



# PIANC

The World Association for Waterborne  
Transport Infrastructure

## THE DESIGN OF TERMINALS FOR RORO AND ROPAX VESSELS



MarCom Working Group Report N° 167 – 2023

# PIANC REPORT N° 167

MARITIME NAVIGATION COMMISSION

## THE DESIGN OF TERMINALS FOR RORO AND ROPAX VESSELS

September 2023

PIANC has Technical Commissions concerned with inland waterways and ports (InCom), coastal and ocean waterways (including ports and harbours) (MarCom), environmental aspects (EnviCom) and sport and pleasure navigation (RecCom).

This report has been produced by an international Working Group convened by the Maritime Navigation Commission (MarCom). Members of the Working Group represent several countries and are acknowledged experts in their profession.

The objective of this report is to provide information and recommendations on good practice. Conformity is not obligatory and engineering judgement should be used in its application, especially in special circumstances. This report should be seen as an expert guidance and state-of-the-art on this particular subject. PIANC disclaims all responsibility in the event that this report should be presented as an official standard.

**PIANC HQ**  
**Boulevard du Roi Albert II 20 B. 3**  
**1000 Brussels | Belgium**

<http://www.pianc.org>

VAT BE 408-287-945

ISBN 978-2-87223-031-0

© All rights reserved

# TABLE OF CONTENTS

LIST OF FIGURES .....	<b>9</b>
<b>1 PRELIMINARIES .....</b>	<b>15</b>
1.1 Scope.....	15
1.2 Introduction.....	15
1.2.1 Terms of Reference .....	15
1.2.2 Structure of Report .....	15
1.2.3 Existing Relevant Reports.....	16
1.2.4 Composition of the Working Group .....	18
1.2.5 Meetings.....	19
1.2.6 Acknowledgements.....	20
<b>2 THE PURPOSE OF RORO AND ROPAX TERMINALS .....</b>	<b>21</b>
2.1 What are RoRo and RoPax? .....	21
2.1.1 Definitions .....	21
2.1.2 Localised Variants.....	21
2.2 The Development of the RoRo Mode .....	21
2.2.1 The Influence of the Railway Boom.....	22
2.2.2 The Development of Road Vehicle RoRo.....	24
2.2.3 The Ongoing Development of RoRo Technology.....	26
2.2.4 Passenger Access.....	27
2.2.5 The Evolution of RoRo Ships and Cargo Handling Systems .....	28
2.3 The Role of RoRo in Shipping .....	31
2.3.1 Harbour and River Crossings.....	31
2.3.2 Inter-Island Lifeline Services .....	31
2.3.3 'Marine Bridge' Services – Short Sea Shipping.....	32
2.3.4 As Part of the Supply Chain in the Manufacturing and Delivery of Wheeled vehicles .....	32
2.3.5 Coastal Short Sea Shipping – The Motorways of the Seas.....	33
<b>3 TYPES OF RORO AND ROPAX SYSTEMS.....</b>	<b>33</b>
3.1 Objective of this Chapter .....	33
3.2 Types of Cargo.....	34
3.3 Freight-Only RoRo .....	36
3.3.1 Vessels for Freight-Only RoRo .....	36
3.3.2 Freight-Only RoRo Terminals.....	37
3.4 RoPax Transport .....	41
3.4.1 Vessels for RoPax Services.....	41
3.4.2 RoPax Terminals .....	46
3.5 Deep Sea RoRo.....	56
3.5.1 Pure Car Carriers (PCC) and Pure Car Truck Carriers (PCTC).....	56
3.5.2 Trade Vehicle Terminals .....	57
3.5.3 ConRo/RoLo Vessels .....	59
3.6 Rail RoRo.....	60
3.6.1 General .....	60
3.6.2 Rail RoRo with Passengers .....	61
3.6.3 Specialised Freight Rail RoRo .....	63
3.6.4 Rail RoRo Terminals.....	64
3.7 Specialised RoRo Operations .....	65
3.7.1 RoRo Barge Systems in the USA.....	65
3.7.2 River Transport Applications.....	67

