Penzance Harbour South Pier & Lighthouse Pier History and Condition (Stage 1)

Cornwall Council

22 March 2013
FINAL REPORT
9Y0638

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Document title	Penzance Harbour South Pier & Lighthouse Pier History & Condition (Stage 1)
Document short title	
Status	FINAL REPORT
Date	22 March 2013
Project name	Penzance Harbour
Project number	9Y0638
Client	Cornwall Council
Reference	9Y0638/RR001/304293/Exet

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Date/initials approval	……	……

SUMMARY

This report has been prepared by Royal HaskoningDHV on behalf of Cornwall Council to address the following questions posed by the brief:

- the current condition of the South Pier and Lighthouse Pier, Penzance Harbour;
- the requirement for further investigations and works necessary to address areas of concern with an indication of costs

The report concludes that both the South Pier and the Lighthouse Pier are generally in fair to good condition with the exception of the defects described in Section 4.

Both piers have localised areas of missing mortar and in some cases, masonry. There is also evidence of voiding and settlement, and some repairs are considered urgent.

Defects are described in more detail in Chapter 4 and the priority of repair works are contained in Table 2.

CONTENTS

		Page
1	INTRODUCTION	1
2	REVIEW OF PREVIOUS STUDIES	4
3	SITE VISIT	6
4	INSPECTION REPORT	7
5	MAINTENANCE & COSTS	12
6	CONCLUSIONS AND RECOMMENDATIONS	14
7	REFERENCES	15
8	BIBLIOGRAPHY	16

Figures

1 INTRODUCTION

1.1 Scope of Work

The southern harbour piers at Penzance are subject to structural degradation and overtopping. Several investigations have been undertaken and proposals have been put forward in an effort to address these issues. Over that period essential maintenance work has been carried out. There has however been continued deterioration and overtopping occurs during stormy conditions.

This Stage 1 report, prepared by Royal Haskoning DHV on behalf of Cornwall Council, therefore specifically addresses the following:

- the current condition of the South Pier and Lighthouse Pier, Penzance Harbour;
- the requirement for further investigations and works necessary to address areas of concern with an indication of costs

A Stage 2 report provides a review of previous proposals and examines the potential need and benefits in undertaking various improvement works to address the operational issues relating to overtopping of the piers.

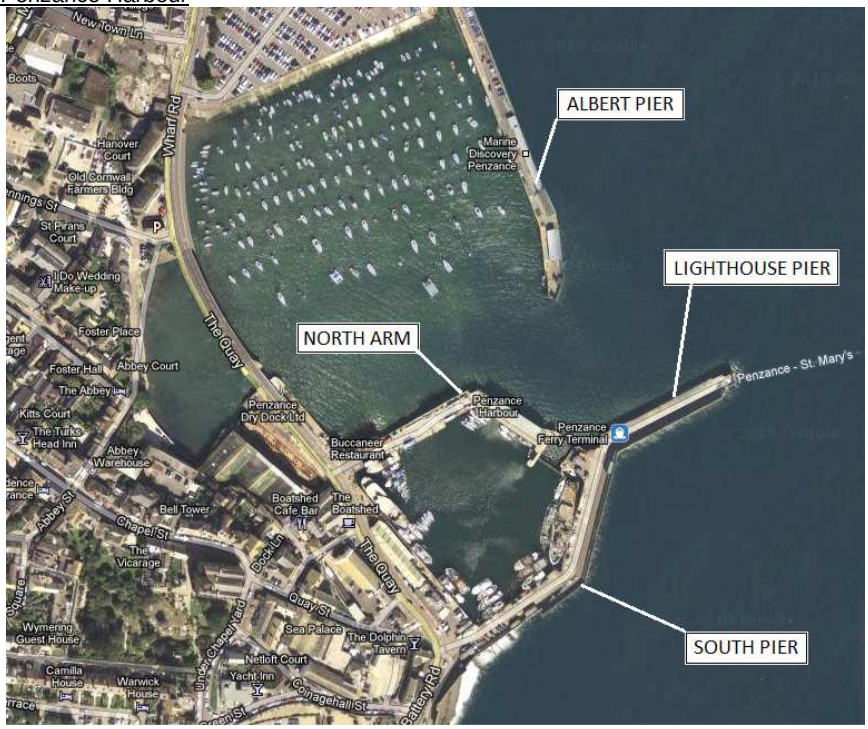
Information has been obtained from previous inspections and preliminary work undertaken by Hyder Consulting in 2004. This report also incorporates Royal HaskoningDHV report /N0001/304293/Exet, a technical note submitted to Cornwall Council in December 2012 which provided preliminary findings based on a review of previous reports, prior to undertaking a visual inspection of the structures.

