IMMINGHAM EASTERN RO-RO TERMINAL

Vessel Impact Protection Structure – Concept Design

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Vessel Impact Protection Structure – Concept Design

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1. Introduction

1.1 Background

Associated British Ports (ABP), the owner and operator of the Port of Immingham, is proposing to construct a new roll-on/roll-off (Ro-Ro) facility within the Port to be known as the Immingham Eastern Ro-Ro terminal (IERRT). This facility is designed to service the embarkation and disembarkation of commercial wheeled cargo (i.e., Ro-Ro freight) carried either by accompanied trailer (where the Heavy Goods Vehicle (HGV) tractor unit and driver travel on the vessel with the trailer) or on unaccompanied trailers which are delivered to the embarkation port and then collected at the port of disembarkation by different HGV tractor units and drivers.

The project is needed to provide additional appropriate Ro-Ro freight capacity within the Humber Estuary in order to meet the growing and changing nature of demand, and thereby strengthen the estuary's contribution to an effective, efficient, competitive and resilient UK Ro-Ro freight sector.

The construction of Vessel Impact Protection Structure (VIPS) may be proposed as part of the IERRT project. The main function of the VIPS is to protect the existing Immingham Oil Terminal (IOT) infrastructure from an accidental collision from an errant vessel operating at IERRT.

1.2 Purpose of this Document

This note reports on the development of the design of structures identified as having the potential to provide vessel impact protection for parts of the existing IOT infrastructure, in the event that a vessel loses power on its approach to the proposed IERRT berths, and makes a high-level estimate of the capability to absorb impact energy.

The designs have been developed to meet the objectives set out in the VIPS Design Basis document (4021009-JAC-ZZ-01-TN-C-00001).

The design presented is intended to support the development of an understanding of the capability of these structures to protect the existing IOT infrastructure and how they may be integrated with the existing and proposed structures.

The work is consistent with RIBA Level 2 and not intended to provide a definitive arrangement.

1.3 VIPS Structures

The Concept Development Study proposed the following vessel impact protection structures:

- IOT Finger Pier Protection dolphin
    - Positioned at the western end of the existing IOT finger pier and would include for the repositioning of the 2no. existing donut fender piles.
- IOT Trunkway Protection Barrier
    - A linear barrier positioned adjacent to the IOT Trunkway.
- IERRT pontoons and associated restraint dolphins
    - For each pontoon, 1no Type 1 Dolphin and 3no Type 2 Dolphins.

The structures are identified in Figure 1-1.

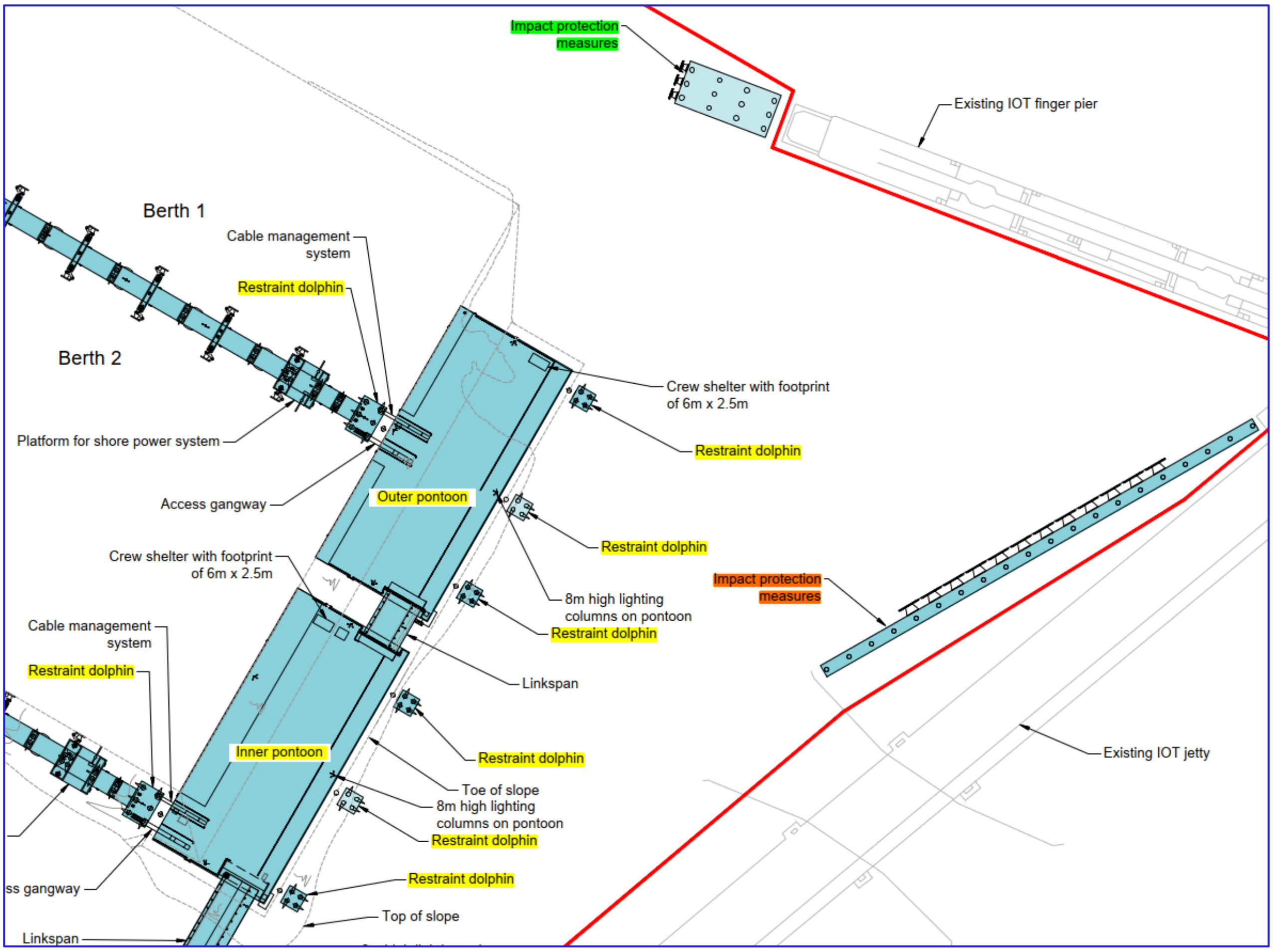


Figure 1-1. Vessel Impact Protection Structures

2. Design Criteria

2.1 General

The Design Basis identifies the following key requirements for the VIPS are:

a) A working Design Life of 50 years.

b) Provide impact protection from IERRT design vessels that have lost steerage / power on an ebb tide.

c) Provide impact protection from the IERRT design vessels at the defined impact speeds (refer to Table 2-1 and Table 2-2).

d) Provide ship impact protection to the western aspect of the IOT structures from the Finger Pier landward, notably:

  i. The western end of the IOT Finger Pier.

  ii. The western face of the IOT Trunkway landward of the Finger Pier, up to the existing navigation passage beneath the IOT Trunkway.

  iii. The western face of the IOT Trunkway landward of the termination of the Trunkway Barrier.

e) Replicate / relocate the existing donut fenders located to the west of the IOT Finger Pier.

f) Assume stern vessel impact from the IERRT vessels.

g) Protection to be provided over the full tidal range.

h) The impact scenarios of the design vessels moving at the speeds specified in this document are considered accidental design situations. It is accepted that the VIPS may no longer be serviceable if these accidental design situations were to take place.