3.7.3	Abnormal Indivisible Loads – RoRo for Special Projects .....	67
<b>4</b>	<b>SHIP AND BERTH REQUIREMENTS .....</b>	<b>69</b>
4.1	Structure of this Chapter .....	69
4.2	Vessel Sizes and Types .....	70
4.2.1	Effect of Vessel Size and Design on Berth Facilities .....	70
4.2.2	Recommended Approach to Ship Size Assessment .....	76
4.2.3	Ship Hull Issues .....	77
4.3	Berth Layout and Structures .....	82
4.3.1	General .....	82
4.3.2	Typical RoRo Berth Layouts .....	83
4.3.3	Berth Approaches .....	90
4.3.4	Berth Location .....	91
4.4	Fenders .....	91
4.4.1	General .....	91
4.4.2	Planning Fendering for RoRo and RoPax Berths .....	92
4.4.3	Fender Types .....	94
4.4.4	Fender Systems .....	98
4.4.5	Berthing Energy .....	102
4.4.6	Fender Panel Dimensions .....	103
4.4.7	Fender Facings .....	104
4.4.8	Comparison of Fender Types .....	104
4.5	Moorings .....	107
4.5.1	General .....	107
4.5.2	Mooring Design Requirements .....	107
4.5.3	Height of Vessel Mooring Points .....	108
4.5.4	Assuring Vessel Positioning .....	108
4.5.5	Solutions for Rapid Turnaround Berths .....	109
4.5.6	Mediterranean Moorings .....	111
4.6	Scour Protection .....	111
4.7	Ship to Shore Access Geometry and Loading Requirements .....	112
4.7.1	General .....	112
4.7.2	Geometric Requirements .....	112
4.7.3	Vessel Movements .....	117
4.7.4	Loadings on Access Systems .....	118
<b>5</b>	<b>SHIP TO SHORE VEHICLE AND PASSENGER ACCESS .....</b>	<b>119</b>
5.1	Introduction .....	119
5.1.1	Objectives of the Chapter .....	119
5.1.2	The Challenges of Ship to Shore Vehicle and Passenger Access .....	120
5.1.3	Selection Criteria .....	121
5.1.4	The Importance of Linkspans and PBBs .....	123
5.1.5	Design Standards and Regulations for Ship to Shore Vehicle and Passenger Access .....	131
5.2	Type and Characteristics of Ship to Shore Vehicle Access .....	132
5.2.1	Fixed Ramps – Main Types and Configurations .....	133
5.2.2	Linkspans - Main Types and Configurations .....	137
5.2.3	Concept Designs and Risk Assessments for Linkspans .....	163
5.2.4	Design Issues – Bearings and Articulation .....	163
5.2.5	Design Issues – Bridge Spans .....	168
5.2.6	Linkspan Decks .....	173

5.2.7	Design Issues – Pontoons .....	174
5.2.8	Design Issues – Seismic Effects .....	181
5.2.9	Design Issues – Transportation and Installation .....	186
5.2.10	Double Decking of Linkspans .....	186
5.3	Type and Characteristics of Passenger Boarding Bridges (PBBs) .....	187
5.3.1	Function of PBBs .....	187
5.3.2	Terminology. ....	188
5.3.3	Types of PBBs .....	190
5.3.4	Deciding on the Range of Access Capability .....	200
5.3.5	The Design of PBBs .....	201
5.4	Machinery, Safety and Reliability .....	215
5.4.1	Key Elements of Linkspans and PBBs .....	215
5.4.2	Lifting Equipment for Linkspans .....	215
5.4.3	Deployment Equipment for Flaps and Finger Flaps .....	219
5.4.4	Pumping Equipment for Floating Linkspans .....	221
5.4.5	Lifting Equipment and Actuators for PBBs .....	221
5.4.6	What is Required for Safety and Reliability? (Hierarchy of Risk Reduction) .....	226
5.4.7	Control System Safety Functions and Functional Safety .....	226
5.4.8	Regulations and Frameworks for Safety and Reliability .....	227
5.5	Procurement Issues .....	230
5.5.1	Upgrading and Refurbishment .....	231
5.6	Skills for Operating and Maintaining the Facility .....	232
5.6.1	Operators .....	232
5.6.2	Maintenance Engineers .....	233
5.7	Operating and Maintenance Manuals .....	233
6	TERMINAL PLANNING .....	<b>234</b>
6.1	Objectives of this Chapter .....	234
6.2	Terms Used in this Chapter .....	235
6.3	The ISPS (International Ship and Port Security) Code of Practice .....	235
6.4	The Key Scenarios for Planning RoRo and RoPax Terminals .....	236
6.4.1	'Marine Bridge' Type RoRo Trades .....	236
6.4.2	'Port Visit' Type RoRo Trades .....	237
6.4.3	'Hybrid' Type RoRo Trades .....	237
6.5	Ship Capacity Issues .....	238
6.5.1	General .....	238
6.5.2	Freight/Car Carrying Capacities .....	238
6.5.3	The Use of Hoistable Mezzanine Decks to Enhance Car Carrying Capacity .....	240
6.5.4	Passenger Carrying Capacities .....	241
6.6	Planning for Future Trade Flows .....	242
6.6.1	Trade Unit Measurement .....	242
6.6.2	Trade Forecasting .....	243
6.6.3	The 'Marine Bridge' Group of RoRo Trades .....	244
6.6.4	The 'Port Visit' Group of Trades .....	251
6.7	RoRo Terminal Zoning .....	253
6.7.1	General Principles .....	253
6.7.2	Other RoRo Operation Requirements .....	262
6.7.3	Area Impacts .....	263
6.7.4	Traffic Circulation .....	268
6.7.5	Gatehouses, Customs and Security .....	269