1.2 Background

Penzance is a small port town on the south coast of Cornwall located approximately 65 miles west of Plymouth. The Penzance Harbour is located within Mounts Bay and comprises four piers which are illustrated below on Photo 1:

- The Albert Pier
- The North Arm
- The Lighthouse Pier
- The South Pier

Photo 1 - Penzance Harbour



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The study focuses on the South Pier and the adjoining Lighthouse Pier which forms the first line of defence against waves travelling north from the English Channel and the Bay of Biscay. It is understood that a harbour wall was first built in medieval times. The pier, as it is today, was constructed in stages between 1764 and 1853 along a rock outcrop. The South Pier is a Grade II* listed structure (upgraded from Grade II in 2011) and large parts of the rest of the harbour area and surrounding buildings are also listed. The following construction summary is provided in the Cahill 2009 historic building analysis:

"Apart from the mediaeval pier, which may have been built with solid stones throughout, all subsequent phases of the pier construction entailed outer walls of coursed masonry (vertically set in ealier phases and in part dry laid), enclosing a rubble masonry core and supporting a parapet wall, with solid flat- laid stonework at the various pier-heads, usually fixed by additional treenailing (i.e. large timber pegs)."

Since their construction, additional works have been undertaken to support the piers, these include the construction of a concrete toe along a section of the South Pier and the placement of rock to the toe of part of the Lighthouse Pier. The key features of Penzance Harbour are illustrated in Figure 1.

Penzance Harbour is recognised in the Cornwall and Isles of Scilly Shoreline Management Plan (SMP) and is situated within Policy Unit 21.1. The SMP outlines that a hold the line policy is to be adopted in and around Penzance Harbour. We are also aware that Cornwall Council has plans to undertake a Flood and Coastal Risk Management (FCRM) Strategy for Mounts Bay in the near future.

The harbour has been the preferred mainland location for a sea link to the Isles of Scilly since 1930. Several proposals were developed, most notably the Route Partnership project, which aimed to provide a reliable and sustainable sea transport link between Penzance and St Mary's. In 2009 a Harbour Revision Order (HRO) was granted permitting:

- The construction of an extension to the Lighthouse Pier to accommodate longer vessels and provide protection to current vessels using the quay;

- Provision of rock armour over the existing and extended Lighthouse Pier and approximately half of the South Pier to reduce overtopping to safe levels and potentially allow all year round berthing;

- Construction of passenger/freight facilities on an area of reclamation seaward of the remaining half of South Pier together with a new sea wall to an increased height.

The works described in the 2009 HRO may be undertaken at any time up to 2019 and the associated listed building consents, which were granted in 2010, remain valid until 2015.

It was intended that the rock armour would reduce overtopping and improve the structural integrity of the South Pier and Lighthouse Pier, providing protection to the existing Grade II* listed harbour wall and to users of the harbour through reducing run up/overtopping. This would increase the level of protection for both the stevedores working on the quays and passengers boarding ferries on the Lighthouse Pier. The project failed to secure DfT funding in 2011 and consequently the proposed work has not been carried out to date.

2 REVIEW OF PREVIOUS STUDIES

2.1 Harbour Inspections

In 2004 an inspection of Penzance Harbour was carried out by Hyder Consulting. The report reference number is DV01104/RT/52/01 and the core findings are summarised below. Figures 2 and 3 include images taken from Hyder Consulting's 2004 report with further details of the condition of the two piers.

South Pier

The 2004 inspection report states:

"The overall condition of the seaward face of the wall is good with some areas of open joints where mortar has been lost, and some voids in behind open joints, with depths from less than 200mm to more than 2700mm."

The Lighthouse Pier

The 2004 inspection report states that:

"The overall condition of the seaward face of the wall is good, with some areas of open joints where mortar has been lost and some voids behind joints, with depths from less than 200mm to more than 2000mm, From Ch236 to Ch270 the rock armour to the toe of the wall has been reinforced with rough in-situ mass concrete."

The report goes on to say:

"On the inside face, the overall condition is poorer, with a large number of open joints, probably due to constant abrasion from vessels moored against the wall."

Additional Comments

Although the report identifies many local areas where mortar is missing, it is only in quite specific areas where there is seen to be deeper voids running into the structure. There are two areas on the South Pier around Ch100 and Ch130 (either side of the concrete blockwork toe) where there appears to have been significant loss of mortar and potential movement of stonework. There is a further section between Ch180 and Ch200 where there are signs of movement and cracking to the structure.

On the Lighthouse Pier, although there is reported to have been some general settlement, much of the defects appear to be quite local in nature.

A further inspection was carried out by Paul Carpenter Associates in January 2010 but does not provide the same level of detail as Hyder Consulting's 2004 report. Neither of the reports indicate any significant scour or instability in terms of overturning. The principle concerns appear to be with respect to local settlement and cracking and the potential washout of material from the core.

With regards to the latter issue of washout, it is noted that some pressure grouting work was undertaken to the Lighthouse Pier, although it is understood that there was significant loss of grout through open joints. The 2010 inspection report makes the valid point that increasing the internal impermeability of the structure may in fact set up increased pressure within the structure that could result in damage to the stone face.

3 SITE VISIT

A site visit was carried out by representatives of Royal Haskoning DHV and Team Van Oord on Monday 14th of January 2013. During the site visit a visual inspection was carried out in order to determine the current general condition of the South Pier and the Lighthouse Pier and any degradation since Hyder Consulting carried out the 2004 inspection.

