg/m^3.

7.3.19. LEACHED PAVEMENTS

These pavements are laid over a 0,04 m thick course of type PA 12 asphalt concrete. Afterwards, a cement slurry with thermosetting resins (polyurethane or epoxy) should be vibrated into the layer.

7.3.20. GRAVEL BEDS

Gravel beds must be laterally confined by a concrete kerb. The beds inside this enclosure should be composed of a duly levelled and compacted course of crushed uniform gravel, similar to a dry bound macadam (item 7.3.4) between 0,35 and 0,40 m thick.

The maximum aggregate size should not be over 50 mm, with a Los Angeles abrasion value not greater than 30. The proportion of crushed particles with two or more fracture faces should be 100 %.

7.4. SURFACE CHARACTERISTICS OF PAVEMENTS

7.4.1. DESCRIPTION

Surface characteristics of pavements are not usually directly related to their structural strength. Since their importance lies in the effect they have on serviceability. These characteristics, which affect operating costs and safety, are the only ones actually of interest to the persons working in the various port areas. The following characteristics, *inter alia*, may be considered:

- Rolling resistance.
- Surface evenness.
- Wear and tear deriving from tyre-pavement contact.
- Skid-resistance.
- Tyre-pavement contact noise.
- Permeability and surface drainage.
- Cleanliness.
- Resistance to oil and fuels.

7.4.2. WORKING AREAS

Surface evenness is of particular importance in these areas, especially in the direction perpendicular to the edge, to ensure proper water runoff.

7.4.3. BULK SOLID STORAGE AREAS

Cleanliness of the surface is of particular importance in these areas, as well as avoiding surface fretting caused by the loaders and loading skips used to handle this cargo.

7.4.4. GENERAL CARGO STORAGE AREAS

The requirements are the same as listed below for container stacking bays.

7.4.5. CONTAINER STACKING BAYS

In the areas where the handling equipment has unrestricted mobility, cornering creates extreme horizontal stresses, thus causing substantial surface damage to the pavement. This is a situation in which pavement and handling equipment must be considered as an integrated whole, because very strong surfaces may lead to high tyre costs. In the rather restricted areas where great horizontal stress is expected (e.g., portal crane cornering areas), the pavement should be reinforced with steel plates 0,020 m thick (see item 3.1.2.3).

7.4.6. ROLL-TRAILER STORAGE AREAS. ROLL-ON/ROLL-OFF TERMINALS

Particularly large impacts occur on the *roll-on/roll-off* working ramps when cargo rides over the gangboard toe supports. Two solutions may be recommended to prevent rapid surface deterioration of the concrete: firstly, using very strong concrete (with special aggregates and additives such as silicon dioxide fumes; the other alternative consists of reinforcing the ramps with steel profiles or plates.

7.4.7. FISHING AREAS

The fishing areas, and in particular the markets, are subject to the provisions of European Community Directive 41/493/ECC of July 22, 1991, which stipulate that the surfaces must be laid in such a way that their porosity, joints, etc. do not accumulate waste from fish handling, constituting a source of pollution. Specifically, the Directive establishes the following requirements for these areas:

- The pavement must be impermeable and easily cleaned and disinfected, and water - either leaking out of crates or used for cleaning - must be readily drained.
- The sewer system must be equipped to prevent stench.
- Special care should be taken to ensure that pavements are skid-resistant when wet.
- Concrete pavements must be float finished to eliminate surface pores, and be treated for surface dust.

7.4.8. TRAFFIC LANES

In traffic lanes, both access and manoeuvring areas, the most important surface characteristics are the same as for highways: skid-resistance and surface evenness. The greater the speed of traffic, the more important these characteristics are.

Skid-resistance requirements are the same as for highways. With regard to surface evenness, the maximum allowable unevenness will depend on the speed of traffic, and should be exactly the same as for highways designed for the same speed. Where this parameter is unknown, speeds of 50 km/h for manoeuvring areas and 90 km/h for access lanes must be used.

7.4.9. OTHER AREAS

Special reference must be made to the auxiliary areas intended for parking, where the most important surface characteristics are cleanliness as well as resistance to oil and fuels.

7.5. CONSTRUCTION FEATURES

7.5.1. RAILWAY GAGES

Where there are either railroad tracks or tracks for restricted mobility cargo handling equipment in the pavement, a suitable easer rail should be made, forming a tread wide and deep enough for the flange of the wheels, and protecting the pavement; there should be no ridge, however, between the track and the adjacent pavement.

The surface water that may accumulate in the small gutter between the track and the easer rail must be drained off to the sea or in-land port areas by devices provided for this purpose.

Railway gages should preferably be paved in the same way as the surrounding areas, providing that track stability can be ensured.

7.5.2. JOINTS

In concrete pavements generally only butt joints (contraction, warping or construction joints) should be used. Groove and tongue joints should be avoided, as should other joint elements such as planks, plastic or metal profiles, etc.. Joints should be sawn into the concrete once it has set enough to do so. The depth of joints should be 1/4 to 1/3 of total slab thickness. Preformed joints, formed by weakening the section with sheets, plastic profiles etc., may only be used in areas intended for light traffic.

Normally, joints do not have to be sealed, with the exception of the areas designed for storage of powdery bulk solids or fish handling.

There must be expansion joints at lane crossings and around structures (bridges or other overpasses, wharves, enclosures and other permanent structures). These expansion joints must be able to accommodate not only horizontal thrust, but relative vertical movement that may also occur as well. Surface water drainage systems must be placed nearby joints running parallel to the edge.

7.6. DRAINAGE

7.6.1. GRADES

Grades refer, in this context, to both the gradient (parallel to the edge) and the cross-fall (perpendicular to the edge); a distinction should however be drawn between surfaces where cargo may be stored or stacked and those intended strictly for traffic.

Every attempt should be made to ensure that there is a cross-fall of at least 0.5 % in permanent pavements and 0.8 % in provisional pavements. As far as possible, these cross-falls should be on a single pitch all along the entire surface, to avoid hips parallel to the wharf edge. The maximum cross fall on surfaces intended for cargo storage should be 1.25 % and 1.75 % in areas intended strictly for cargo handling traffic.

The maximum gradients found by dividing the difference between the maximum and minimum elevation along a line parallel to the edge by the length of that line should not be greater than 0.8 % on surfaces where cargo may be stored or than 1.25 % on surfaces intended for handling equipment. The gradient must not be over 1 % at any point on a surface for cargo storage, or 1.5 % on surfaces intended strictly for cargo handling equipment. Where changes in gradient are inevitable, such changes must not be in excess of 1 %.

7.6.2. DUCTS AND INTAKES

There should be no ridges or other barriers to hinder water from running of the surface freely, and areas where water may dam up or accumulate should be eliminated. Further, measures should be taken to ensure the continuity of grades, and eliminate obstacles and areas where puddles may form. In bulk solid storage areas or areas where general cargo is to be stacked directly on the pavement the stored or stacked material should not block the flow of surface water, and where it does, appropriate by-pass devices must be provided.

The amount of water to be drained should be estimated using the procedure described in Division of Highways Standard 5.1 *(Surface drainage)*.

Rainwater should flow to gutters (continuous gullies), covered by trafficable steel grids. The distance surface water must flow should not in any case be over 25 m. The gutters should have the highest possible downgrade that is compatible with surface geometry* layout and the Equinoctial High Tide level. Gutters perpendicular to the edge should spill into others that are parallel to it, while the parallel gutters should drain off into pipes going directly to the sea and placed at 50-m intervals, at most. Drains equipped with the corresponding sand beds should be installed at gutter crossings and in any case at 25-m intervals, at most.