6.7.6	Effects on the Hinterland.....	269
6.7.7	Other Ship Services .....	269
6.7.8	Terminal Safety.....	269
6.7.9	Special Requirements for Rail RoRo.....	270
6.7.10	Intermodality.....	270
6.7.11	Specialist RoRo Trades.....	271
6.7.12	Allowing for Future Development.....	271
<b>7</b>	<b>MECHANICAL AND ELECTRICAL SERVICES .....</b>	<b>271</b>
7.1	General.....	271
7.2	Water Supply and Distribution .....	271
7.3	Storm Water Drainage .....	271
7.4	Foul Drainage and Sewage Disposal .....	272
7.5	Electric Services .....	272
7.5.1	Power Supply .....	272
7.5.2	Power Requirements.....	272
7.5.3	Lighting.....	274
7.6	Communications Networks.....	274
7.7	Fuel Bunkering .....	274
<b>8</b>	<b>PASSENGER TERMINAL BUILDINGS .....</b>	<b>275</b>
8.1	Introduction.....	275
8.2	Passenger Terminal Buildings .....	275
8.2.1	Layout of this Part of the Report.....	275
8.2.2	Passenger Processes .....	281
8.2.3	Evaluating Passenger and Personnel Numbers .....	283
8.2.4	The Impact of Information Technology .....	288
8.2.5	The Impact of the ISPS (International Ship and Port Security) Code of Practice .....	288
8.2.6	Terminal Building Elements .....	288
8.2.7	Other Facilities .....	295
8.2.8	Waste Management.....	296
8.2.9	Building Materials and Technical Solutions .....	297
8.3	Other Terminal Buildings .....	297
8.4	Positioning the Terminal Building .....	297
<b>9</b>	<b>THE PORT CITY INTERFACE .....</b>	<b>298</b>
9.1	Introduction.....	298
9.2	Different Interfaces – Different Impacts.....	300
9.2.1	The Spatial Interface.....	300
9.2.2	The Economic Interface.....	301
9.2.3	The Political Interface.....	301
9.2.4	The Social Interface .....	301
9.2.5	The Environmental Interface .....	301
9.3	The Present Environment of the City – Port Relationships .....	302
9.4	Co-operation and Communication .....	304
9.5	A Passenger Terminal in a Ferry Port is an Urban Enhancement .....	305
<b>10</b>	<b>Procurement and Implementation.....</b>	<b>306</b>
<b>11</b>	<b>Management, Operation and Maintenance .....</b>	<b>307</b>
11.1	General.....	307
11.2	Port Ownership and Management.....	308
11.3	Operations.....	309
11.4	The Importance of Maintenance .....	309

12	SUSTAINABILITY AND FUTURE PROOFING OF RORO AND ROPAX TERMINALS .....	<b>310</b>
12.1	Sustainability .....	310
12.1.1	General .....	310
12.1.2	Modalities and Connectivity .....	311
12.1.3	Dredging Impacts.....	313
12.1.4	Energy and Climate Change Mitigations.....	314
12.1.5	Climate Adaptation.....	315
12.1.6	Landscape Management and Quality of Life.....	316
12.2	Future Proofing RoRo and RoPax Terminals .....	316
12.2.1	Case Study – The FastShip Concept.....	317
12.2.2	The Move to 'Net Zero' Carbon Emissions .....	317
12.2.3	Allowing for Future Machinery Upgrades .....	319
12.2.4	The Impact of Autonomous Vehicles on RoRo .....	319
12.3	The Future of RoRo.....	320
13	REFERENCES.....	<b>320</b>
	APPENDIX A: TERMS OF REFERENCE.....	<b>327</b>
	A.1 Historical Background (Definition of the Problem).....	327
	A.2 Objectives of the Working Group.....	327
	A.3 Existing Reports .....	327
	A.4 Matters to be Investigated.....	328
	A.5 Suggested Final Product of the Working Group .....	328
	A.6 Desirable Disciplines of the Members of the Working Group .....	328
	A.7 Relevance for Countries in Transition .....	328
	APPENDIX B: GLOSSARY AND ABBREVIATIONS .....	<b>329</b>
	B.1 Glossary.....	329
	B.2 Abbreviations .....	333
	APPENDIX C PORT CITY INTERFACE CASE STUDIES.....	<b>334</b>
	C.1 CASE STUDY – PORT OF SANTANDER .....	334
	C.2 CASE STUDY – PORT OF TANGIERS CITY [71].....	335
	C.3 CASE STUDY – PORT OF BARCELONA .....	336