During the inspection, a discussion was held with the Harbour Master and other harbour employees with respect to experience of overtopping, in particular discussing anecdotal evidence and photographs as to the location and magnitude of overtopping along the harbour wall.

It was confirmed by the Harbour Master that significant overtopping occurs during normal / "frequent" storm conditions and this was considered in relation to wave direction and areas of damage observed during the inspection of the structure. A separate report has been prepared considering overtopping issues.

The site visit was carried out on a day with minimal waves and a relatively high tidal range. The tide times and heights are included below in Table 1.

Table 1 - Tide Times and Heights

Tide Time	Tide Height (mCD)
00:46	0.5m
06.22	5.8m
13:11	0.4m
18:50	5.5m

At low tide the South Pier was accessible on foot between the Jubilee Pool and the concrete toe. The remaining section of the South Pier and the Lighthouse Pier was surveyed by boat.

The first of two foot surveys was carried out between 09:00am and 11:30am. The boat survey was carried out between 11:30am and 12:30pm. A further foot survey was carried out between 12:30pm and 13:30pm, at which point the tide was at its lowest.

4 INSPECTION REPORT

This chapter contains the findings from the visual inspection. The observations made are compared to those reported from the survey undertaken in 2004. Deterioration to the harbour wall identified during both the 2004 and 2013 inspections is described and illustrated in Figures 2 and 3. These figures also look at repairs and maintenance that has been carried out since the 2004 inspection.

4.1 Overview

The inspection primarily focuses on the areas of concern, however, it should be noted that the overall condition of the South Pier is still generally considered to be fair to good. There is very little by way of cracks and voids on the section of the South Pier between the Jubilee Pool and the initial section of rock armour shown in Photo 1 on Figure 2. Working further seaward along the Pier, generally there is some change in local areas which were previously identified as areas of concern, with some further deterioration. In other areas, the condition appears not to have changed. A local area of missing masonry was identified and was highlighted during discussions after the inspection. It is understood that action will be put in hand to address this immediate problem. The inspection and comparison of the South Pier is discussed in more detail below.

It was noted that new stainless steel pinning had been undertaken to the masonry of the Lighthouse Pier. It was also evident that there was, or has been in the past, some settlement of the north east corner of the Pier. This appears to have opened a gap between the main body of the Pier and the masonry facing on the seaward side. While this gap has been in-filled and there appeared to be little further deterioration of the seaward face, this may explain the need for stitching of the masonry. This is discussed in more detail below.

Cornwall Council also confirmed that repairs were undertaken to the Colonnade Building on the South Pier (following storm damage in January 2010).

4.2 Detailed Discussion of the South Pier

The key elements of potential structural damage identified during the 2013 South Pier inspection are as follows:

1. Deterioration of the South Pier (at and above the drying areas of the natural rock outcrop);
2. Water spurting out of the wall just to the north of the rock out crop.
3. Previous defects identified to the south of the concrete toe.
4. Missing block north of the concrete toe;
5. Previous concerns over the most seaward section of the South Pier.

<u>Deterioration of the South Pier (at and above the drying areas of the natural rock outcrop)</u>

Photo 6 on Figure 2 illustrates the section of the south pier where the natural rock outcrop at the foot of the structure meets the pebble beach. There are two areas that show signs of further movement since 2004 and these areas are considered to be in need of repair work. Within this section there appears to be areas of mortar missing at the lower part of the wall

(Photo 9) and in the upper part of the wall there appears to be a line of masonry blocks missing (Photo 10). Masonry within the two areas highlighted appears to have moved since 2004, being pushed back further within the structure. This would suggest some voiding. The harbourmaster believes that there is a void within the pier extending from surface level to below mean sea level. There is no evidence that repairs have been carried out to address this deterioration and further investigation is required of possible voids. Repair work is considered to be a high priority within a planned maintenance programme. Repairs would need to be undertaken irrespective of any other options associated with managing the use or overtopping of the Pier..

Water spurting out of wall to the north of the rock outcrop

Water is evidently discharging from the impounded inner harbour area (See Photo 11). There is no sign of movement of masonry in the outer (seaward face). While the water demonstrates the permeability of the Pier, this is not considered to be a significant defect. Clearly this would need to be monitored but, at this time, no specific action is recommended.

Previous defects south of the concrete toe

Some minor movement and missing pointing was identified to the south of the concrete toe in an area exposed to wave impact (see photos 12 to 14 from Figure 2). This area does not appear to have changed since 2004 and while areas of the wall require repointing, there is no immediate action required.

Missing block to the north of the concrete toe

A large block was missing from the pier wall to the north of the concrete toe (see photos 8 and 14). During the 2004 inspection this section of wall was still intact. However, an area of missing mortar could be seen directly beneath the missing block. It appears that the wall is backed by relatively large stones (reportedly part of an old quay wall). Some of this fill behind has been displaced but it appears that it is relatively stable. It is likely that waves breaking within the voids between blockwork have caused large pressures between the outer face and the relatively solid inner face and that this has pushed the block out from within. This mechanism was put forward as a key concern, in the Paul Carpenter Associates' report in January 2010, as an argument against internal grouting of the structure. (The defect was raised during the discussion during the site visit and it is understood that the immediate action is to be taken to repair this section of the wall).