2.2 IERRT Design Vessels

The IERRT Design Vessels are presented in Table 2-1:

Table 2-1. IERRT Design Vessels

Vessel Particulars		2000-A	3000-A	1500-A	Future vessel*
Deadweight (DWT)	(t)	12,300	8,423	8,600	-
Displacement	(t)	23,372	21,451	27,900	48,431
Length overall (LOA)	(m)	195.16	212.0	239.7	240.0
Length between perpendiculars (LBP)	(m)	-	194.8	227.7	225
Beam (B)	(m)	25.6	26.7	27.8	35.0
Draft, laden	(m)	7.5	6.3	6.4	8.0
Draft, light/ballast	(m)	6.6	4.7	5.1	-

* The Future Vessel tonnage is estimated using an envelope of Client defined maximum dimension in accordance with BS 6349-1-1 2013.

2.3 IERRT Vessel Impact Speed

Table 2-2 presents the Impact Speeds of the IERRT Design Vessel to be assumed by the Concept Design.

Table 2-2. IERRT Vessel Impact Speeds

Vessel Particulars		2000-A	3000-A	1500-A	Future vessel
Impact speed of Vessel	knots	2.5	2.5	2.5	1.8
	m/s	1.29	1.29	1.29	0.93

2.4 IOT Design Vessel

The IOT Design Vessels are presented in Table 2-3:

Table 2-3. IOT Design Vessels

Vessel	LOA (m)	Beam (m)	Draft (m)	Displacement (t)
Thames Fisher	91.5	15.5	6	6000
Thun Grace	103.46	15	4.9	5000
Barge	60.8	7.6		
Tugs 25t (bollard pull)	30			

3. Layout

The arrangement proposed has been evaluated in the Environmental Statement in respect to habitat loss, limits of deviation, and maximum pile diameter for vibration and noise assessments. The contractor's design will have to be shown to meet the DCO conditions in Stage 1 of the contract.

The Environmental Statement in the draft Development Consent Order identifies limitations and restrictions related to piles and piling including but not limited to; habitat loss, noise, vibration, maximum diameter, etc. the Contractor will take into consideration in the preparation of their design and the implementation of the works these limitations and restrictions.

3.1 IOT Finger Pier Protection Dolphin

a) The Finger Pier Protection Dolphin is to extend no further than 35m from the end of the existing IOT Finger Pier.

b) The Finger Pier Protection Dolphin is to be no wider than 14m.

c) The dolphin is to be positioned within a parallel extension of the IOT Finger Pier berthing lines.

d) There is to be an isolation gap of 5m between the existing IOT Finger Pier and the Protection Dolphin, to allow for deformation of the dolphin structure, space for construction as well as future inspection and maintenance.

e) Provide an approach channel of not less than 86m between the IERRT structures and the IOT Finger Pier VIPS dolphin.

f) Not limit or intrude upon the IOT Design Vessel berthing and mooring arrangements of the existing IOT Finger Pier.

g) Have a finished deck level elevation not higher than +5.25mOD.

The project environmental assessment has assumed that the IOT Finger Pier Dolphin will consist of twelve 1520mm dia. steel piles connected by concrete beams or deck. Fewer or smaller diameter piles are assumed to be acceptable as they would have a lower environmental impact.

3.2 IOT Trunkway Protection Barrier

a) The Protection Barrier is to be structurally isolated from the IOT structures.

b) The Protection Barrier is to align with, but not connect to the existing IOT impact barrier at the root of the Finger Pier. The distance between the Protection Barrier and the IOT Trunkway is to be 5m or greater.

c) The Barrier may extend up to, but not beyond the channel markers for the navigational arch, under the Trunkway.

d) Fenders mounted on the western face of the structure.

e) Have a finished deck level elevation not higher than +5.25mOD.

The project environmental assessment has assumed that the IOT Trunkway Protection Barrier will consist of twenty, 1520mm dia. steel piles connected by a concrete capping beam approximately 154m long. Fewer or smaller diameter piles are assumed to be acceptable as they would have a lower environmental impact.

3.3 IERRT pontoons and associated restraint dolphins

a) The project reference design identifies two pontoons located at the northern extent of an approach structure providing vehicle access from the land. The pontoon long axis' are oriented north / south.

b) This assessment assumes that each pontoon has a restraint dolphin arrangement consisting of 3no restraint dolphins along the eastern face of the pontoon. The project reference design refers to these as Type 2 dolphins. The reference design also allows for a single Type 1 dolphin is positioned centrally on the western face of the pontoon.

The project environmental assessment has assumed that each pontoon and restraint dolphin arrangement will comprise:

- Pontoons each with a maximum dimensions 40m wide by 90m long. The indicative draught of the pontoons is 4.5m. A line of simple D-fenders are fixed to the pontoon at the water line below where the vessel ramps will land.
- Type 1 dolphins formed of 1no 1420mm dia. steel vertical guide pile and pile cap supported by six 1220mm dia. steel piles; 5 of which are raking piles.
- Type 2 dolphins to comprise, 1no 1420mm dia. steel vertical guide pile and 4no of 1220mm dia. steel raker pile topped with a concrete dolphin cap. There will be arch fenders fixed to the pontoon around the guide pile yoke system and these are designed to absorb energy from operational movements of the pontoon, including effects from a surge of the berthed vessel. Each dolphin will have an 'emergency' fender fixed to the concrete deck and in line with the guide pile so that an accidental impact on the pontoon/guide pile that fails the pile would transmit the force to the through the emergency fender.

Fewer or smaller diameter piles are assumed to be acceptable as they would have a lower environmental impact.

4. Impact scenarios

The concept designs assume that a vessel impact will occur on an ebb tide and that the initial impact will be a stern impact.

The Protection Dolphin and the Protection Barrier are expected to have a finished level at levels similar to, or less than the existing IOT structures, i.e. +5.25 mOD. The associated concrete works are expected to be at least 2.5m and 4m deep respectively.

The level and depth of the structures, combined with the IERRT Design Vessel stern profile results in an overlap that despite the operational water level range (of the order 7 m) will result in the initial vessel impact being the proposed fenders.