Where the above-sea-level foundation underneath gravel beds is not sufficiently permeable, underground drainage must be provided to remove water filtering down though the beds. Such systems may consist of cut-off drains covered by geotextiles with grooved plastic pipes on a layer of uniform gravel, and should also include the corresponding intakes. If these requirements are met, the gravel beds may be used as surface water gullies for adjacent paved areas.

ANNEX A BASIC DESIGN THEORY

A.1. INTRODUCTION

There are two possible approaches to the structural design of pavements:

— Explicit consideration of basic structural design factors (traffic, subgrade, characteristics of the materials and climactic variables), in order, as in any traditional engineering procedure, to obtain stresses, strains and displacements and compare these results with the acceptable values. This is the analytical approach to structural design.

— Implicit consideration of all of these factors with a global approach, in a process which is fundamentally based on past experience with pavement performance. This is the empirical approach to structural design.

From a practical point of view, the empirical methods are presented in tables, graphs, design charts or catalogues of pavement structures. Analytical methods, on the contrary, entail direct calculation. However, both groups of methods have progressively converged over the last few years: a substantial number of the so called empirical methods are based not only on the analysis of available experience, but also on calculations showing the quantitative impact of the different variables. Analytical methods, in turn, must be contrasted to practical experience both when selecting design parameters and particularly when analyzing results. Indeed, the models themselves must be compared to real situations.

The structural design methodology proposed in these guidelines is in the form of a catalogue of standard pavement structures. This method has been developed employing empirical as well as analytical considerations.

A.2. ANALYTICAL METHODS

Analytical methods in structural design are based on the study of stresses and strains produced by the factors considered (loads, temperatures, etc.) with subsequent consideration of the impact of such factors on the deterioration of the pavement structures. Analytical methods consist therefore of two components: a response model and a deterioration analysis.

Response models may be classified in three broad groups: mechanistic regression and probabilistic models, the first being the most widely used. There are three types of mechanistic models that differ with regard to the geometric and calculation modelling principles on which they are based: multi-layer systems, plate theory and numerical methods (finite elements, for example). They can also be classified according to the constitutive equations of the materials considered into elastic and visco-elastic models. Up to the present time, the models based on multi-layer systems and elastic equations (Burmister hypotheses) are the most widely developed for flexible and semi-rigid pavements. In contrast, the most common methods used for rigid pavements are based on plate theory and elastic equations (Westergaard hypotheses).

A.2.1. BURMISTER'S HYPOTHESES

The following is a summary of these hypotheses:

— The geometric structure of the pavement is assumed to be a series of horizontal and parallel courses, horizontally infinite and of uniform thickness, supported in a Boussinesq half-space.

— Each course behaves like a linear, homogeneous, isotropic, continuous elastic medium. Its mechanical characteristics are defined by its Young's modulus and Poisson coefficient.

— Each load applied to the pavement (for example, a wheel load) is represented by the pressure - usually vertical - uniformly distributed over a circular area.

— Each layer is borne by the underlying one in a continuous way. Contact between layers can be modeled in complete adherence conditions (equal horizontal strain), or zero adherence.

— Both inertial and thermal effects are disregarded.

— Little strain occurs in the system.

— The shear stress occurring at the points of contact between loads and the pavement surface are not usually taken into consideration. This is due to the fact that, except in very few cases, they are practically insignificant.

Given these hypotheses, the partial derivative equations resulting from this approach are solved through transforms. The structure's response is therefore obtained in the form of definite integrals which are solved numerically. This task may be carried out by a wide variety of computer programs which are readily available on the market.

The limitations to the models based on these hypotheses stem from the hypotheses themselves and may be summarized as follows:

— The pavement structures are characterized by axial symmetry, which means that the loads as well as the pavement itself are considered to be symmetrical around an axis. The effects of the loads produced by a vehicle's tyres near cracks or edges cannot therefore be analyzed using these methods. The effects of loads whose contact imprint is not circular is also beyond the scope of direct analysis. This is the case of containers or the front ends of roll-trailers. Although three-dimensional models could be used applying a finite elements method, the amount of computer time involved and the time needed to analyze the results make it rather impractical.

— The inertial forms created in the pavement due to dynamic loads are disregarded. This practice may not be acceptable in the case of slow moving vehicles on granular or bituminous materials or when vehicles make sudden turns.

— All of the materials used in pavement construction are, to a greater or lesser degree, anisotropic, heterogeneous, non-linear and non-elastic. Some of their properties are weather-dependent and may be affected by changes in temperature or humidity, for example. Therefore, in order to obtain a better estimate of stresses and strains, more complex, non-linear theories would have to be employed. In practice, the application of the elastic theory has proved to be sufficiently valid.

A.2.2. WESTERGAARD'S HYPOTHESES

These hypotheses, applicable to concrete pavements, may be summarized as follows:

— The slab is assumed to be of uniform thickness and act like a linear, homogeneous, isotropic and continuous elastic medium, mechanically characterized by its Young's modulus and Poisson coefficient.

— The slab is in equilibrium under the traffic loads, its own weight, the reactions of adjacent slabs and the slab support.

— The reaction of the support is assumed to be proportional to its vertical movement (Winkler's hypothesis) at each point with a ratio called the modulus of subgrade reaction.

A fundamental parameter in the formulae established by Westergaard as well as in later modifications is the so-called radius of relative stiffness, which may be expressed as follows:

$$l = \left[\frac{E \cdot h^3}{12 \cdot (1-\upsilon^2) K} \right]^{1/4}$$

where:

l: radius of relative stiffness (m)
E: Young's modulus of the concrete (MPa)
h: slab thickness (m)
υ: Poisson coefficient of the concrete
K: modulus of subgrade reaction (MPa/m)

In the event of circular loads, maximum slab stresses for the different positions of the load are given by expressions such as:

$$\sigma_{máx} = \frac{Q}{h^2} f\left(\frac{l}{a}\right)$$

where:

Q: magnitude of the circular load (N)
a: load radius (m)

The major advantage to this method is that it facilitates the study of stresses caused by loads located near the edges of the slabs.

A.2.3. PROCEDURE

The procedure to be followed in the methods based on the above hypotheses consists of the following steps:

— Assessment of applied loads (isolated or repeated, static or dynamic, etc.) during the design life of the pavement, evaluation of the effects of different actions (design loads) and integration of these effects.

— Modelling of the pavement structure by:

  - in the case of flexible and semi-rigid pavements, a theoretical, multi-layer system together with a series of performance hypotheses to be able to run the calculations on a computer (Burmister hypothesis);

  - in the case of rigid pavements, a slab on a Winkler support (Westergaard hypothesis).

— Selection of the materials to be used in the different courses and estimation of the necessary thicknesses.

— Analysis of the pavement structures to determine the maximum stresses, strains and displacements that may occur.

— Comparison of these values with the allowable values for each material in accordance with the deterioration criteria considered.

— Verification, using these criteria, that each course can endure to the end of its design life with an acceptable degree of deterioration. This deterioration ought to be similar in all layers.

— Where the above does not hold, the pavement will have to be re-calculated modifying the thicknesses or the strength characteristics of the layers so that each one reaches an acceptable and similar level of deterioration by the end of its design life.

— Cost comparison of the various feasible options to choose the most economic solution for each situation.

A.2.4. MECHANICAL CHARACTERISTICS OF MATERIALS AND ENVIRONMENTAL CONDITIONS

A.2.4.1. SUBGRADE

The value of Young's modulus of the Boussinesq half-space is usually established based on the subgrade CBR using the expression:

$$E\ (MPa) = 10\ .\ CBR$$

For a Winkler space, the moduli of subgrade reaction which may be considered are as follows (based on empirical correlations):

CBR = 3	K = 30 MPa/m
CBR = 5	K = 40 MPa/m
CBR = 10	K = 55 MPa/m
CBR = 20	K = 70 MPa/m
CBR = 30	K = 90 MPa/m
CBR = 100	K = 220 MPa/m

With regard to the Poisson coefficient, it may vary between 0,35 for granular soils and 0,50 for clays.