## LIST OF FIGURES

Figure 2.1: Examples of horse ferry river crossings RoRo dated 1905, 1893 .....	22
Figure 2.2: An early rail RoRo facility in Scotland .....	22
Figure 2.3: First World War train ferry carrying rail wagons and road vehicles at Richborough secret port – 1916.....	23
Figure 2.4: RoRo Linkspan with flaps dropping onto the vessel (Dover) .....	24
Figure 2.5: An example of Mediterranean Mooring of RoRo ships – Durres, Albania.....	25
Figure 2.6: Ship ramp on a linkspan – Rosslare Ferryport, Ireland .....	25
Figure 2.7: Ocean going RoRo vessels with quarter ramp. ....	26
Figure 2.8: Internal ramps in a RoRo ship .....	26
Figure 2.9: Linkspan for a very large tidal range (Elizabeth Harbour, St Helier, Jersey) .....	27
Figure 2.10: Simple gangway for passenger access .....	27
Figure 2.11: Glass sided passenger boarding bridges in Helsinki.....	28
Figure 2.12: The capsizing of the MV Herald of Free Enterprise .....	29
Figure 2.13: Double deck access onto a ferry –Holyhead.....	29
Figure 2.14: Access through the side of the vessel (Trelleborg) .....	30
Figure 2.15: Unaccompanied highway trailers, parked on land and stowed in a RoRo ship. ....	30
Figure 2.16: Examples of a cross harbour/river ferries (Tanzania and UK) .....	31
Figure 2.17: PCTC Vessel (Tilbury, UK) .....	33
Figure 3.1: Categorisation of main RoRo vessel types.....	34
Figure 3.2: Low loader carrying a dump truck. ....	35
Figure 3.3: Swap bodies.....	35
Figure 3.4: Example of a Freight-only RoRo ship.....	36
Figure 3.5: RoRo Terminal Parking Layouts.....	38
Figure 3.6: Flowchart of the typical process that a trailer follows on its.....	38
Figure 3.7: Flowchart of the typical process that a container follows on its boarding and landing....	39
Figure 3.8: Aerial view of the zoning of Britannia Dok terminal .....	39
Figure 3.9: Unloading operations with terminal tractors (Source: MCVALNERA).....	40
Figure 3.10: Ferry in the Strait of Gibraltar. ....	42
Figure 3.11: Unloading vehicles of a ferry by bow ramp.....	42
Figure 3.12: Pont Aven cruise ferry.....	43
Figure 3.13: Passenger car only ferry connecting Ceuta and Algeciras (Spain).....	44
Figure 3.14: Passenger car only ferry operated in Dartmouth (United Kingdom) .....	44
Figure 3.15: Passenger only ferry sharing the dock with another ferry at Adámas (island of Milos, Greek) .....	45
Figure 3.16: Fast ferry unloading vehicles in Ceuta, Spain.....	45
Figure 3.17: HSC Francisco covering the route between Buenos Aires and Montevideo. ....	46
Figure 3.18: Main flows in the Algeciras RoPax terminal.....	48
Figure 3.19: Flowchart for Embarking Cars with Passengers .....	50
Figure 3.20: Flowchart for disembarking cars with passengers.....	51
Figure 3.21: Cars boarding a fast ferry in Algeciras. ....	52
Figure 3.22: Gates for customs control after disembarking in Algeciras. ....	52
Figure 3.23: Boarding area of a RoPax terminal (Port of Algeciras).....	53
Figure 3.25: Flowchart for embarkation and disembarkation of accompanied trucks.....	54
Figure 3.26: A pre-check in parking area for freight vehicles in the port of Algeciras.....	55
Figure 3.27- Post check-in marshalling of accompanied freight at the Port of Helsinki.....	55
Figure 3.28: Customs inspection post in the Port of Algeciras. ....	56
Figure 3.29: Pure Car Truck Carrier.....	57
Figure 3.30: Low height deck inside a car carrier. ....	57
Figure 3.31: Flowchart of the typical process that a car follows on its boarding and landing .....	58
Figure 3.32: PCC terminal in Port of Pasaja, Spain, showing multistorey trade car parking.. ....	58
Figure 3.33: ConRo vessel at Port of Seville, in Spain. ....	59
Figure 3.34: Linkspan for Rail RoRo vessel in Frederikshavn (Denmark).....	61
Figure 3.35: Villa San Giovanni port terminal dedicated to RailRo transport.....	61