4.1 Impact scenarios

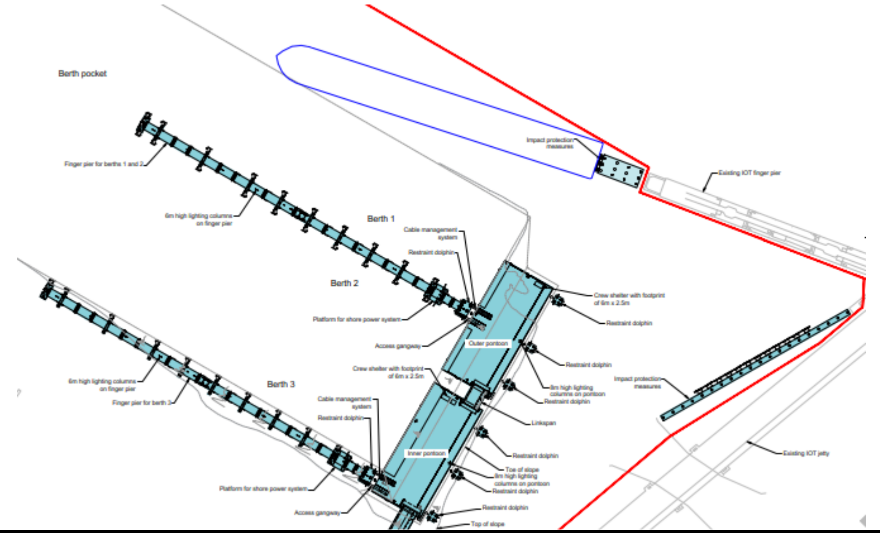
Eight vessel impact scenarios have been identified for assessment; these are summarised in Table 4-1.

These have not been derived from vessel track modelling. Modelling of vessel tracks with the proposed structures in place would allow for increased confidence in the track of a vessel experiencing loss of power on the approach to the proposed IERRT berths.

Table 4-1. Summary of Assessed Impact Scenarios

<table>
<tr>
<td>

Scenario 1 – Protection Barrier



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- Impact load onto protection dolphin at centreline.
- Load applied is perpendicular to axis.

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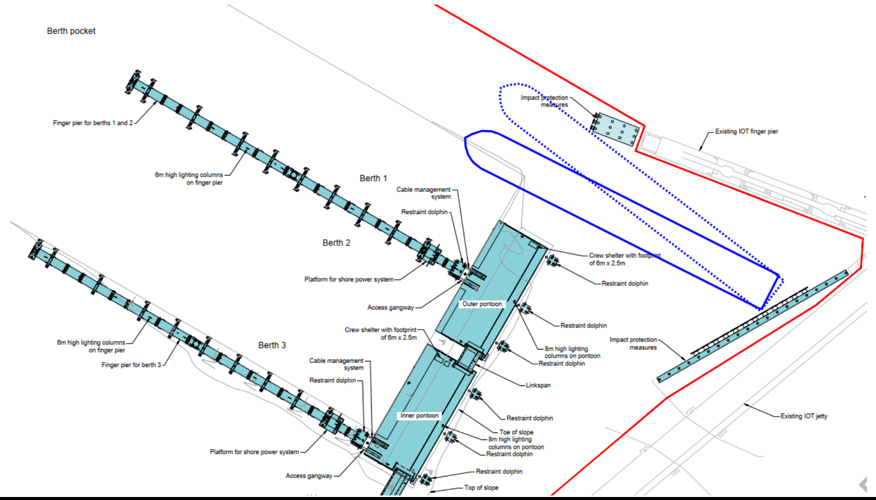
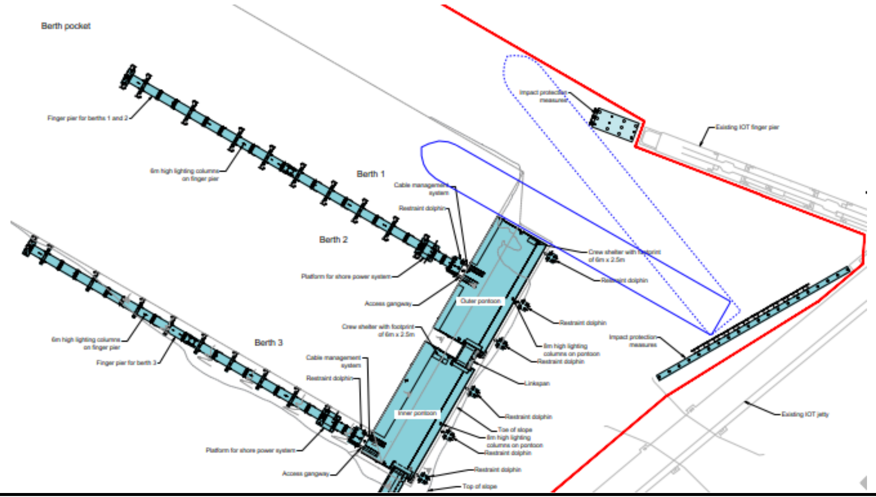
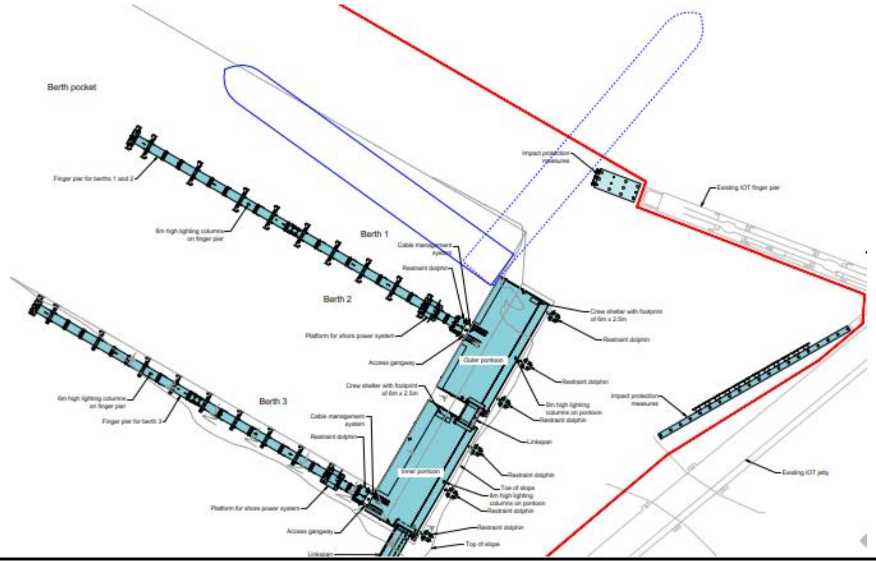
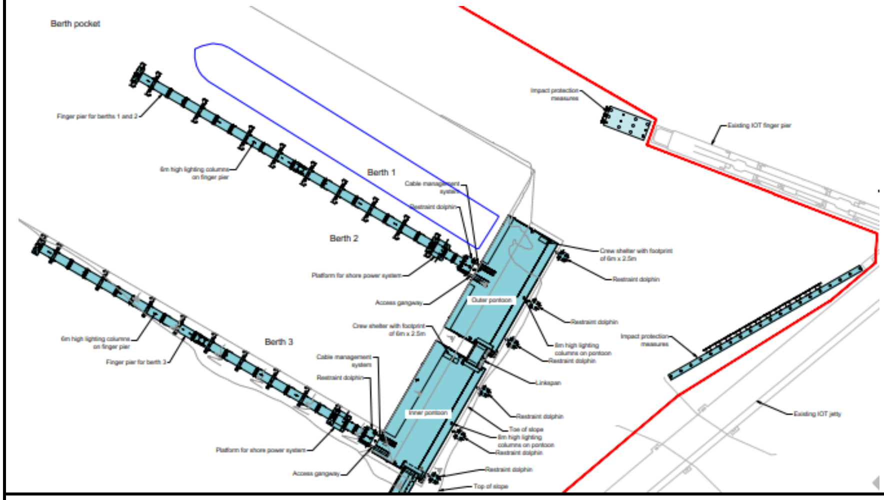
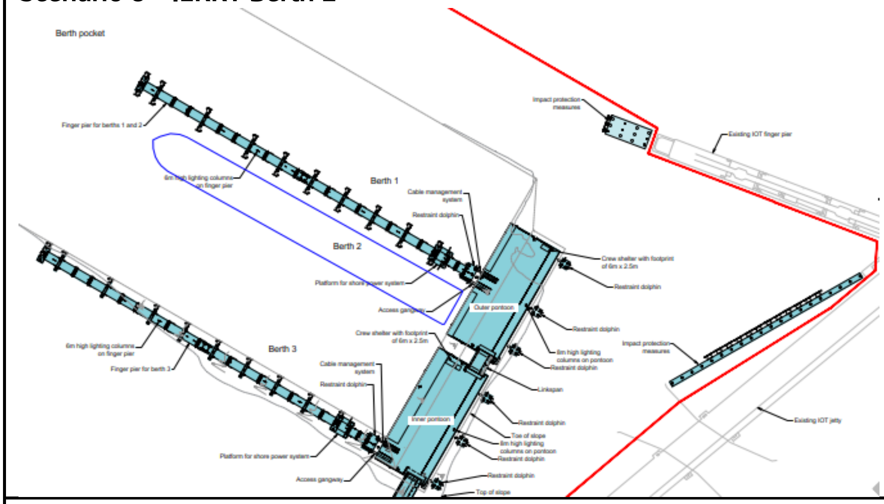
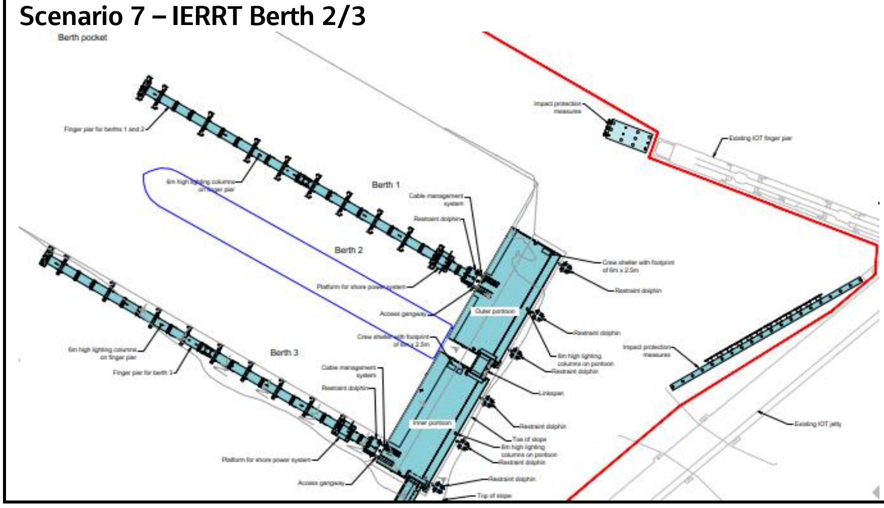
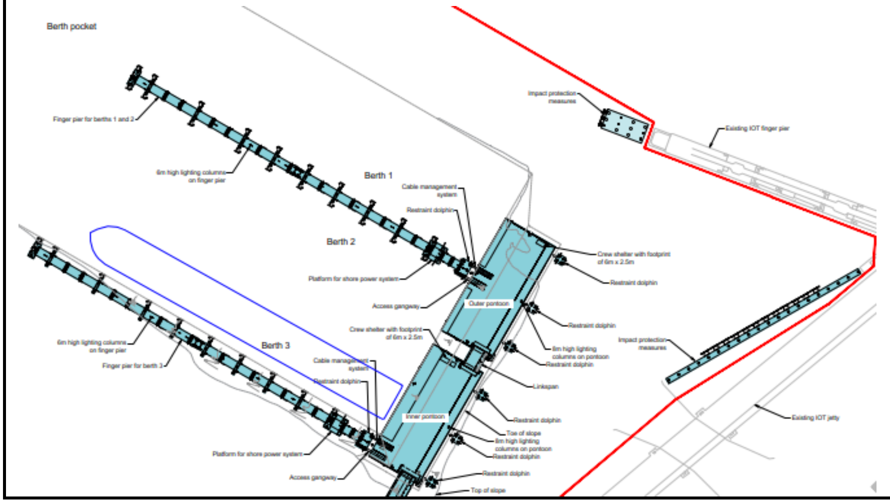
Scenario 2 – Protection Barrier North  	• Vessel stern impacts the linear protection structure engaging 1 fender at mid point. • The vessel then rotates and engages with 2 fenders, but the bow does not impact the IOT Finger Pier Protection Dolphin.
Scenario 3 – Protection Barrier South  	• Vessel stern impacts the barrier engaging 1 fender at southern end of barrier. • The vessel then rotates and engages with 2 fenders, and the bow, or side, of the vessel impacts the IOT Finger Pier Protection Dolphin
Scenario 4 – IERRT Berth 1  	• Vessel stern impacts the northern corner of the pontoon. • Anticipated that two restraint dolphins are engaged with rotational movement being controlled by the remaining two dolphins. • If restraint dolphin(s) do not fail, and vessel rotates clockwise, then vessel impacts Finger Pier Protection Dolphin.