Previous concerns over the most seaward section of the South Pier

Some minor movement and missing pointing was identified in this area. However, in general the condition of this section of the pier is generally in fair to good condition. The area does not appear to have changed since 2004 and it is considered that no immediate action required.

4.3 Detailed Discussion of the Lighthouse Pier

The key issues identified during the 2013 Lighthouse Pier inspection are as follows:

1. Settlement of the northern end of the Light House Pier
2. Deterioration and vulnerability of the masonry seaward face.
3. Deterioration and vulnerability of the masonry along the inner face.

Settlement of the northern end of the Lighthouse Pier

During the site visit it was clear settlement of the Lighthouse Pier has occurred. This was most obvious at the northwest corner of the light house pier and further evidenced by the off-vertical alignment of the lighthouse. It is uncertain to what degree this movement is continuing or to what degree this movement may have occurred immediately following construction. It is reported that the Pier is constructed on silty sand. This is supported by the 2008 Halcrow Group Ltd geotechnical report (Project Number PE080598)

It was noted that this area may be within the area of influence of the berth and may have or continue to be affected by possible dredging or scour around the inner face and head of the Pier.

Associated with this movement, it was noted that there had been separation between the main body of the Pier and the seaward masonry face. This gap has been in-filled, at least at the surface, by concrete. As previously noted, it is uncertain whether movement is continuing and whether this gap may reopen.

Deterioration and vulnerability of the masonry seaward face

Historically, the masonry in this area has been stitched together. The steel stitching bars had rusted away, as identified in the 2004 report, and have now been replaced by stainless steel staples (See Photos 22 & 23). The need for stitching seems likely to have been a result of the separation of the wall from the body of the Pier, as discussed above. There does not seem to have been any substantial movement of the masonry since 2004, which does suggest that this was an historic problem. Critically, however, the wall has to be considered as being vulnerable to wave action and movement.

Several significant open joints have been identified towards the top of the end section of the lighthouse pier (see Photo 19 of Figure 3). Two further deep voids are with depths of approximately 700mm and 1000mm are also highlighted. It is possible that these crack and voids were a product of the general subsidence of this section. However, from the 2013 inspection it appears that they have been filled in.

While the problem is linked to possible further settlement of the Lighthouse Pier, it can be seen as an existing problem even if no further settlement is occurring. In effect the masonry face may be acting as a standalone wall. While the stitching has provided some relief to this problem, this may be a key area where options such as a rock revetment or other means of supporting or reinforcing this wall need to be considered. This is discussed further in the Stage 2 Report.

Deterioration and vulnerability of the masonry inner face

Some movement and missing pointing was identified on the inner face of the Lighthouse Pier (see photo 20 from Figure 3). This area does not appear to have changed since 2004 and while areas of the wall require repointing, there is no immediate action required.

4.4 Summary of Repairs and Maintenance Work

It was evident from the site visit that elements of maintenance/ repair work had been carried out since the 2004 Inspection. The majority of this work has been carried out on the Lighthouse Pier and included the replacement of the staples on the Lighthouse Pier and the filling of the voids at the end of the Light House Pier. Following discussions with the Harbour Master it is understood that approximately £50k/year has been spent over the last two years on staples, general repointing and repairs to the Colonnade Building.

In other areas, it is understood that a rolling programme of maintenance and repair is to be undertaken. Table 2 sets out priority areas and outline costs for such a programme. The extent of repair work is difficult to estimate with accuracy until the voids / defects are investigated. Only then can the scope be confirmed. It is therefore considered that further investigation is required to identify the mechanisms of failure and extent of repairs.

Table 2 – Priority Actions

Location	Description	Priority	Outline Costs (£)	Notes
South Pier adjacent to first rock outcrop	Missing row of masonry	Medium	Approx. £1000 based on 5m^2 of work required	Necessary to prevent further deterioration
	Two sections of masonry displaced in to wall. Potential voids behind.	High	Approx. £10,000 to £20,000	Necessary to prevent further deterioration
South Pier to north of concrete toe	Loss of masonry blocks. Re-pack and replace, Repointing over larger area.	High	Approx. £1000 based on 5m^2 of work required	Necessary to prevent further deterioration
South Pier General	General repointing	Medium to Low	Approx. £200 per m^2	Necessary to prevent further deterioration
Lighthouse Pier	Settlement of the pier head. This requires monitoring to ascertain whether movement is active or historic.	High	As part of normal monitoring of the structure.	Consideration needs to be given to possible reactivation of movement if the berth were deepened.
Lighthouse Pier, end seaward face	Potential separation between the body of the Pier and the masonry face. Potential need for additional support.	Medium	Cost dependent on monitoring and selection of remedial option.	
Lighthouse Pier General	General repointing	Medium to Low	Approx. £200 per m^2	Necessary to prevent further deterioration

Cornwall Council have obtained Listed Buildings Consent for maintenance works to the Piers, including a schedule of repair works.