Figure 3.36: RailRo vessel at the Port of Villa San Giovanni.....	62
Figure 3.37: Messina's storage area dedicated to RailRoad transport.....	62
Figure 3.38: Rail RoRo service between Coatzacoalcos (Mexico) and Mobile, Alabama (USA).....	63
Figure 3.39: Rail RoRo vessel at Coatzacoalcos (Mexico) terminal.....	63
Figure 3.40: Train barge traveling between New Jersey and Long Island .....	64
Figure 3.41: Rail RoRo terminal in Mobile (Alabama).....	65
Figure 3.42: RoRo barges at port in the USA.....	65
Figure 3.43: Loading a RoRo barge in the Port of San Juan (Puerto Rico).....	66
Figure 3.44: Crowley terminal specialising in barge trailer transport in Jacksonville (Florida).....	66
Figure 3.45: Transport of freight vehicles in the Danube River.....	67
Figure 3.46: Transport of construction equipment in a RoRo vessel at the Port of Tacoma (USA).....	68
Figure 3.47: Disembarkation of the Common Booster Core (CBC), part of the Delta IV rocket,...	68
Figure 3.48: Embarkation of a helicopter at the Port of Jacksonville (USA).....	69
Figure 4.1: Trends for dimensions and estimated displacements of RoRo freight vessels.....	73
Figure 4.2: Trends for dimensions and estimated displacements of Ro-Pax (ferry) vessels.....	74
Figure 4.3: Trends for dimensions and estimated displacements of ocean-going PCC and PCTC vessels .....	75
Figure 4.4: Example of belting on a ferry vessel .....	77
Figure 4.5: MV Dover Seaways showing the "ducktail" bow feature .....	78
Figure 4.6: Damage to a vessel belting .....	78
Figure 4.7: Typical belting structure details.....	79
Figure 4.8: Semi-circular belting design .....	79
Figure 4.9: Examples of framings of belted RoPax and RoRo vessels .....	80
Figure 4.10: Impact of fender panels on a belted ship .....	81
Figure 4.11: North and south finger piers (Grimsby, UK) .....	83
Figure 4.12: Dolphin and linkspan berths (Brittaniadok, Zeebrugge, Belgium) .....	87
Figure 4.13: Finger pier and linkspan berths (South Killingholme, UK) .....	87
Figure 4.14: RoRo berths alongside quay walls (Vlaardingen, Netherlands) .....	88
Figure 4.15: Echelon berth layouts (Calais, France) .....	88
Figure 4.16: "Mediterranean mooring" (Durrës, Albania) .....	89
Figure 4.17: Berthing "pockets" (Puttgarden, Germany) .....	89
Figure 4.18: PCC and PCTC berths (Bristol, UK) .....	90
Figure 4.19: Typical ferry and RoRo vessel berthing modes .....	92
Figure 4.20: Front panel fender damage from belting/rubbing bar effect in Rostock Port .....	93
Figure 4.21: Stern approach (Dover, UK) .....	94
Figure 4.22: Side fender (Rostock, Germany).....	94
Figure 4.23: Timber pile fenders.....	95
Figure 4.24: High fender panels for fast ferries.....	95
Figure 4.25: Modes of bow and stern impact adjacent to linkspans.....	96
Figure 4.26: Fenders protecting linkspans .....	96
Figure 4.27: Bulbous bow impact fender .....	97
Figure 4.28: Floating bow fender to engage a "ducktail" .....	97
Figure 4.29: Nesting fenders (Dover, UK) .....	98
Figure 4.30: Nesting fender berth for double-ender ferries (Puttgarden, Germany) .....	98
Figure 4.31: Pile or Pivot Fenders.....	99
Figure 4.32: Examples of parallel motion fenders .....	100
Figure 4.33: Long panel fenders at ferry ports (non-parallel motion) .....	100
Figure 4.34: Arch fenders at Berth 27 (Rostock, Germany) .....	101
Figure 4.35: Floating or cylindrical fenders.....	102
Figure 4.36: Requirements for the sizing of fender panels for belted vessels .....	103
Figure 4.37: Setback mooring points (Dunkerque, France) .....	108
Figure 4.38: High level mooring points (BC Ferries, Canada).....	108
Figure 4.39: Tie back moorings.....	109
Figure 4.40: Automoorings system (Puttgarden, Rostock, Germany and Rødby, Denmark) .....	110