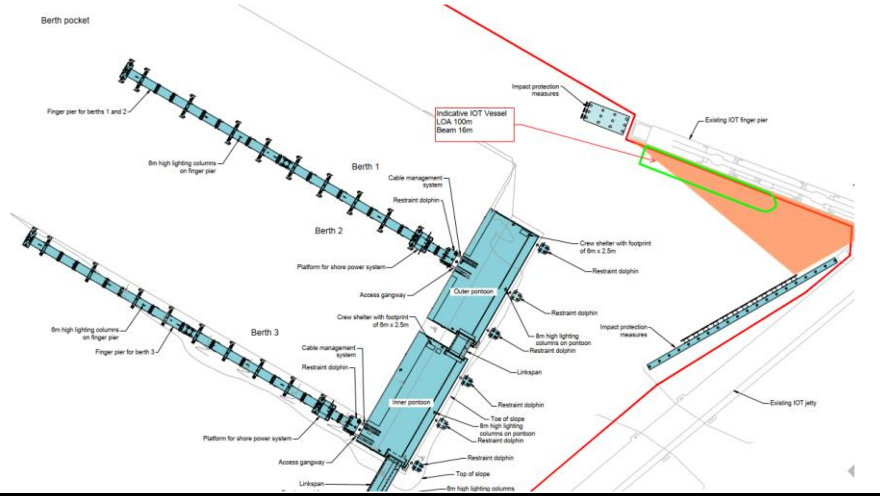
Scenario 5 – IERRT Berth 1 	• Vessel stern impacts the northern corner of the pontoon. • Assume benefit of at least two restraint dolphins.
Scenario 6 – IERRT Berth 2 	• Vessel stern impacts pontoon. • Assume benefit of at least two restraint dolphins.
Scenario 7 – IERRT Berth 2/3 	• Vessel stern impacts corner of two pontoons. • Assume benefit of up to four restraint dolphins.