A.2.4.2. GRANULAR COURSES

For these materials, Young's modulus is a function of the moduli of the confining layers, of the thickness of the granular course itself and of the friction angle of the aggregates.

In practice this can be expressed:

$$E = k \cdot E_{i-1}$$

where E_{i-1} is the modulus adopted for the underlying course and k is a coefficient which varies between 2 and 4 according to the indicated factors. The Poisson coefficient of a granular material may vary between 0,35 and 0,40.

A.2.4.3. CEMENT-TREATED LAYERS

These materials are the easiest to characterize mechanically. Young's modulus may even be deduced through relatively reliable correlations from compressive strength or indirect tensile strength. However, no fixed values may be recommended for the calculation given the wide range of different materials. For materials used in Spain, the values in table A.1 may be recommended on an indicative basis.

TABLE A.1. ELASTIC CHARACTERISTICS OF CEMENT-TREATED LAYERS

	E (MPa)	υ
Cement-stabilised (improved) soil	100 - 1000	0,30
Soil-cement	4000 - 15000	0,25
Cement bound granular material	15000 - 22500	0,25
Lean concrete	20000 - 25000	0,20
Gravel/slag mix	10000 - 20000	0,30

A.2.4.4. ASPHALT CONCRETE AND MATERIALS STABILIZED WITH BITUMINOUS BINDERS

These are materials with characteristics that vary widely. They are, therefore, difficult to model. Their stiffness varies with temperature and the amount of time that a load is applied. For dense asphalt concrete (in Spain mixes with a low bitumen content and an aggregate matrix with high internal friction are in use), Young's modulus values of between 4.000 and 7.000 MPa and Poisson coefficient values of between 0,30 and 0,35 may be adopted.

A.2.4.5. CONCRETE

A Young's modulus of around 30.000 MPa and a Poisson coefficient of 0,15 to 0,20 may be estimated for concrete used for pavements.

A.2.4.6. ADHERENCE CONDITIONS BETWEEN COURSES

The Burmister hypotheses assume that there is contact between the pavement layers with either total or zero adherence. In the first case the equations are solved assuming that the horizontal strains in the contact between both courses is equal. The level of real adherence between two materials depends on the nature of these materials and more importantly on the manner in which construction was carried out. Furthermore, it is very important to note that even where almost total adherence is achieved at the outset, stiffness differences will lead to a certain degree of separation due to the effects of load and water. Moreover, the zero adherence hypothesis does not faithfully represent reality, given that there is always friction between materials of different layers.

Furthermore, it should be noted that the adherence or lack thereof between two consecutive layers is one of the most important variables affecting stresses and strains. Therefore, the results of the two hypotheses should be compared for layers which may be critical to structural design.

A.2.5. VERIFICATION

Verification is the main problem which must be faced when dealing with analytical methods of structural design; the extent to which the conclusions reached do in fact concur with reality. For example, cracked surfaces which may be considered to be very deteriorated from a structural point of view may have no adverse affect on normal traffic. Furthermore, not all pavements which reach an appreciable level of deterioration (cracks, deformations, etc.) will quickly progress towards complete ruin. Some even have a certain capacity for self repair under favourable conditions, or their design life, may be extended through simple maintenance.

Three types of basic criteria may be used to determine the state of deterioration of a pavement:

— Global indicators which define the condition of the pavement surface on the basis of the existing deformations and cracks. In this case, threshold limits are usually established and once these limits are exceeded, the pavement is considered unacceptable.

— Parameters which take into account one or several of the characteristics related to pavement strength or to specific properties of the pavement surface.

— Theoretical-experimental considerations which determine structure failure on the basis of an analysis of the structure using specific deterioration criteria such as maximum allowable stresses.

A.3. EMPIRICAL METHODS

Although there are computer programs for the analysis of pavement structures. The existing guidelines are often based on standard structures or calculation charts that relate the characteristics of materials to thicknesses and estimated traffic throughout the design life. Generally, these empirical methods (with regard to port pavements, the most widely used method is the one developed by the British Ports Association) are based not only on experimental criteria obtained through observation and on-site and laboratory tests, but also, in a more or less explicit manner, on mechanistic hypotheses most of which have been contrasted to calculation programs. The justification for empirical methods lies in the fact that they simplify the designer's work. They should not, however, be used in scopes other than the one for which the method was originally conceived, since it may be very difficult to assimilate traffic typology, material characteristics and specifications, seasonal factors, etc. Extrapolations for other design loads, thickness limitations, material equivalences, etc. are even less justifiable.

The following procedure is common to all structural design empirical methods:

— Establishment of a design life at the end of which a given level of deterioration is reached.

— Determination of input parameters: characterization of the subgrade evaluation of expected traffic volume, local and seasonal conditions.

— Formulation of the solution or solutions tailored to each method: design charts, tables or catalogues of pavement structures.2

A general trend which has been followed in these Guidelines and which has been observed in the most recent versions of different empirical structural design methods is to make the thickness of the lower course (normally granular subbase) independent of the rest of the courses: The thickness and characteristics of the subbase are determined exclusively as a function of the bearing capacity of the subgrade. This means that the sub-base course is considered as a working layer for construction which must have the proper bearing capacity and be homogeneous over the entire surface to be paved. On the contrary, the thicknesses of the upper courses are determined according to traffic volume.

In some empirical procedures, a fictitious thickness of a standard material is assumed and subsequently transformed into real course thicknesses formed by other materials by means of equivalency coefficients or substitution relationships. In this manner, multi-layer structures may be configured with different materials and thicknesses. When calculation charts are used, final pavement structure design must be adjusted. This is accomplished through a series of limitations included in each method and which do not allow for the arbitrary selection of thicknesses. The thicknesses of the courses of different materials may sometimes be at odds with the on-site construction conditions or with technical and strength considerations. For that reason, all of the methods include a series of final limitations so as to obtain pavement structures that meet strength requirements in a harmonious and balanced manner, since the deterioration of one course means that the rest will be overloaded and hence will soon itself deteriorate. This harmony is only achieved with the proper balance of thicknesses and stiffnesses, accommodating the type and magnitude of the design loads, climatic conditions, etc.

Catalogues of pavement structures are based on the establishment of bearing capacity intervals of subgrades and of design loads. Apparently, this process has the disadvantage of allowing for less flexibility in matching the design thicknesses to expected traffic volume. Nevertheless, catalogues allow for the estimation of the initial parameters within a sufficiently wide range so as to avoid the adverse effects caused by a lack of precision. This is not to say that values should not be determined as precisely as possible, but rather that if the parameters have been correctly evaluated, the possible deviations will generally remain within the acceptable limits. Furthermore, the use of a catalogue allows for the standardisation of structural design criteria in a given scope, which facilitates monitoring, since only a relatively small number of pavements structures is built.

A.4. SELECTED REFERENCES

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C CATALOGUE OF STANDARD PAVEMENT STRUCTURES

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Contents

C CATALOGUE OF STANDARD PAVEMENT STRUCTURES

A wide range of surfacing solutions, both permanent and provisional, is presented in tabular form for the various port areas in accordance with traffic and subgrade categories.

C.1. HOW TO USE THE CATALOGUE

The purpose of this catalogue is to present port pavement solutions for the various uses and areas described in Part 2, assuming a design life of 15 or 25 years; provisional solutions, for a design life of 3 or 8 years, are likewise presented. Several options are given under each set of circumstances, specifying in each case the materials that should be used for the various courses and the thickness of each layer. Although the choice of a particular solution from among the various possibilities should essentially be made on the basis of economic studies, operational, environmental and aesthetic considerations should also be weighed.