Figure 4.41: Automatically controlled vacuum automooring system (Den Helder, Netherlands)	110
Figure 4.42: Propeller erosion.....	111
Figure 4.43: Key horizontal geometric requirements of linkspans.....	112
Figure 4.44: Minimum roadway widths.....	113
Figure 4.45: Fixed RoRo ramp (Rostock, Germany) .....	114
Figure 4.46: Typical vertical geometry guidelines for linkspan and RoRo fixed ramps transitions	115
Figure 4.47: Clearances required under double deck ramps .....	117
Figure 5.1: RoRo/Ro Pax Vessel Movements.....	122
Figure 5.2: Examples of facilities with personnel being supported by active machinery .....	123
Figure 5.3 – Outline flowchart of the recommended procurement/manufacturing processes for safe.....	128
Figure 5.4 – Outline flowchart of the recommended operational safety control processes .....	129
Figure 5.5: Stern ramp directly onto shore. Durres , Albania .....	133
Figure 5.6: Typical quarter ramp geometry .....	134
Figure 5.7: Quarter ramp in Southampton, UK .....	134
Figure 5.8: Slipway type shore ramp - Kigamboni, Dar es Salaam, Tanzania .....	135
Figure 5.9: Examples of Type A, Mechanically Lifted Linkspans .....	140
Figure 5.10: Type A Mechanically lifted linkspans with counterweights .....	141
Figure 5.11: Variant with the lifting equipment designed for self weight only with locking pins for trafficked operation.....	142
Figure 5.12: Examples of Type B (pontoon and link bridge) facilities.....	143
Figure 5.13- Adjusting freeboard using differential ballasting.....	144
Figure 5.14 - Variant of Type B (pontoon and linkbridge) where the link bridge passes over the pontoon.....	146
Figure 5.15: Examples of Type C, Semi-Submersible, Linkspans .....	147
Figure 5.16: Pendant ropes attached to a Type C Linkspan .....	147
Figure 5.17: Demonstration of hydrostatic instability of semi-submersible linkspans .....	148
Figure 5.18: Examples of Type D, Integral Tank Linkspans .....	149
Figure 5.19: Perforations of box girder in an integral tank linkspan to avoid buoyant uplift .....	150
Figure 5.20: Type D-V2 integral tank linkspan at Dunkirk, France.....	151
Figure 5.21: Examples of Type i) final link.....	156
Figure 5.22: Examples of Type ii) final link, Dover, UK .....	157
Figure 5.23: Example of Type iii) final link with linkspan supported directly on the vessel – Woolwich ferry, London, UK .....	159
Figure 5.24: Possible articulation of linkspans and link bridges .....	164
Figure 5.25: Steel on steel sliding/rocking bearing arrangements for semi-submersible linkspans	166
Figure 5.26: Bearings for pontoon link bridges.....	167
Figure 5.27: Effect of tolerances on cylinder angle during lifting .....	168
Figure 5.28: Types of Linkspan Bridge Structure .....	169
Figure 5.29: Plate Girder Link Bridges (U Frame Type).....	170
Figure 5.30: Plate girder linkspans with underhanging girders.....	171
Figure 5.31: Torsionally Stiff and Torsionally Flexible Truss Structures .....	171
Figure 5.32: Examples of buoyant uplift on box girders.....	172
Figure 5.33: Typical steel and concrete pontoon construction.....	174
Figure 5.34: Examples of steel and concrete pontoon berths.....	175
Figure 5.35: Pontoon restraint systems schematic diagrams .....	177
Figure 5.36: Examples of pontoon restraints in practice.....	178
Figure 5.37: Example of attaching the pontoon to piled restraints.....	178
Figure 5.38: Integral Tank Linkspan special case .....	179
Figure 5.39- An Example of measures to allow free movement in linkspans.....	183
Figure 5.40 - An example of damage to a ferry linkspan in Japan.....	184
Figure 5.41 - Seismic effects on pile restrained and boom restrained floating pontoons .....	185
Figure 5.42: Geometric issues with double deck linkspans .....	187