Costs included in Table 2 have been based on similar work carried out at Maryport Harbour. It should be noted that costs are indicative and rates may vary dependant on mobilisation costs, access constraints and the results of further investigation.

A monitoring programme should also be developed to track the deterioration of the two piers. This should include harbour inspections at regular intervals and monitoring of the subsidence of the head of the Lighthouse Pier. Items will be added to the priority actions table as the monitoring programme progresses.

5 MAINTENANCE AND COSTS

5.1 Deterioration of the Piers

The 2013 inspection identifies several areas where the harbour wall is in need of maintenance work. The recommended works includes replacement of missing blocks and repointing in several locations. Details of the maintenance works are outlined in more detail in Chapter 4 of this report.

The worst structural damage is located on the Lighthouse Pier with cracks and voids resulting from the general subsidence of the seaward end of the pier and also exposure and vulnerability to wave action. Relatively recent repair work has been carried out to this section in the form of replacement stainless steel staples fixed to the masonry.

5.2 Proposed Repair Works

A regular rolling programme of maintenance, addressing priority areas identified in Table 2. The works with the highest priority would be expected to sustain the structures over the short to medium term.

A key area of concern that may not be addressed through regular maintenance is the potential continuing subsidence of the seaward end of the Lighthouse Pier. Critical to the management of this is establishing, through monitoring whether this is historic movement or an on-going issue.

Associated with this, but considered to be a separate issue, is the vulnerability of the seaward masonry face to the end of the Pier. Historically this has been addressed through stapling the masonry blocks together. This approach may not resolve the problem in the longer term, especially if movement of the head of the pier were on-going.

While maintenance is seen as being the prerequisite for management of the Piers, it does not address the potential vulnerability at the end of the Lighthouse Pier.

The options for addressing the structural integrity of this area of the Lighthouse Pier are:

i. Unpicking the existing pier wall and repair/ restoration like for like
ii. Supporting/buttressing the pier with rock armour
iii. Encasement of the damaged section of the pier wall

It is considered that Option i) is a like for like replacement of the exiting pier and could be undertaken as maintenance works. If the pier were continuing to move, this option may not be viable. The types of work permissible under the 2009 HRO would need to be confirmed before proceeding.

Option ii) is covered within the 2009 HRO, as set out in Section 1.2 of this report. With this option further work might be required, should the pier continue to subside, in order to address the gap between the front face and the main body of the Pier.

Option iii) would require new consent as works would substantially change the nature of the structure. The issues of settlement would still need to be addressed.

5.3 Costs

The costs for these types of repairs are difficult to estimate with accuracy as it is not until the voids around the missing blocks are investigated / the results of further monitoring are known that the scope of works can be confirmed. In particular the two areas at the landward end of the South Pier are difficult to fully assess from a surface inspection, because the movement seems to have been of blocks actually being pushed into the structure, there could be voiding behind. Therefore, purely repointing may effectively be patching over a weakness.

In similar cases, the approach Royal Haskoning DHV have developed with other harbour authorities has been to set up a rates based approach with a contractor, covering a range of different possible remediation measures based on initial repair / restoration concepts. The contract then progresses as a continuous process where the repairs are progressed in stages. As the causes of the problem are exposed, a responsive design is developed. This requires an interactive approach between client, designer and contractor.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Inspection

The report concludes that the overall condition of the South Pier is generally considered to be fair to good with very little by way of cracks and voids on the section between the Jubilee Pool and the initial section of rock armour. However, in locations exposed to greater wave action there are areas which require repointing. There are also two significant areas where masonry has been dislodged.

The Lighthouse Pier is also generally in fair to good condition over its main length. There is continuing concern over its seaward section where movement of the body of the Pier appears to have caused separation from the front masonry wall. It appears that the seaward end has subsided and there are some areas of cracks and voids associated with this subsidence. The inspection identified that maintenance and repair work has been carried out on the Lighthouse Pier in the form of filling in cracks and the replacement of the corroded staples. The report highlights, however, the vulnerability of the masonry seaward face of the structure to any further movement.

With the exception of the seaward end of the Lighthouse Pier, the report concludes that repair and maintenance would be the most effective way in which the defects could be addressed. The deterioration over much of the Pier is due to general exposure and deterioration with age. Other measures such as reduction in wave exposure could slow further deterioration but would not address the more fundamental need for maintenance.

6.2 Recommendations

This report has reviewed several options in terms of managing the deterioration of the piers. The recommendations are as follows:

1. Where specified, immediate repairs are required to be undertaken irrespective of any option for rock armour;
2. A monitoring program should be developed to understand the rate of degradation of the piers; and
3. This report is used as the basis for further discussion in determining the most effective course of future actions.