Scenario 8 – IERRT Berth 3	
	• Vessel stern impacts pontoon. • Assume benefit of three restraint dolphins.

4.2 Other Impact Scenarios

This assessment notes that the protection structures identified in Section 1.3 do not provide protection to the south side of the IOT Finger Pier, vessels berthed at IOT Berth 7 and Berth 8.

Impact protection to the IOT Trunkway will be reduced north of the Protection Barrier fenders.

Scenario 9 – IERRT Berth 3	
	

5. Design parameters

5.1 Design Codes

A list of the standards, codes and industry guidance to be used in the design is as follows:

1) BS EN 1990 – Basis of Structural Design
2) BS EN 1991 – Actions on structures
3) BS EN 1992- Design of concrete structures
4) BS EN 1993 – Design of steel structures
5) BS EN 1997 – Geotechnical design
6) BS 6349-1-1: 2013: Maritime Works Part 1-1: General – Code of practice for planning and design for operations
7) BS 6349-1-2: 2017: Maritime Works Part 1-2: General – Code of practice for assessment of actions
8) BS 6349-1-4: 2021: Maritime Works Part 1-4: General – Code of practice for materials

5.2 Design Factors

5.2.1 Actions

The vessel impact scenario is considered an accidental design situation. As such, no factors are applied to the impact action/energy, in accordance with exp. 6.11b of BS EN 1990.

5.2.2 Materials

- Structural steel (γ_{M0}): 1.0, in accordance with Clause 5.1.1 (4) of BS EN 1993-5.
- Reinforced concrete: in accordance with Table 2.1N of BS EN 1992-1-1:
    - Concrete (γ_c):1.2
    - Reinforcing steel (γ_s): 1.0

For the fenders, the manufacturing tolerance of ±10% is not incorporated due to the accidental nature of the design situation.

5.3 Structural Materials

Structural Concrete:

- Grade: C35/45
- Exposure class: XSM3

Structural steel:

- Grade: S355 or S420

All tubular steel piles to be minimum Class 2 cross-sections to enable the development of the plastic moment of resistance of the sections.

5.4 Site Geology

The geological information and associated geotechnical data are obtained from the Preliminary Geotechnical Design Assessment report (document no. 4021009-JAC-ZZ-01-RP-G-00025 P01).

For the purpose of this study, the ground model derived for the Finger Pier structure along its first 180m is assumed to be representative of the geological makeup at the location of the VIPS, refer to Figure 5-1 and Figure 5-2 which show the location and detail of the ground model.

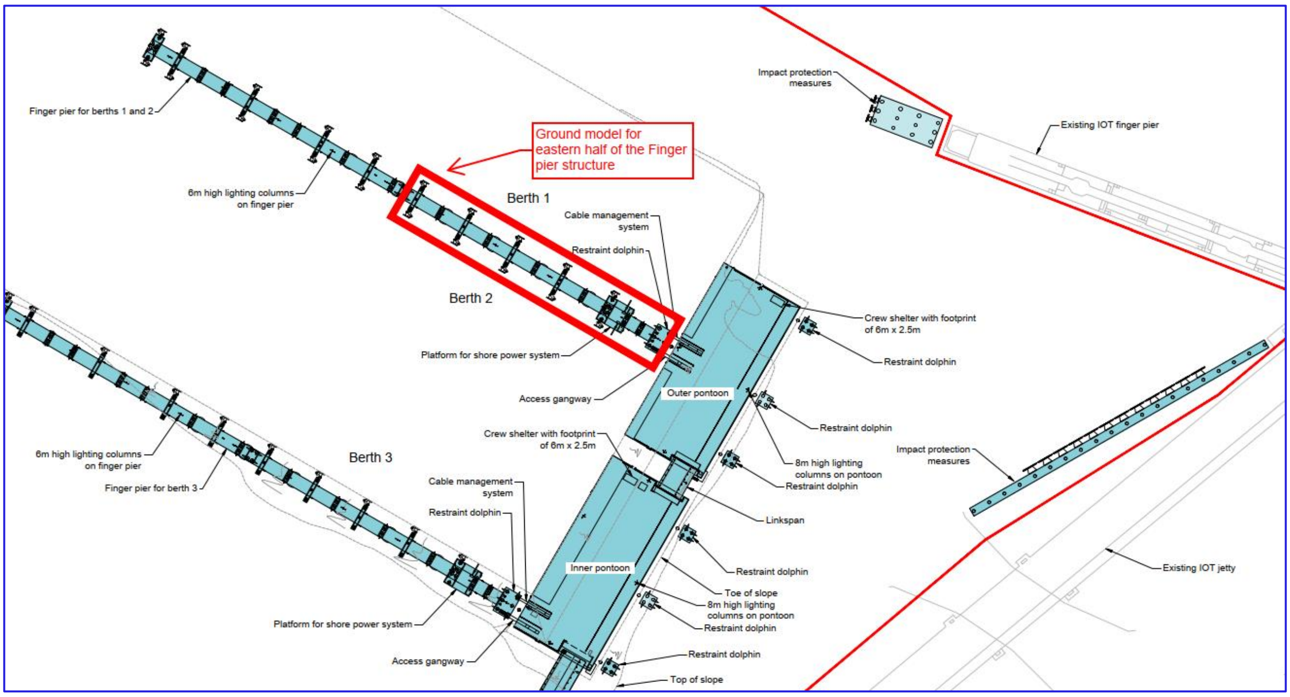


Figure 5-1. Plan view of IERRT indicating area of adopted ground model.

Level From (mOD)	Level to (mOD)	Strata
-12.8	-20.8	TIDAL FLAT DEPOSITS
-20.8	-22.9	COHESIVE TILL
-22.9	-23.7	GRANULAR TILL
-23.7	-37.2	COHESIVE TILL
-37.2	-40.7	CHALK GRADE D
-40.7	-80.7	CHALK GRADE A to C

Figure 5-2 Assumed ground model for the VIPS study.

6. Methodology and Limitations

6.1 Methodology

The study is based on an assessment of the energy-absorbing capabilities of:

- Rubber fender units and,
- The structures to which the fenders are attached.

The impact energy that is to be resisted by the structures is calculated on the basis of the mass of the vessels (including a 10% increase to account for the additional hydrodynamic mass) travelling at a specific velocity at the instant when the accidental impact occurs. The hydrodynamic mass allowance reflects BS EN 1991-1-7 cl 4.6.1 (4) together with Appendix C.4.3 (2) [Advanced ship impact for inland waterways].

A series of structural models were created to determine the maximum capacity of the protection structures. Subsequently, the allowable vessel velocity for each required vessel was back-calculated based on the combined structural capacity and deformation of the fender units. Additional energy absorption due to the deformation of the structures themselves was considered for the pontoon restraint dolphins.

For the modelling, elastic global analysis and the plastic resistance of the pile cross-sections are adopted for the structures with reference to BS EN 1993-5.

6.2 Impact Energy

The assessment assumes that the potential maximum impact energy of the 1500-A vessel at 2.5 knots is 25,382 kNm, which includes the10% allowance of hydrodynamic mass described in the preceding section.