Figure 5.43: Type A PBB, Motorised carriage near to the quayside with fixed swivel at the shore building .....	191
Figure 5.44-Example of a Type A PBB .....	192
Figure 5.45: Type B PBB, Motorised carriage near to the quayside with slave carriage and pod .....	192
Figure 5.46: Example of a Type B PBB .....	193
Figure 5.47: Type C PBB, Traversing drawbridge on boarding pod.....	193
Figure 5.48: Example of a Type C PBB, Harwich Berth 2 .....	194
Figure 5.49: Type D PBB - Single (or zig zag) tunnel on rail mounted gantries.....	194
Figure 5.50: Example of a Type D PBB, Port of Helsinki.....	195
Figure 5.51: Stern access PBBs at Dover.....	196
Figure 5.52: Example of range of boarding positions at a ferry port.....	200
Figure 5.53: Some examples of heights from passenger door to waterline .....	202
Figure 5.54: Example of handling large vertical range of door position .....	203
Figure 5.55: Excerpt from EN 1991-4, Eurocode - Actions on Structures, Part 1.4 General Actions, Wind Actions [51].....	205
Figure 5.56: Effect of keeping the space uninterrupted for vertical movement of the PBB elements .....	206
Figure 5.57: Example of a through truss structure.....	207
Figure 5.58: Schematic Diagram of the Ramsgate PBB, 1994 showing the key effects.....	207
Figure 5.59: The collapsed span of the Ramsgate PBB, 1994 .....	208
Figure 5.60: Schematic of a possible articulation scheme .....	209
Figure 5.61: Different forms of final link to ship.....	212
Figure 5.62: Example of envelope of movements of a final link including additional movements for alarm triggers and withdrawal and retrieval.....	213
Figure 5.63: Two types of telescopic end assemblies on PBBs .....	213
Figure 5.64: Drawbridge and gangway type final link .....	214
Figure 5.65: Control issues for lifting equipment .....	217
Figure 5.66: Examples of sensor types .....	218
Figure 5.67: Finger flap deployment systems.....	220
Figure 5.68: Pumping equipment inside a pontoon .....	221
Figure 5.69: A winch lifted PBB, Plymouth, UK .....	222
Figure 5.70: Hydraulic cylinder lifting actuation systems .....	224
Figure 5.71: Ballscrew type lifting actuator systems (Harwich International Port).....	224
Figure 5.72: Example of extending actuators (Harwich Cruise Terminal, UK).....	225
Figure 6.1: Trend for RoRo Vessel Capacity, 1967 to 2020.....	239
Figure 6.2: Trend for RoPax Vessel Capacity, 1960 to 2020.....	240
Figure 6.3: Trend for PCC/PCTC Vessel Capacity, 1972 to 2020.....	240
Figure 6.4: Example of area variations arising from hoistable mezzanine decks.....	241
Figure 6.5: Trend for RoPax Vessel Passenger Carrying Capacity, 1960 to 2022.....	242
Figure 6.6: Example of the effect of premium time sailings on berth number requirements .....	246
Figure 6.7: Arriving and departing unaccompanied trailer movements through a terminal .....	249
Figure 6.8: Arriving accompanied truck movements through a terminal .....	249
Figure 6.9: Schematic of a typical Freight-only RoRo Terminal.....	254
Figure 6.10: Schematic of a Typical RoPax Terminal (all elements shown) .....	257
Figure 6.11: Schematic of a PCC/PCTC RoRo Terminal .....	261
Figure 6.12 DFDS support chair system at Immingham .....	263
Figure 6.13: Examples of double deck ramps .....	266
Figure 6.14 Multiple Berth Terminals .....	267
Figure 6.15: Dover Eastern Dock- The "Ultimate" integrated terminal? .....	268
Figure 6.16: The Modlohr Railway system, special loading bays. ....	270
Figure 8.1: Flowchart of foot passenger movements .....	276
Figure 8.2: Maritime Station at Port of Algeciras - Ground Floor.....	285
Figure 8.3: Maritime Station at Port of Algeciras - First Floor.....	286
Figure 8.4: Helsinki West Harbour Passenger Terminal 2.....	287