The procedure for selecting a pavement can be broken down into the following steps:

— Definition of subgrade category.
— Determination of general use of the area to be paved.
— Determination of kind of area under the general use considered.
— Definition of traffic category.

C.2. GENERAL COMMENTS

The entries consider the surfacing only, since, except where expressly mentioned otherwise, the bases and subbases are identical under all circumstances and dependent only upon the subgrade category.

The thicknesses shown should be considered to be minimum thicknesses at any given point on the pavement, so that mean thicknesses should be on the order of 0,01 to 0,03 m greater, depending on the tolerance allowed in each case and the finishing on the underlying course.

The catalogue refers, in principle, only to normal situations in port paving. For other port paving conditions not expressly shown in the catalogue, designers should adopt one of the solutions given for analogous circumstances that are explicitly considered. The approach in cases that are out of the ordinary should be along the lines discussed in part 6 and the corresponding annex.

For permanent pavements a design life of 25 years has been assumed. Where the designer establishes a 15-year design life, the appropriate pavement alternatives are those corresponding to one traffic category immediately under the one actually determined following the procedure described in part 3. Where the traffic category is found to be D, the solutions for a 15-year design life would the same as those specified for a 25-year design life.

The design life adopted for provisional pavements is 8 years. Where the designer establishes a design life of only 3 years, the appropriate pavement alternatives are those corresponding to one traffic category immediately under the one actually determined following the procedure described in part 3. Where the traffic category is found to be D, the solutions for a 3-year design life would the same as those specified for an 8-year design life.

C-3. CATALOGUE ENTRIES

The catalogue of standard port pavement structures comprises the following tables or entries:

Table C.0	General typology of port pavements structures recommended in the catalogue
Table C.1	Traffic categories
Table C.2	Subgrade categories
Table C.3	Bases and subbases
Tables C.4 to C.9	Commercial use
Tables C.10 to C.11	Industrial use
Tables C.12 to C.13	Military use
Tables C.14 to C.16	Fishing
Tables C.17 to C.18	Recreational use
Table C.19	Provisional pavements

In addition to the indications given in the catalogue entries themselves, designers should bear the following in mind:

— For situations not expressly considered in the catalogue entries, solutions should be adopted in accordance with the principles discussed in Parts 2 and 3.

— Designers should consider whether concrete block paving is an advisable solution in bulk solid storage areas, from the standpoint of cleanliness.

— In container stacking bays there are two aspects to be distinguished: container stacking and handling equipment traffic. The solutions shown in the corresponding catalogue entries (where the gravel beds are shown as a specific solution for stacking) are directly applicable to areas intended strictly for traffic. In areas intended for stacking containers, on the contrary, the following should be considered:

- Concrete pavers and gravel beds adapt perfectly well to this situation.
- Concrete pavement solutions do not meet theoretical calculation model requirements. The surfacing may crack, although this would not affect its serviceability.
- In the event of continuously reinforced and steel-fibre reinforced concrete pavements, the bars in the one case and the fibres in the other would tie the cracks together, so deterioration is not to be feared.
- For plain (vibrated or compacted) concrete, cracking may have a negative effect only where there is a great deal of heavy vehicle traffic. Therefore, cracking may be considered to be allowable and compatible with operations, providing it occurs in areas strictly intended for stacking containers (if the areas are devoted strictly to traffic, design meets the theoretical model calculations requirements, as indicated above).
- In order to totally guarantee concrete surfacing against failure of any kind in container stacking bays, reinforced concrete floor slabs must be included as part of the pavement design, following the criteria and procedures set out in Instruction EH-91.

By way of information only, these slabs, usually 0,30 to 0,40 m thick, are reinforced on both the under- and upperside and have grids equivalent to grids with 16-20 diameter mm bars, placed at about 20-cm intervals.

— In roll-trailer parking areas, if the solution involves specific, differential surfacing of a 1-m wide strip, the rest of the area should be paved following the criteria set out in Instruction 6.1 and 2 IC on pavement structures.

— Manoeuvring lanes must be surfaced to meet the strictest requirements of the highest traffic category found for the areas that they connect.

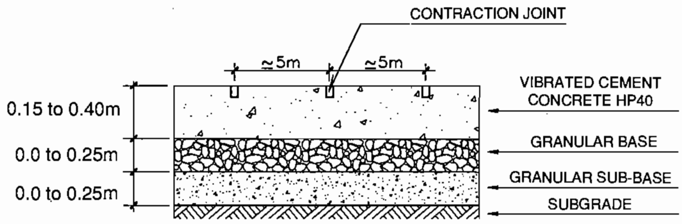
— The solution for access lanes should be determined in accordance with the provisions of Instruction 6.1 and 2 IC on pavement structures.

— In auxiliary areas intended for traffic, solutions should generally be adopted in accordance with Instruction 6.1 and 2 IC on pavement structures. However, designers may choose solutions such as those indicated for auxiliary parking areas. In any case, the solutions adopted should be in keeping with surfacing policy in nearby city streets.

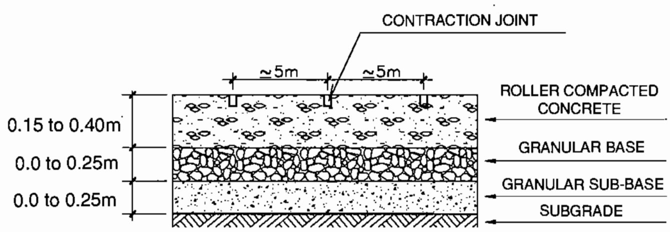
— The solutions shown in Table C.19 for provisional surfacing are merely indicative. Designers should weigh the advantages of solutions traditionally implemented in the port in question.

TABLE C.0. GENERAL TYPOLOGY OF STRUCTURAL SECTIONS FOR PORT PAVEMENTS RECOMMENDED IN THIS CATALOGUE.

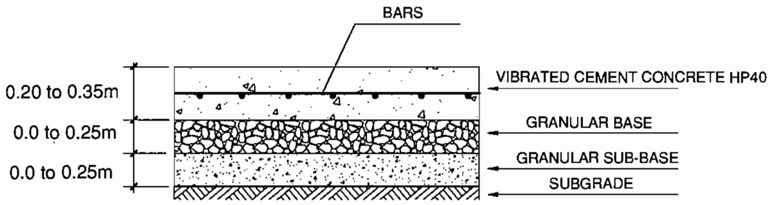
PERMANENT PAVEMENTS



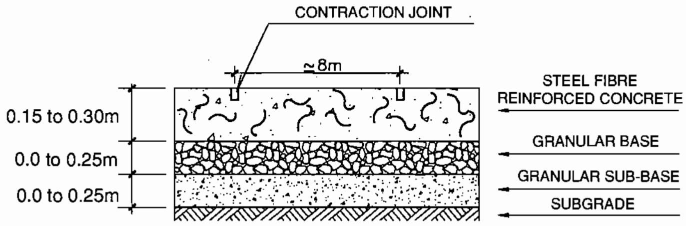
VIBRATED CEMENT CONCRETE PAVEMENT



ROLLER COMPACTED CONCRETE PAVEMENT



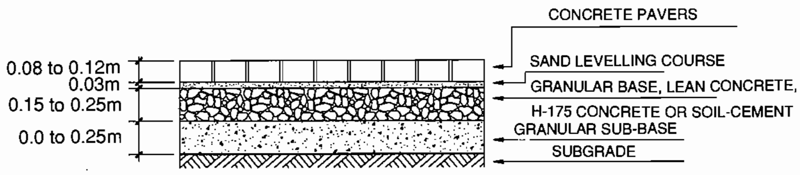
CONTINUOUSLY REINFORCED CONCRETE PAVEMENT



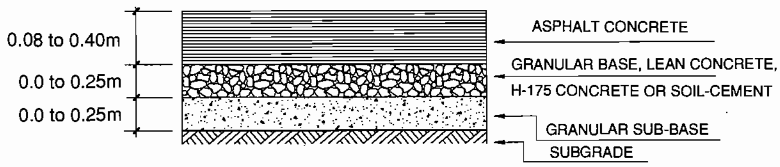
STEEL FIBRE REINFORCED CONCRETE PAVEMENT

TABLE C.0. (Continued)