6.3 Geotechnical Checks

Geocentrix Repute models were created to model the soil-structure interaction. The adopted ground model is based logs and tests from borehole 22JBH02. The Repute models were used to validate the level of the spring supports in the structural models.

6.4 Limitations

- Linear elastic stiffness soil properties have been considered, meaning that the modelling exercises undertaken for this study will not capture yielding of the ground.
- For the pontoon restraint dolphin system, no allowance has been made for the deformation of the pontoon.

7. Structural models

7.1 Pier Protection Dolphin

7.1.1 Geometry

The Protection Dolphin model simulates the piles as frame elements and the concrete cap as a grillage, which comprises primary and secondary beams on grid measuring approximately 9.0m x 6.0m in plan and infill plate elements measuring 0.50m x 0.50m to form a rigid cap. The primary and secondary beams have a height of 2.5m and a width of 2m. The pile elements are modelled with soil springs extending from -20 mOD (the riverbed) to a depth of -32 mOD. The Protection Dolphin is supported by twelve steel tubular piles 1520mm dia. x 42mm (Grade S420).

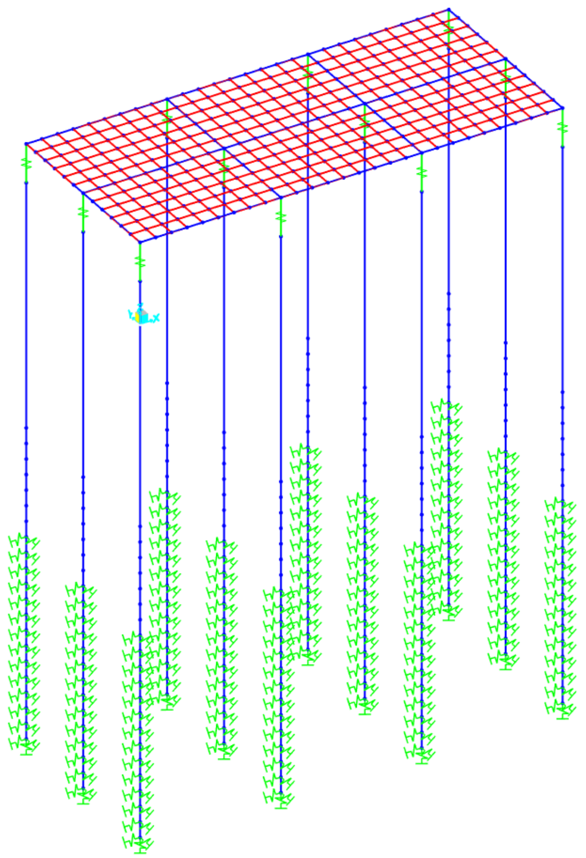


Figure 7-1. Structural model of Pier Protection Dolphin

7.1.2 Assumptions

1. A stiff and heavily reinforced concrete cap is provided.
2. Vessel stern impact onto the structure.
3. Three, SCN 2500 F 2.6 fenders installed at an even spacing across the western face of the protection dolphin.
4. The engagement of three fenders is required at the stated velocity.
5. The structure will not be serviceable after the accidental event.

7.1.3 Impact Energy

At 2.5 knots, this assessment assumes that the maximum energy a Trelleborg SCN 2500 F2.6 fender can absorb at the rated deflection is 10,363 kNm. The associated reaction force is 7,467 kN.

Assuming that the structure is equipped with 3no. fender units, the total energy absorption capacity could be 3 x 10,363 kNm, or 31.09 MNm, with an associated total reaction force of three 7,467 kN, or 22.40 MN. When subjected to this load, the Pier Protection Dolphin piles remain within their plastic moment of resistance.

The energy absorption capacity (31.09 MNm) is greater than the impact energy of 25.38 MNm (refer to Section 6.2), therefore the structural concept of the Pier Protection Dolphin is deemed suitable to resist the impact energy albeit with permanent plastic deformation of the piles.

7.1.4 Geotechnical Model

The results of the Repute assessment show that the proposed structures under high collision loads will produce large moments and horizontal deflections with the piled group foundations. The preliminary assessment predicts that, although there will be large deformation within the ground, the strata below the upper layer of silt will not yield, and it is predicted that from a geotechnical point of view the piles will not fail.

7.2 Linear Protection Structure

7.2.1 Geometry

The linear protection structure models the pile and capping beam as frame elements with soil springs extending from -20 mOD to a depth of -32 mOD. The pile spacing is 8.0m centre-to-centre, and the fenders, which are to be fixed on the capping beam at each pile, will have the same spacing as the piles. The piles modelled are 20no. 1520mm dia. with wall thickness of 42mm (Grade S355).

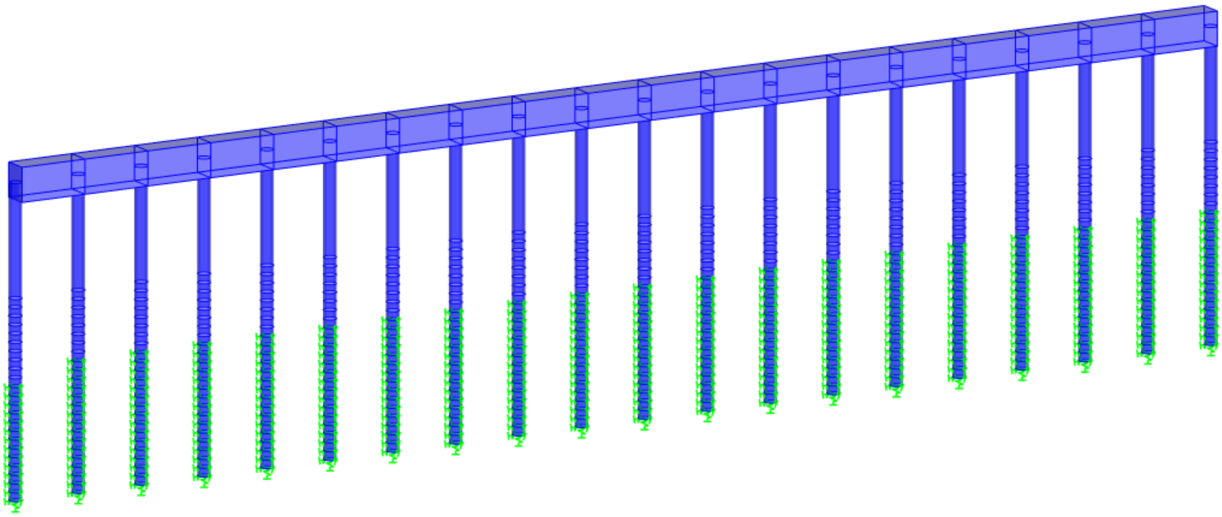


Figure 7-2. Structural model of Linear Protection Structure

7.2.2 Assumptions

1. A stiff and heavily reinforced capping beam is provided.
2. Vessel stern impacts the structure.
3. SCN 2500 F3.0 fender units are installed alongside the linear protection structure.
4. The structure may not be serviceable after the accidental event.
5. The maximum number of fenders likely to be engaged is two.