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FIGURES

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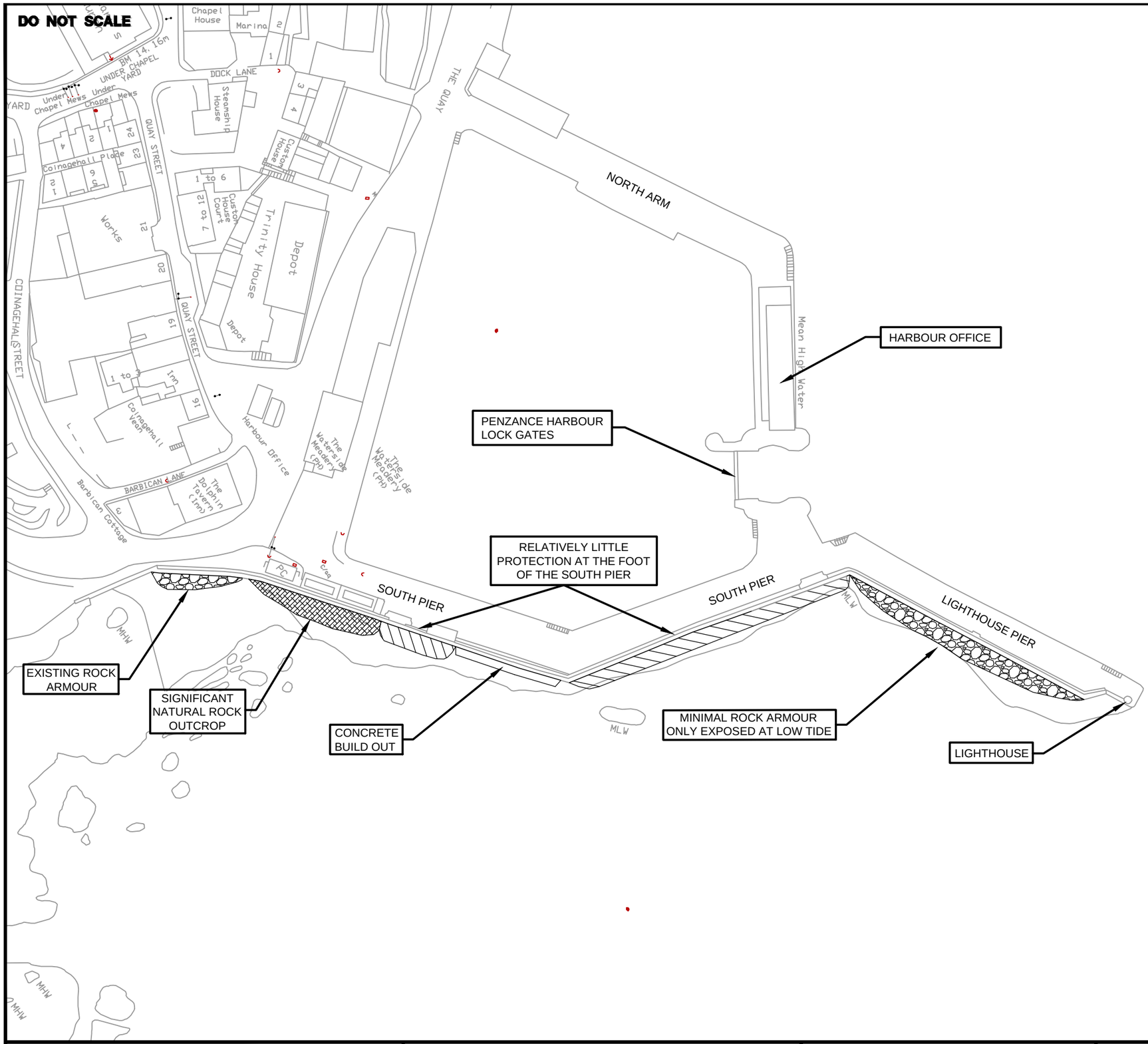

NOTES:

1. ALL DIMENSIONS ARE IN MILLIMETRES UNLESS NOTED OTHERWISE.
2. ALL LEVELS ARE IN METRES RELATIVE TO ORDNANCE DATUM NEWLYN UNLESS NOTED OTHERWISE.
3. ALL MATERIALS AND WORKMANSHIP WILL BE AS DEFINED IN THE SPECIFICATION UNLESS NOTED OTHERWISE.
4.