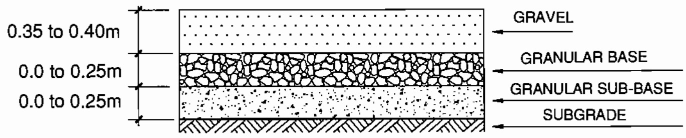
PERMANENT PAVEMENTS



CONCRETE PAVER PAVEMENT

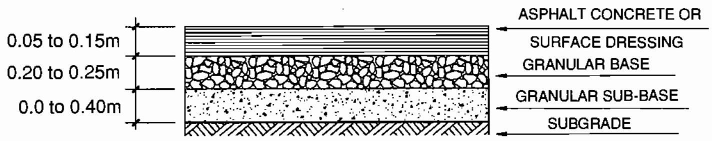


ASPHALTIC PAVEMENT



GRAVEL BEDS

PROVISIONAL PAVEMENTS



ASPHALTIC PAVEMENT

TABLE C.1.

TRAFFIC CATEGORIES (1)

USE RATES	DESIGN LOAD		
	LOW	MEDIUM	HIGH
LOW	D	C	B
MEDIUM	D	B	A
HIGH	C	B	A

NOTES:

(1) Except for access lanes and auxiliary traffic areas.

TABLE C.2.

SUBGRADE CATEGORIES

	FILL					
CAPPING LAYER	MNC (1)	RNC (1)	BNC (1)	MC	RC	BC
Absence (1)	E0	E0	E0	E0	E0	E1
Adequate soils	E0	E0	E0	E1	E1	E1
Selected soils	E1	E1	E1	E1	E2	E2
Ungraded quarry material	E1	E1	E1	E2	E2	E3
Selected soils with CBR>20	E1	E1	E2	E2	E3	E3

NOTES:

(1) In these cases proisional pavements should be laid.

TABLE C.3.

GRANULAR LAYERS

SUBGRADE CATEGORY	SUBBASE: UNBOUND GRANULAR MATERIAL	BASE: WET MIX MACADAM (3)
E0 (1)	0,40 m (2)	0,25 m
E1	0,25 m (2)	0,25 m
E2	----------	0,25 m
E3	----------	----------

NOTAS:

(1) For provisional surfacing only.
(2) Up to 0,05 m less is required if the unbound granular material is replaced by wet mix macadam.
(3) Except in those cases indicated below (concrete block paving with A or B traffic).

COMMERCIAL USE	WORKING AREAS		TABLE C.4.a.
I: VIBRATED CEMENT CONCRETE HP 40 [1]			
TRAFFIC A 0,32 m	TRAFFIC B 0,29 m	TRAFFIC C 0,26 m	TRAFFIC D 0,23 m
II: ROLLER COMPACTED CONCRETE			
TRAFFIC A 0,32 m	TRAFFIC B 0,29 m	TRAFFIC C 0,26 m	TRAFFIC D 0,23 m
III: CONTINOUSLY REINFORCED CONCRETE PAVEMENT			
TRAFFIC A 0,28 m	TRAFFIC B 0,25 m	TRAFFIC C 0,22 m	TRAFFIC D 0,20 m

NOTAS:

(1) Where HP 35 concrete is used, the thickness must be increased by 0,03 m

COMMERCIAL USE	WORKING AREAS		TABLE C.4.b.
IV: STEEL FIBRE-REINFORCED CONCRETE PAVEMENT			
TRAFFIC A	TRAFFIC B	TRAFFIC C	TRAFFIC D
0,25 m	0,22 m	0,20 m	0,18 m
V: CONCRETE BLOCK PAVING (1)			
TRAFFIC A (2)	TRAFFIC B (2)	TRAFFIC C	TRAFFIC D
0,12 m	0,10 m	0,10 m	0,08 m

NOTAS:

(1) In all cases the concrete pavers are laid on a sand levelling course that must be at least 0,03 m thick after compaction.
(2) Even where the subgrade category is E3, the base must consist of a course of one of the following materials: lean concrete (0,15 m), H-175 concrete (0,15 m) or cement-bound granular material (0,20 m).

COMMERCIAL USE	BULK SOLID STORAGE		TABLE C.5.a.
	I: VIBRATED CEMENT CONCRETE HP 40 (1)		
	TRAFFIC B 0,26 m	TRAFFIC C 0,23 m	TRAFFIC D 0,20 m
	II: ROLLER COMPACTED CONCRETE		
	TRAFFIC B 0,26 m	TRAFFIC C 0,23 m	TRAFFIC D 0,20 m
	III: CONTINOUSLY REINFORCED CONCRETE PAVEMENT (2)		
	TRAFFIC B 0,20 m	TRAFFIC C 0,18 m	TRAFFIC D 0,18 m

NOTES:

(1) Where HP 35 concrete is used, the thickness must be increased by 0,03 m.
(2) This solution is particularly recommendated for scrap metal storage areas.

COMMERCIAL USE	BULK SOLID STORAGE		TABLE C.5.b.
	IV: CONCRETE BLOCK PAVING [1]		
	TRAFFIC B [2]	TRAFFIC C	TRAFFIC D
	0,10 m	0,10 m	0,08 m
	V: ASPHALT CONCRETE		
	TRAFFIC B [3]	TRAFFIC C	TRAFFIC D
	0,30 m	0,25 m	0,20 m

NOTES:

(1) In all cases the concrete pavers are laid on a sand levelling course that must be at least 0,03 m thick after compaction.

(2) Even where the subgrade category is E3, the base must consist of a course of one of the following materials: lean concrete (0,15 m), H-175 concrete (0,15 m) or cement-bound granular material (0,20 m).

(3) This solution may only be used where handling equipment or cargo are guaranteed nor to cause surfacing. Designer should consider the possibility of replacing the upper 0,04 m with a leached pavement of the same thickness.

COMMERCIAL USE	GENERAL CARGO STORAGE		TABLE C.6.a.
	I: VIBRATED CEMENT CONCRETE HP 40 [1]		
TRAFFIC A 0,32 m	TRAFFIC B 0,29 m	TRAFFIC C 0,26 m	TRAFFIC D 0,23 m
	II: ROLLER COMPACTED CONCRETE		
TRAFFIC A 0,32 m	TRAFFIC B 0,29 m	TRAFFIC C 0,26 m	TRAFFIC D 0,23 m
	III: CONTINOUSLY REINFORCED CONCRETE PAVEMENT		
TRAFFIC A 0,28 m	TRAFFIC B 0,25 m	TRAFFIC C 0,22 m	TRAFFIC D 0,20 m

NOTES:

(1) Where HP 35 concrete is used, the thickness must be increased by 0,03 m.