Figure 8.5: Passenger Entrance Hall of the Port of Algeciras Maritime Station, with ticket offices (E2) at the end .....	289
Figure 8.6: Passenger Hall in Helsinki Olympic Terminal Building in the South Harbour .....	289
Figure 8.7: Helsinki West Harbour Passenger Terminal 2 Check-In Gates .....	290
Figure 8.8: Passenger Waiting Area in a ferry terminal .....	291
Figure 8.9: Passenger Waiting Area in Helsinki West Harbour Terminal 2 .....	291
Figure 8.10: San Beltran Quay, Port of Barcelona: Tramediterranea ferry Terminal and passenger walkway .....	292
Figure 8.11: Helsinki West Harbour Passenger Terminal 2 Building .....	292
Figure 8.12: An example of wheelchair turning space requirements .....	294
Figure 8.13: Travelators within the Helsinki West Harbour Passenger Terminal 2 .....	295
Figure 8.14: Tunnel in Stockholm by Ports of Stockholm's Värta Harbour .....	298
Figure 9.1: Barcelona pier. Ro-Pax and Cruises Terminals showing a fine example of port city relationships.....	299
Figure 9.2: Port of Stockholm, Värta Harbour Passenger Terminal .....	300
Figure 9.3: Port of Helsinki, Katajanokka Harbour Area .....	303
Figure 9.4: Port of Barcelona and Logistic cluster main facilities and areas .....	304
Figure 9.5: Port of Helsinki West Harbour Passenger Terminal Building .....	305
Figure 9.6: City and port of Denia. Maritime Station. ....	306
Figure 12.1: Piggyback carrying of freight vehicles by rail.....	312
Figure 12.2: The effect of linkspan location and cargo dwell time on distances travelled and energy used in an unaccompanied RoRo terminal area of equivalent capacity .....	314
Figure 12.3: The FastShip concept- a revolutionary RoRo system for transatlantic crossings .....	317
Figure 12.4: Cable Management System for RoRo vessel in Port of Kiel, Germany .....	318
Figure C-0-1: The Passenger Terminal of Santander. Source:- Google Earth .....	334
Figure C-0-2: Port of Santander: Maritime Station, Centro Botin, Pereda Gardens and Santander city .....	334
Figure C-0-3: The Port of Tangier City. Master Plan .....	335
Figure C-0-4: The three main areas of the Port of Barcelona .....	336
Figure C-0-5: The Port Vell area. General view .....	337
Figure C-0-6: The ferry terminal of Balearia in the Barcelona North Quay. ....	338
Figure C-0-7: Passenger terminals at the Port of Barcelona according to the Uses Plan .....	339
Figure C-0-8: : RoPax and Cruise Terminals at the Barcelona and Sant Beltran quays.....	339
Figure C-0-9: San Beltran Quay: Tramediterranea ferry Terminal (left) and passenger's walkway (right) .....	340
Figure C-0-10: Parking areas separated by "transparent" fences in Balearia Terminal (left).....	340
Figure C-0-11: Ro-Ro Terminals accesses with the Ronda Litoral (urban highway) .....	341

## LIST OF TABLES

Table 1-1: PIANC reports referred to in the present report.....	177
Table 1-2: Members of Working Group 167 .....	188
Table 1-3: Meetings of Working Group 167.....	19
Table 1-4: Acknowledgements.....	20
Table 4-1: Trend changes for average characteristics of ships constructed between the 1960s and 2020 .....	71
Table 4-2: Types of RoRo and RoPax berths .....	86
Table 4-3: Comparison of fender types .....	106
Table 4-4: International recommendations for fixed RoRo ramp, linkspan and PBB vertical gradients .....	116
Table 4-5 Allowances for vessel movements recommended by BS 6349 Part 8 (2007) .....	118
Table 4-6: Different international loading standards .....	119
Table 5-1: Terms used in this report .....	120
Table 5-2 – A sample of items from the schedule of Essential Health and Safety Requirements, Annex 1, Directive 2006/42/EC of the European Parliament and of the Council [22].....	127
Table 5-3: Summary of types of fixed shore ramps .....	136
Table 5-4: Main types of linkspan.....	137
Table 5-5: Advantages and disadvantages of different types of lifting arrangements for linkspans .....	155
Table 5-6- Type of final link to vessels for linkspan arrangements.....	162
Table 5-7 - Terms relating to PBBs used in this report.....	190
Table 5-8: Advantages and disadvantages of different types of PBB.....	199
Table 5-9: Comparison of lifting actuator types for linkspans .....	216
Table 5-10: Comparison of lifting actuator types for PBBs.....	223
Table 6-1: Trend changes for capacities the 1960s and 2020. ....	239
Table 6-2: Cargo Measurement Units in the RoRo trade.....	243
Table 6-3: Comparison of dwell times for different trades, including RoRo .....	248
Table 6-4: Freight-only RoRo Terminal Area Elements (including containers) .....	255
Table 6-5: RoPax Terminal Area Elements.....	259
Table 6-6: Trade Car and Vehicle Terminal Area Elements .....	262
Table 6-7: Typical Areas for Different Parking/Storage Modes .....	263
Table 8-1: Summary of terminal building area requirements.....	280
Table 11-1 - Possible ownership arrangements .....	308