TITLE
Site Location Plan & Harbour Features

PROJECT
Penzance Harbour Inspection and Proposed Works

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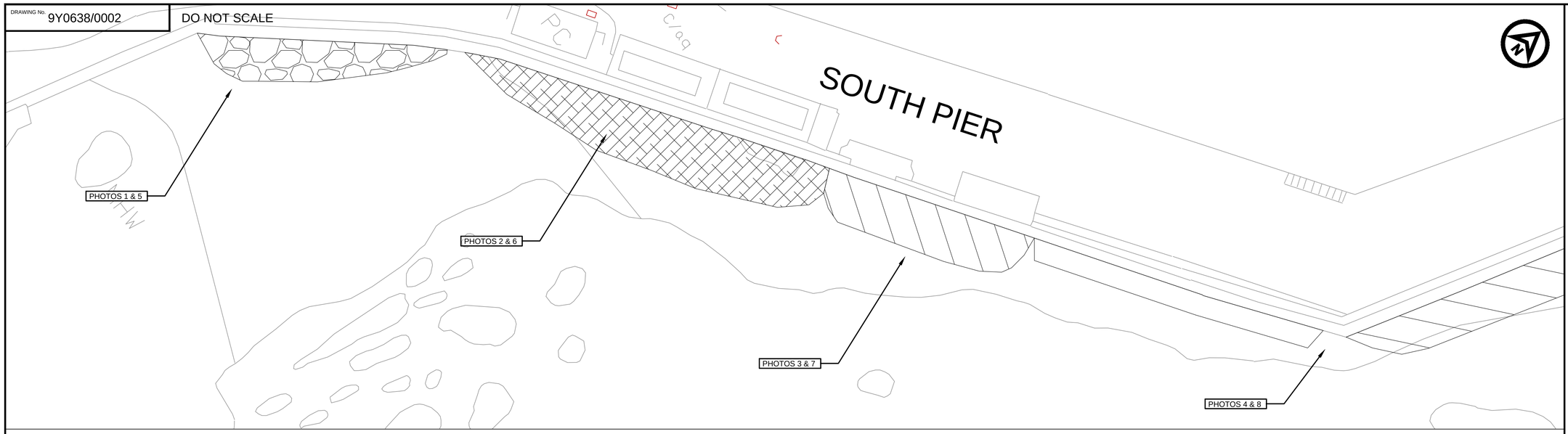

2004 Hyder Report

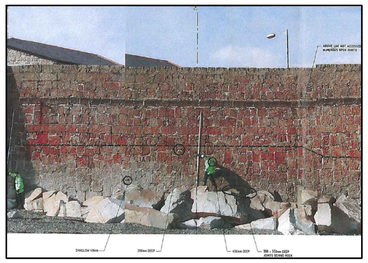

Photo 1 South Pier Protected by Rock Armour
2004 Hyder Report (Chainage 0m - 20m)

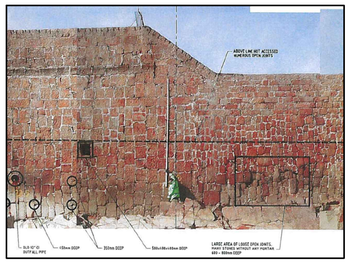

Photo 2 - South Pier Protected by Rock Outcrop
2004 Hyder Report (Chainage 35m - 45m)

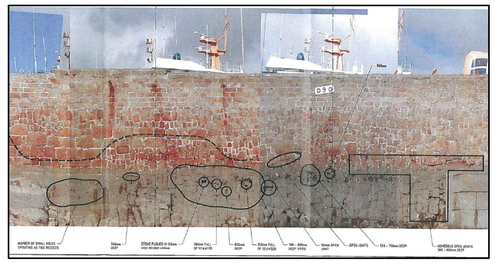

Photo 3 - South Pier - Exposed Area to the Left of Concrete Build-out
2004 Hyder Report (Chainage 70m - 100m)

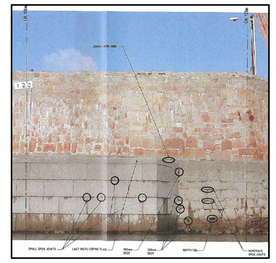

Photo 4 - South Pier Right of Concrete Build-out
2004 Hyder Report (Chainage 120m - 133m)

2013 RHDHV Inspection

Photo 5 South Pier Protected by Rock Armour
2013 RHDHV Inspection

Photo 6 - South Pier Protected by Rock Outcrop
2013 RHDHV Inspection

Photo 7 - South Pier - Exposed Area to the Left of Concrete Build-out
2013 RHDHV Inspection

Photo 8 - South Pier Right of Concrete Build-out
2013 RHDHV Inspection

Photo 9

Photo 10

Photo 11

Photo 12

Photo 13

Photo 14

Photo 15

South Pier - Protected by Rock Armour

The South Pier is was in reasonably good condition during the 2004 Hyder survey and minimal deterioration is evident. The beach also appears to be at a similar elevation in both 2004 and 2013.

South Pier - Protected by Rock Outcrop

In the 2004 inspection, large areas of loose open joints are identified at the base of this section. Also, many stones are without mortar and there are voids are between 600mm - 800mm deep.

In 2013 the damage at the base of the wall has not been addressed (See Photo 9). Furthermore, a large rectangular block is now missing from the top of this section (See Photo 10). It is considered that this could result from direct wave impact, or pressure building up within the wall due to the missing mortar at the base.

South Pier - Exposed Area to the left of the Concrete Build out

This section of the harbour wall has relatively little by way of protection and is exposed to direct wave action during most phases of the tide. The 2004 inspection recorded a number of small holes spouting as the tide recedes. A number voids and open joints with depths of up to 800mm are also identified, particularly in the vicinity of the concrete build out. The 2004 inspection also identified missing masonry from the top of the harbour wall.

The 2013 inspection has confirmed that the spouting at low tide, open joints and voids still exist (see Photos 11 to 14). A comparison between Photo 3 and Photo 7 suggest that there may have been a slight deterioration in the condition of this section of the Harbour Wall. However, maintenance has been carried out on the missing masonry at the top of the structure.