COMMERCIAL USE	GENERAL CARGO STORAGE		TABLE C.6.b.
IV: STEEL FIBRE-REINFORCED CONCRETE PAVEMENT			
TRAFFIC A 0,25 m	TRAFFIC B 0,22 m	TRAFFIC C 0,20 m	TRAFFIC D 0,18 m
V: CONCRETE BLOCK PAVING [1]			
TRAFFIC A [2] 0,12 m	TRAFFIC B [2] 0,10 m	TRAFFIC C 0,10 m	TRAFFIC D 0,08 m
VI: ASPHALT CONCRETE			
TRAFFIC A [3] 0,40 m	TRAFFIC B [3] 0,35 m	TRAFFIC C 0,30 m	TRAFFIC D 0,25 m

NOTES:

(1) In all cases the concrete pavers are laid on a sand levelling course that must be at least 0,03 m thick after compaction.
(2) Even where the subgrade category is E3, the base must consist of a course of one of the following materials: lean concrete (0,15 m), H-175 concrete (0,15 m) or cement-bound granular material (0,20 m).
(3) Designers should consider the possibility of replacing the upper 0,04 m with a leached pavement of the same thickness.

COMMERCIAL USE	CONTAINER STACKING		TABLE C.7.a.
I: VIBRATED CEMENT CONCRETE HP 40 (1) (2)			
TRAFFIC A	TRAFFIC B	TRAFFIC C	TRAFFIC D
0,35 m	0,32 m	0,29 m	0,26 m
II: ROLLER COMPACTED CONCRETE (2)			
TRAFFIC A	TRAFFIC B	TRAFFIC C	TRAFFIC D
0,35 m	0,32 m	0,29 m	0,26 m
III: CONTINUOSLY REINFORCED CONCRETE PAVEMENT			
TRAFFIC A	TRAFFIC B	TRAFFIC C	TRAFFIC D
0,31 m	0,28 m	0,25 m	0,22 m

NOTES:

(1) Where HP 35 concrete is used, the thickness must be increased by 0,03 m.
(2) In container stacking bays cracking may occur at the thicknesses indicated; this may be allowed if the areas in question are to be used for storage only and nor for traffic.

COMMERCIAL USE	CONTAINER STACKING		TABLE C.7.b.
IV: STEEL FIBRE-REINFORCED CONCRETE PAVEMENT			
TRAFFIC A 0,28 m	TRAFFIC B 0,25 m	TRAFFIC C 0,22 m	TRAFFIC D 0,20 m
V: CONCRETE BLOCK PAVIG (1)			
TRAFFIC A (2) 0,12 m	TRAFFIC B (2) 0,10 m	TRAFFIC C 0,10 m	TRAFFIC D 0,08 m
VI: GRAVEL BEDS (3)			
TRAFFIC A 0,40 m	TRAFFIC B 0,40 m	TRAFFIC C 0,35 m	TRAFFIC D 0,35 m

NOTES:

(1) In all cases the concrete pavers are laid on a sand levelling course that must be at least 0,03 m thick after compaction.
(2) Even where the subgrade category is E3, the base must consist of a course of one of the following materials: lean concrete (0,15 m), H-175 concrete (0,15 m) or cement-bound granular material (0,20 m).
(3) For container stacking only. A different solution must be adopted for the traffic areas.

COMMERCIAL USE	ROLL-TRAILER PARKING LOTS [1]		TABLE C.8.a.
I: VIBRATED CEMENT CONCRETE HP 40 [2]			
TRAFFIC A 0,26 m	TRAFFIC B 0,23 m		
II: ROLLER COMPACTED CONCRETE			
TRAFFIC A 0,26 m	TRAFFIC B 0,23 m		

NOTES:

(1) Over the entire area, or only in a 1-m wide strip where the front end of the roll-trailer is set after being uncoupled from the tractor. In the later case, the solution for the rest of the area should be the same as for auxiliary parking areas (Table C.9).
(2) Where HP 35 concrete is used, the thickness must be increased by 0,03 m.

COMMERCIAL USE	ROLL-TRAILER PARKING LOTS [1]		TABLE C.8.b.
III: STEEL FIBRE-REINFORCED CONCRETE PAVEMENT			
TRAFFIC A 0,20 m	TRAFFIC B 0,18 m		
IV: CONCRETE BLOCK PAVING [2]			
TRAFFIC A [3] 0,10 m	TRAFFIC B [3] 0,08 m		

NOTES:

(1) Over the entire area, or only in a 1-m wide strip where the front end of the roll-trailer is set after being uncoupled from the tractor. In the later case, the solution for the rest of the area should be the same as for auxiliary parking areas (Table C.9).
(2) In all cases the concrete pavers are laid on a sand levelling course that must be at least 0,03 m thick after compaction.
(3) Even where the subgrade category is E3, the base must consist of a course of one of the following materials: lean concrete (0,15 m), H-175 concrete (0,15 m) or cement-bound granular material (0,20 m).

COMMERCIAL USE	AUXILIARY AREAS. PARKING		TABLE C.9.a.
I: VIBRATED CEMENT CONCRETE HP 40 [1]			
TRAFFIC A 0,26 m	TRAFFIC B 0,23 m	TRAFFIC C 0,20 m	TRAFFIC D 0,20 m
II: ROLLER COMPACTED CONCRETE			
TRAFFIC A 0,26 m	TRAFFIC B 0,23 m	TRAFFIC C 0,20 m	TRAFFIC D 0,20 m
III: CONTINOUSLY REINFORCED CONCRETE PAVEMENTS			
TRAFFIC A 0,20 m	TRAFFIC B 0,18 m		

NOTES:

(1) Where HP 35 concrete is used, the thickness must be increased by 0,03 m.

COMMERCIAL USE	AUXILIARY AREAS. PARKING		TABLE C.9.b.
IV: CONCRETE BLOCK PAVING [1]			
TRAFFIC A [2]	TRAFFIC B [2]	TRAFFIC C	TRAFFIC D
0,10 m	0,08 m	0,08 m	0,08 m
V: ASPHALT CONCRETE			
TRAFFIC A [2] [3]	TRAFFIC B [2] [3]	TRAFFIC C [2] [4]	TRAFFIC D [2] [5]
0,18 m	0,15 m	0,12 m	0,08 m

NOTES:

(1) In all cases the concrete pavers are laid on a sand levelling course that must be at least 0,03 m thick after compaction.
(2) Even where the subgrade category is E3, the base must consist of a course of one of the following materials: lean concrete (0,15 m), H-175 concrete (0,15 m) or cement-bound granular material (0,20 m).
(3) Designers should consider the possibility of replacing the upper 0,04 m with a leached pavement of the same thickness.
(4) Two courses of hot asphalt concrete, the upper one with a thickness of 0,06 m.
(5) Two 0,04 m courses of open cold mix, later on slurry sealed.

INDUSTRIAL USE	WORKING AREAS		TABLE C.10.a.
I: VIBRATED CEMENT CONCRETE HP 40 [1]			
TRAFFIC A	TRAFFIC B	TRAFFIC C	TRAFFIC D
0,32 m	0,29 m	0,26 m	0,23 m
II: ROLLER COMPACTED CONCRETE			
TRAFFIC A	TRAFFIC B	TRAFFIC C	TRAFFIC D
0,32 m	0,29 m	0,26 m	0,23 m
III: CONTINOUSLY REINFORCED CONCRETE PAVEMENT			
TRAFFIC A	TRAFFIC B	TRAFFIC C	TRAFFIC D
0,28 m	0,25 m	0,22 m	0,20 m

NOTES:

(1) Where HP 35 concrete is used, the thickness must be increased by 0,03 m.

INDUSTRIAL USE	WORKING AREAS		TABLE C.10.b.
IV: STEEL FIBRE-REINFORCED CONCRETE PAVEMENT			
TRAFFIC A 0,25 m	TRAFFIC B 0,22 m	TRAFFIC C 0,20 m	TRAFFIC D 0,18 m
V: CONCRETE BLOCK PAVING (1)			
TRAFFIC A (2) 0,12 m	TRAFFIC B (2) 0,10 m	TRAFFIC C 0,10 m	TRAFFIC D 0,08 m

NOTAS:

(1) In all cases the concrete pavers are laid on a sand levelling course that must be at least 0,03 m thick after compaction.
(2) Even where the subgrade category is E3, the base must consist of a course of one of the following materials: lean concrete (0,15 m), H-175 concrete (0,15 m) or cement-bound granular material (0,20 m).