7.2.3 Impact Energy

The maximum energy a Trelleborg SCN 2500 F3.0 fender can absorb at the rated deflection is 11,337 kNm. The associated reaction force is 8,475 kN.

It is assumed that during the impact scenario, 2 no. fenders are compressed to their rated deflection and thus impose a total force 2 x 8,475 kN, or 16,950 kN, on two piles., bringing them close to their plastic moment of resistance. The energy absorbed by both fenders is therefore 2 x 11,337 kNm, or 22.67 MNm.

Since the energy absorption capacity of the fenders is less than the impact energy calculated in section 6.2, additional energy absorption due to the deformation of the structure is required.

From the structural model, the maximum transverse displacement of the structure when subjected to an overall load of 16,950 kN is 0.6 m:

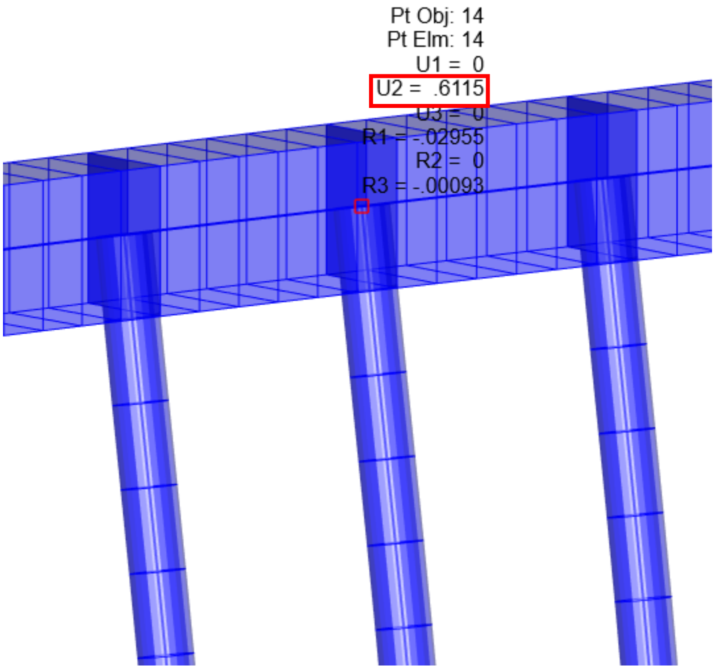


Figure 7-3 Snapshot of structural model showing the magnitude of transverse displacement at the top of the Linear Protection Structure in response to the vessel impact load.

The additional energy absorption due to the structure sway is therefore calculated as 16,950 kN x 0.6 m x 0.5 = 5,085 kNm.

The total energy absorption is therefore 27.76 MNm, which is greater than the impact energy of 25.38 MNm (refer to Section 6.2), therefore the structural concept of the Linear Protection Structure is deemed suitable to resist the impact energy.

7.2.4 Geotechnical Model

The results of the Repute assessment show that the proposed structures under high collision loads will produce large moments and horizontal deflections with the piled group foundations. The preliminary assessment predicts that, although there will be large deformation within the ground, the strata below the upper layer of silt will not yield, and it is predicted that from a geotechnical point of view the piles will not fail.

7.3 Pontoon and restraint dolphins

7.3.1 Geometry

The restraint dolphin model comprises, one vertical guide pile and four raking piles as frame elements with soil springs extending from -20 mOD to a depth of -37 mOD. The concrete cap is modelled as a plate element to function as a rigid cap, transferring the impact force to the raker piles.

Each dolphin comprises:

- 1no 1420x35mm steel vertical guide pile (S355) and,
- 4no of 1220x35mm raking piles (S420).

For the purpose of this assessment, the vertical guide pile will be ignored and only the restraint dolphin with its raking piles will be considered in the structural modelling.

It is assumed that each dolphin will be equipped with 1no Trelleborg SCN F3.1 fender unit.

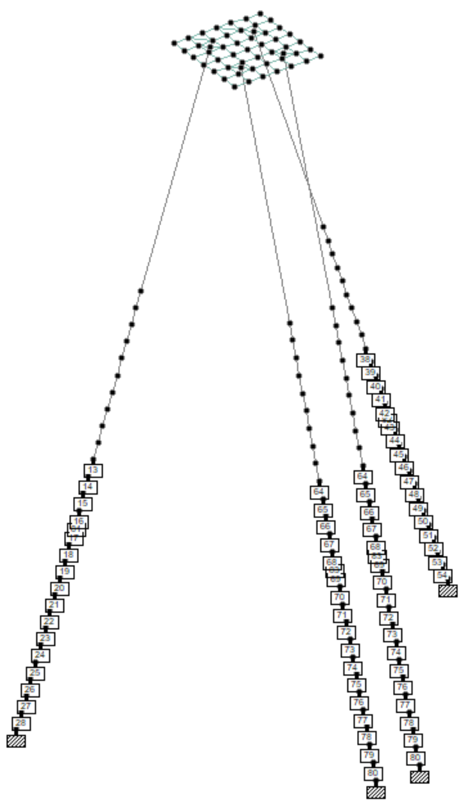


Figure 7-4 Snapshot of structural model of pontoon restraint dolphin.

7.3.2 Assumptions

1. The vessel stern impacts on the pontoon.
2. 2no. pontoon restraint dolphins and thus, 2no. Trelleborg SCN F3.1 fender units are compressed up to their rated deflection.
3. The structures may not be serviceable after the accidental event.

4. The calculations neglect any contribution from the vertical guide piles.

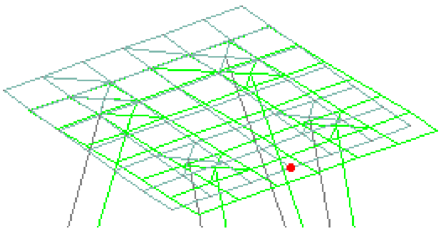
7.3.3 Impact Energy

At 2.5 knots, this assessment assumes that the maximum energy a Trelleborg SCN 2500 3.1 fender can absorb at the rated deflection is 12,470 kNm. The associated reaction force is 9,322 kN.

When subjected to the above fender reaction force applied at the centre of the dolphin concrete deck, the piles remain with their plastic moment of resistance.

Assuming that 2 No. pontoons and their respective fenders are engaged, the energy absorbed by the fenders would amount to a total of 2 x 12,470 kNm, or 24.94 MNm, which is marginally smaller than the impact energy quoted in section 6.2 (25.38 MNm).

Following the the approach to the Linear Protection Barrier, this assessment considers the additional energy absorption from the structural deformation. Figure 7-5shows the deck displacement due to the applied fender reaction force.



All / Summary

		Horizontal	Vertical	Horizontal	Resultant
Node	L/C	X mm	Y mm	Z mm	mm
16	1004 VESSEL	2.074	70.415	190.074	202.708
17	1004 VESSEL	2.079	70.277	189.480	202.104
18	1004 VESSEL	2.070	70.122	188.893	201.499
19	1004 VESSEL	2.061	69.930	188.321	200.896
20	1004 VESSEL	-0.864	5.030	188.291	188.360
21	1004 VESSEL	-0.228	17.995	188.327	189.185
22	1004 VESSEL	0.356	31.119	188.338	190.892
23	1004 VESSEL	0.918	44.218	188.331	193.455
24	1004 VESSEL	[illegible]	[illegible]	[illegible]	[illegible]

Figure 7-5 Snapshot of structural model showing the magnitude of horizontal displacement at the top of the Pontoon Restraint Dolphin in response to the vessel impact load.