INDUSTRIAL USE	STORAGE AREAS		TABLE C.11.a.
	I: VIBRATED CEMENT CONCRETE HP 40 [1]		
TRAFFIC A	TRAFFIC B	TRAFFIC C	TRAFFIC D
0,32 m	0,29 m	0,26 m	0,23 m
	II: ROLLER COMPACTED CONCRETE		
TRAFFIC A	TRAFFIC B	TRAFFIC C	TRAFFIC D
0,32 m	0,29 m	0,26 m	0,23 m
	III: CONTINOUSLY REINFORCED CONCRETE PAVEMENT		
TRAFFIC A	TRAFFIC B	TRAFFIC C	TRAFFIC D
0,28 m	0,25 m	0,22 m	0,20 m

NOTES:

(1) Where HP 35 concrete is used, the thickness must be increased by 0,03 m.

INDUSTRIAL USE	STORAGE AREAS		TABLE C.11.b.
IV: STEEL FIBRE-REINFORCED CONCRETE PAVEMENT			
TRAFFIC A	TRAFFIC B	TRAFFIC C	TRAFFIC D
0,25 m	0,22 m	0,20 m	0,18 m
V: CONCRETE BLOCK PAVING (1)			
TRAFFIC A (2)	TRAFFIC B (2)	TRAFFIC C	TRAFFIC D
0,12 m	0,10 m	0,10 m	0,08 m
VI: ASPHALT CONCRETE			
TRAFFIC A (3)	TRAFFIC B (3)	TRAFFIC C	TRAFFIC D
0,40 m	0,35 m	0,30 m	0,25 m

NOTES:

(1) In all cases the concrete pavers are laid on a sand levelling course that must be at least 0,03 m thick after compaction.
(2) Even where the subgrade category is E3, the base must consist of a course of one of the following materials: lean concrete (0,15 m), H-175 concrete (0,15 m) or cement-bound granular material (0,20 m).
(3) Designers should consider the possibility of replacing the upper 0,04 m with a leached pavement of the same thickness.

MILITARY USE	WORKING AREAS		TABLE C.12.a.
I: VIBRATED CEMENT CONCRETE HP 40 [1]			
TRAFFIC A 0,32 m	TRAFFIC B 0,29 m	TRAFFIC C 0,26 m	TRAFFIC D 0,23 m
II: ROLLER COMPACTED CONCRETE			
TRAFFIC A 0,32 m	TRAFFIC B 0,29 m	TRAFFIC C 0,26 m	TRAFFIC D 0,23 m
III: CONTINOUSLY REINFORCED CONCRETE PAVEMENT			
TRAFFIC A 0,28 m	TRAFFIC B 0,25 m	TRAFFIC C 0,22 m	TRAFFIC D 0,20 m

NOTES:

(1) Where HP 35 concrete is used, the thickness must be increased by 0,03 m.

MILITARY USE	WORKING AREAS		TABLE C.12.b.
IV: STEEL FIBRE-REINFORCED CONCRETE PAVEMENT			
TRAFFIC A	TRAFFIC B	TRAFFIC C	TRAFFIC D
0,25 m	0,22 m	0,20 m	0,18 m
V: ONCRETE BLOCK PAVING (1)			
TRAFFIC A (2)	TRAFFIC B (2)	TRAFFIC C	TRAFFIC D
0,12 m	0,10 m	0,10 m	0,08 m

NOTES:

(1) In all cases the concrete pavers are laid on a sand levelling course that must be at least 0,03 m thick after compaction.
(2) Even where the subgrade category is E3, the base must consist of a course of one of the following materials: lean concrete (0,15 m), H-175 concrete (0,15 m) or cement-bound granular material (0,20 m).

MILITARY USE	STORAGE AREAS		TABLE C.13.a.
I: VIBRATED CEMENT CONCRETE HP 40 (1)			
TRAFFIC A	TRAFFIC B	TRAFFIC C	TRAFFIC D
0,29 m	0,26 m	0,26 m	0,23 m
II: ROLLER COMPACTED CONCRETE			
TRAFFIC A	TRAFFIC B	TRAFFIC C	TRAFFIC D
0,29 m	0,26 m	0,26 m	0,23 m
III: CONTINOUSLY REINFORCED CONCRETE PAVEMENT			
TRAFFIC A	TRAFFIC B	TRAFFIC C	TRAFFIC D
0,25 m	0,22 m	0,22 m	0,20 m

NOTES:

(1) Where HP 35 concrete is used, the thickness must be increased by 0,03 m.

MILITARY USE	STORAGE AREAS		TABLE C.13.b.
IV: STEEL FIBRE-REINFORCED CONCRETE PAVEMENT			
TRAFFIC A 0,22 m	TRAFFIC B 0,20 m	TRAFFIC C 0,20 m	TRAFFIC D 0,18 m
V: CONCRETE BLOCK PAVING [1]			
TRAFFIC A [2] 0,10 m	TRAFFIC B [2] 0,10 m	TRAFFIC C 0,08 m	TRAFFIC D 0,08 m
VI: ASPHALT CONCRETE			
TRAFFIC A [3] 0,40 m	TRAFFIC B [3] 0,35 m	TRAFFIC C 0,30 m	TRAFFIC D 0,25 m

NOTES:

(1) In all cases the concrete pavers are laid on a sand levelling course that must be at least 0,03 m thick after compaction.
(2) Even where the subgrade category is E3, the base must consist of a course of one of the following materials: lean concrete (0,15 m), H-175 concrete (0,15 m) or cement-bound granular material (0,20 m).
(3) Designers should consider the possibility of replacing the upper 0,04 m with a leached pavement of the same thickness.

FISHING USE	WORKING AREAS		TABLE C.14.a.
I: VIBRATED CEMENT CONCRETE HP 40 [1]			
TRAFFIC A 0,32 m	TRAFFIC B 0,29 m	TRAFFIC C 0,26 m	TRAFFIC D 0,23 m
II: ROLLER COMPACTED CONCRETE			
TRAFFIC A 0,32 m	TRAFFIC B 0,29 m	TRAFFIC C 0,26 m	TRAFFIC D 0,23 m
III: CONTINOUSLY REINFORCED CONCRETE PAVEMET			
TRAFFIC A 0,28 m	TRAFFIC B 0,25 m	TRAFFIC C 0,22 m	TRAFFIC D 0,20 m

NOTES:

(1) Where HP 35 concrete is used, the thickness must be increased by 0,03 m.

FISHING USE	WORKING AREAS		TABLE C.14.b.
IV: STEEL FIBRE-REINFORCED CONCRETE PAVEMENT			
TRAFFIC A 0,25 m	TRAFFIC B 0,22 m	TRAFFIC C 0,20 m	TRAFFIC D 0,18 m
V: CONCRETE BLOCK PAVING (1)			
TRAFFIC A (2) 0,12 m	TRAFFIC B (2) 0,10 m	TRAFFIC C 0,10 m	TRAFFIC D 0,08 m
VI: ASPHALT CONCRETE			
TRAFFIC A (3) 0,40 m	TRAFFIC B (3) 0,35 m	TRAFFIC C 0,30 m	TRAFFIC D 0,25 m

NOTES:

(1) In all cases the concrete pavers are laid on a sand levelling course that must be at least 0,03 m thick after compaction.
(2) Even where the subgrade category is E3, the base must consist of a course of one of the following materials: lean concrete (0,15 m), H-175 concrete (0,15 m) or cement-bound granular material (0,20 m).
(3) Designers should consider the possibility of replacing the upper 0,04 m with a leached pavement of the same thickness.

FISHING USE	CLASSIFICATION, PREPARATION AND SELLING		TABLE C.15
I: VIBRATED CEMENT CONCRETE HP 40 [1]			
TRAFFIC A 0,29 m	TRAFFIC B 0,26 m	TRAFFIC C 0,26 m	TRAFFIC D 0,23 m
II: ROLLER COMPACTED CONCRETE			
TRAFFIC A 0,29 m	TRAFFIC B 0,26 m	TRAFFIC C 0,26 m	TRAFFIC D 0,23 m
III: ASPHALT CONCRETE			
TRAFFIC A [2] 0,40 m	TRAFFIC B [2] 0,35 m	TRAFFIC C 0,30 m	TRAFFIC D 0,25 m

NOTES:

(1) Where HP 35 concrete is used, the thickness must be increased by 0,03 m.
(2) Designers should consider the possibility of replacing the upper 0,04 m with a leached pavement of the same thickness.

FISHING USE	AUXILIARY AREAS. PARKING		TABLE C.16.a.
I: VIBRATED CEMENT CONCRETE HP 40 [1]			
TRAFFIC A 0,26 m	TRAFFIC B 0,23 m	TRAFFIC C 0,20 m	TRAFFIC D 0,20 m
II: ROLLER COMPACTED CONCRETE			
TRAFFIC A 0,26 m	TRAFFIC B 0,23 m	TRAFFIC C 0,20 m	TRAFFIC D 0,20 m
III: CONTINOUSLY REINFORCED CONCRETE PVEMENTS			
TRAFFIC A 0,20 m	TRAFFIC B 0,18 m		

NOTES:

(1) Where HP 35 concrete is used, the thickness must be increased by 0,03 m.

FISHING USE	AUXILIARY AREAS. PARKING		TABLE C.16.b.
IV: CONCRETE BLOCK PAVING [1]			
TRAFFIC A [2]	TRAFFIC B [2]	TRAFFIC C	TRAFFIC D
0,10 m	0,08 m	0,08 m	0,08 m
V: ASPHALT CONCRETE			
TRAFFIC A [2] [3]	TRAFFIC B [2] [3]	TRAFFIC C [2] [4]	TRAFFIC D [2] [5]
0,18 m	0,15 m	0,12 m	0,08 m

NOTES:

(1) In all cases the concrete pavers are laid on a sand levelling course that must be at least 0,03 m thick after compaction.
(2) Even where the subgrade category is E3, the base must consist of a course of one of the following materials: lean concrete (0,15 m), H-175 concrete (0,15 m) or cement-bound granular material (0,20 m).
(3) Designers should consider the possibility of replacing the upper 0,04 m with a leached pavement of the same thickness.
(4) Two courses of hot asphalt concrete, the upper one with a thickness of 0,06 m.
(5) Two 0,04 m courses of open cold mix, later on slurry sealed.

RECREATIONAL USE	WORKING OR LAUNCHING AREAS		TABLE C.17.a.
I: VIBRATED CEMENT CONCRETE HP 40 [1]			
TRAFFIC A 0,32 m	TRAFFIC B 0,29 m	TRAFFIC C 0,26 m	TRAFFIC D 0,23 m
II: ROLLER COMPACTED CONCRETE			
TRAFFIC A 0,32 m	TRAFFIC B 0,29 m	TRAFFIC C 0,26 m	TRAFFIC D 0,23 m
III: CONTINOUSLY REINFORCED CONCRETE PAVEMENT			
TRAFFIC A 0,28 m	TRAFFIC B 0,25 m	TRAFFIC C 0,22 m	TRAFFIC D 0,20 m

NOTES:

(1) Where HP 35 concrete is used, the thickness must be increased by 0,03 m.

RECREATIONAL USE	WORKING OR LAUNCHING AREAS		TABLE C.17.b.
IV: CONCRETE BLOCK PAVING [1]			
TRAFFIC A [2]	TRAFFIC B [2]	TRAFFIC C	TRAFFIC D
0,12 m	0,10 m	0,10 m	0,08 m
V: ASPHALT CONCRETE			
TRAFFIC A [3]	TRAFFIC B [3]	TRAFFIC C	TRAFFIC D
0,40 m	0,35 m	0,30 m	0,25 m

NOTES:

(1) In all cases the concrete pavers are laid on a sand levelling course that must be at least 0,03 m thick after compaction.
(2) Even where the subgrade category is E3, the base must consist of a course of one of the following materials: lean concrete (0,15 m), H-175 concrete (0,15 m) or cement-bound granular material (0,20 m).
(3) Designers should consider the possibility of replacing the upper 0,04 m with a leached pavement of the same thickness.

RECREATIONAL USE	AUXILIARY AREAS. PARKING		TABLE C.18.a.
I: VIBRATED CEMENT CONCRETE HP 40 [1]			
TRAFFIC A 0,26 m	TRAFFIC B 0,23 m	TRAFFIC C 0,20 m	TRAFFIC D 0,20 m
II: ROLLER COMPACTED CONCRETE			
TRAFFIC A 0,26 m	TRAFFIC B 0,23 m	TRAFFIC C 0,20 m	TRAFFIC D 0,20 m
III: STEEL FIBRE-REINFORCED CONCRETE PAVEMENT			
TRAFFIC A 0,20 m	TRAFFIC B 0,18 m		

NOTES:

(1) Where HP 35 concrete is used, the thickness must be increased by 0,03 m.

RECREATIONAL USE	AUXILIARY AREAS. PARKING		TABLE C.18.b.
IV: CONCRETE BLOCK PAVING (1)			
TRAFFIC A (2)	TRAFFIC B (2)	TRAFFIC C	TRAFFIC D
0,10 m	0,08 m	0,08 m	0,08 m
V: ASPHALT CONCRETE			
TRAFFIC A (2) (3)	TRAFFIC A (2) (3)	TRAFFIC C (2) (4)	TRAFFIC D (2) (5)
0,18 m	0,15 m	0,12 m	0,08 m

NOTES:

(1) In all cases the concrete pavers are laid on a sand levelling course that must be at least 0,03 m thick after compaction.
(2) Even where the subgrade category is E3, the base must consist of a course of one of the following materials: lean concrete (0,15 m), H-175 concrete (0,15 m) or cement-bound granular material (0,20 m).
(3) Designers should consider the possibility of replacing the upper 0,04 m with a leached pavement of the same thickness.
(4) Two courses of hot asphalt concrete, the upper one with a thickness of 0,06 m.
(5) Two 0,04 m courses of open cold mix, later on slurry sealed.

TABLE C.19.

PROVISIONAL SURFACING [(1)]

I: ASPHALT CONCRETE AND SURFACE DRESSINGS			
TRAFFIC A [(2)]	TRAFFIC B [(2)]	TRAFFIC C [(3)]	TRAFFIC D
0,15 m	0,12 m	0,08 m	0,05 [(4)] or DTS [(5)]

NOTES:

(1) For all uses and areas, providing that expected deformation is compatible with operation. In certain situations (caterpillar vehicle parking areas, for instance), designers may consider the possibility of on surfacing whatsoever, using the wet mix macadam as such. In this case, this course would be laid even on subgrade category E3.
(2) Two courses of hot asphalt concrete, the upper one, with a thickness of 0,06 m. In this layer the material should be highly resistant to plastic deformation.
(3) Two 0,04 m courses of open cold mix, later on slurry sealed.
(4) One course of open cold mix, later on slurry sealed.
(5) Double surface dressing.