The additional energy absorption due to the structure sway is therefore calculated as 9,322 kN x 0.19 m x 0.5 x 2no dolphins = 1,771 kNm.

The total energy absorption is therefore 24.94 MNm + 1.77MNm, or 26.71 MNm, which is greater than the impact energy of 25.38 MNm (refer to Section 6.2), therefore the structural concept of the Pontoon Restraint Dolphin is deemed suitable to resist the impact energy.

7.3.4 Geotechnical Model

The results of the Repute assessment show that the proposed structures under high collision loads will produce large moments and horizontal deflections with the piled group foundations. The preliminary assessment predicts that although there will be large deformation within the ground, the strata below the upper layer of silt will not yield, and it is predicted that from a geotechnical point of view the piles will not fail.

8. Results

For each of the structures analysed, a number and type of Trelleborg SCN fender units have been selected. The criteria for the selection were:

- To absorb the totality (or the majority) of the impact energy; and
- Limit the forces exerted by the fender units onto the structures to a magnitude that would engage the piled foundations up to their plastic moment of resistance.

For each structure, the limiting factor is the bending capacity of the piles. The allowable impact energy has been determined based on the maximum pile capacity.

The maximum allowable velocity for each vessel has then been calculated from the allowable impact energy.

The tables below indicate:

- The energy that each structure or arrangement can absorb.
- Whether the structure described can resist the IERRT Design Vessels at the stated speed.

For reference, the impact energy of a 1500-A vessel travelling at 2.5knots is 25.38 MNm.

8.1 Pier Protection Dolphin

Vessel	Displacement (t)	Energy Absorbed by Fenders and Structure (MNm)	Target Speed m/s (knots)	Pass / Fail
2000-A	23,372	31.09	1.28 (2.5)	pass
3000-A	21,451	31.09	1.28 (2.5)	pass
1500-A	27,900	31.09	1.28 (2.5)	pass
Future vessel	48,431	30.64	0.93 (1.8)	Pass
Notes	Assumes three fenders are engaged.			

Table 8-1 Capacity and performance of the Protection Dolphin

The expected movement of the structure whilst absorbing this energy is less than 1 m at deck level.

8.2 Linear Protection Barrier

Vessel	Displacement (t)	Energy Absorbed by Fenders and Structure (MNm)	Target Speed m/s (knots)	Pass / Fail
2000-A	23,372	27.76	1.28 (2.5)	Pass
3000-A	21,451	27.76	1.28 (2.5)	Pass
1500-A	27,900	27.76	1.28 (2.5)	Pass
Future vessel	48,431	27.36	0.93 (1.8)	Pass
Notes	Assumes two fenders are engaged.			

Table 8-2 Capacity and performance of the Trunkway Protection Barrier

The anticipated movement of the structure whilst absorbing this energy is less than 1m at the level of the beam.

8.3 Restraint dolphins

Vessel	Displacement (t)	Energy Absorbed by Fenders and Structure (MNm)	Target Speed m/s (knots)	Pass / Fail
2000-A	23,372	26.71	1.28 (2.5)	pass
3000-A	21,451	26.71	1.28 (2.5)	pass
1500-A	27,900	26.71	1.28 (2.5)	pass
Future vessel	48,431	26.29	0.93 (1.8)	Pass
Notes	Assumes two restraint dolphins are engaged.			

Table 8-3 Capacity and performance of the Restraint Dolphins

Assuming equal loading, the anticipated movement of the restraint dolphins whilst absorbing this energy is less than 0.5 m at the pile cap.

9. Discussion and Conclusion

9.1 Discussion

This Note identifies structures that have the potential to provide protection to the existing IOT infrastructure from impact by an IERRT Design Vessel that has lost power in its approach to the proposed IERRT berths.

Using a series of structural models and trial impact forces, the arrangements were developed and adapted to accommodate the impact energy associated with the IERRT Design Vessels at the stated speeds.

The results are for the stated assumptions and limitations. Subsequent phases of the design process could be expected to develop these arrangements to maturity.

We anticipate that further refinement and capacity could be sought from:

- **Pile design:** no structural or durability benefit has been taken from infill of the piles with concrete.
- **Pile design:** no structural benefit has been taken from the use of reinforcement within a concrete infill.
- **Pile design:** no structural benefit has been taken from plating.
- **Pile design:** the geotechnical parameters used are known to be conservative. In advance of detailed design further boreholes and test piles could reasonably be expected to allow for refinement of the design of all piles.
- **Pontoon design:** no energy absorption benefit has been assumed from the moving or crumpling/tearing of the pontoon.
- **Geometry:** subject to constructability reviews, the finished level of the concrete elements could be lowered to reduce loads on the piles.
- **Geometry:** subject to a review of the vessels structure, the depth of the concrete works (pile cap / beams) could be increased to increase the impact area and reduce the potential for impacts on to the piles.
- **Arrangement:** the Protection Dolphin and Protection Barrier do not benefit from raking piles. The inclusion of raking piles has the potential to improve the performance of these structures but would require a more detailed review of the existing IOT pile positions.
- **Arrangement:** the assessment of the Pontoon and Restraint Dolphin system does not consider benefit from the Type 1 dolphin present on the eastern edge.

This study has not considered environmental loading however, these loads are expected to be nominal in comparison to those associated with a vessel impact.

The layout presented is aligned to modelling supporting an environmental assessment. Significant changes to the arrangements presented, e.g. changes to pile spacing or layout may need to be supported by further environmental assessment modelling.

The proposed impact protection structures have been positioned to maintain existing IOT operations to IOT Berths 8 and 9 and the navigation under the IOT Trunkway. The structures proposed are of a form that will allow for the inclusion of fendering to aid and protect vessels accessing the IOT Finger Pier. These requirements and designs should be developed during subsequent phases of design development.

9.2 Conclusion

The designs have been developed such that they are consistent with the VIPS Design Basis document (4021009-JAC-ZZ-01-TN-C-00001).

The structures developed and presented in this note have the potential to protect the defined extents of the existing IOT structure from impact by an IERRT Design Vessel. This is primarily the western facing elements of the IOT Finger Pier and the Trunkway South of the Finger Pier.

Where they are subjected to an impact from the IERRT Design Vessels at the speeds identified in this note, the structures may no longer be serviceable.

To improve confidence in the assumptions made in this assessment, as well as identify opportunities for refinement we suggest that in advance of further protection structure design work, that investigation be made into:

- Vessel tracking (ongoing navigational risk assessments will clarify the areas of the IOT structure that are at risk and better understand the orientation of the direction of the loads imposed).
- Operational constraints (which have the potential to limit impacts that could be imposed on the protection structures).
- The vessel / structure interface (to ensure that the structures remain effective over the operational tidal range).
- The geotechnical parameters (further, location specific site information will allow for refinement of the designs).