South Pier - Right of the Concrete Build-Out

The 2004 Hyder inspection considered the concrete build out to be in fairly good condition. However to the right of the concrete build out numerous open joints were identified with one particular void, 1.8m in depth.

The 2013 inspection shows there has been a deterioration in this section of the wall. A large block has been displaced by wave action (see Photo 15). It is considered that this likely to have resulted from a build up of pressure within the 1.8m void recorded in the 2004 inspection. .

NOTES

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CORNWALL COUNCIL

PROJECT

Penzance Harbour Inspection and Proposed Works

TITLE

Figure 2
Penzance Harbour Inspection
Part 1

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Royal HaskoningDHV
Enhancing Society Together

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Jan '13	NTS	-

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REVISION D1

DRAWING No. 9Y0638/0003

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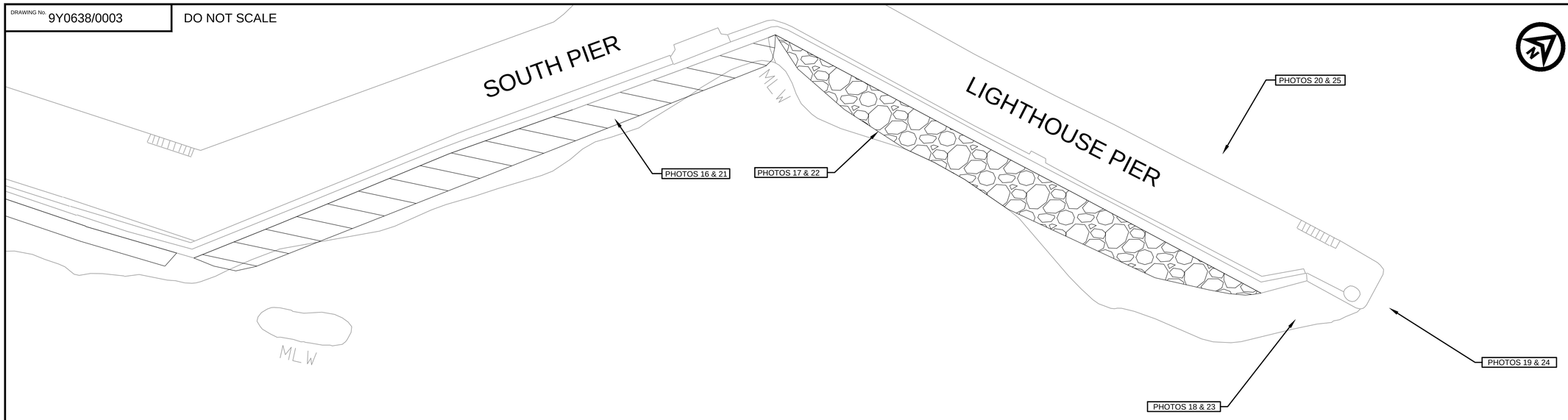

2004 - Hyder Report

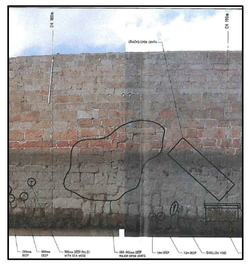

Photo 16 - Northern Section of the South Pier
2004 Hyder Report (Chainage 175m to 190m)

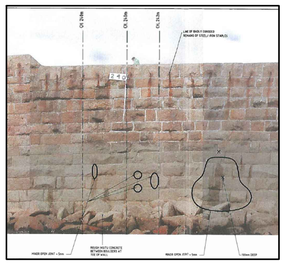

Photo 17 - Eastern Section of the Lighthouse Pier (Southern Face)
2004 - Hyder Report (Chainage 235m to 250m)

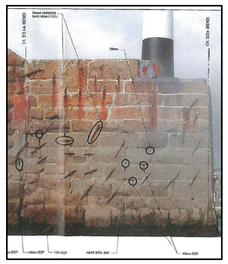

Photo 18 Western Section of the Lighthouse Pier (Southern Face)
2004 - Hyder Report (Chainage 313m to 322m)

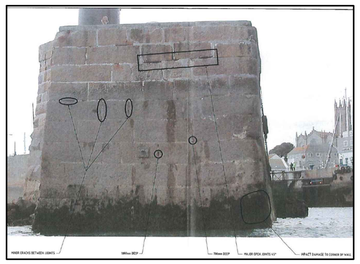

Photo 19 - End Section of Lighthouse Pier
2004 - Hyder Report (Chainage N/A)

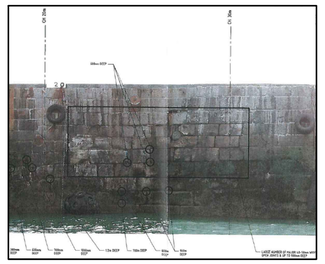

Photo 20 - Northern Face of the Light House Pier
2004 Hyder Report (Chainage 20m - 35m)

2013 RHDHV Inspection

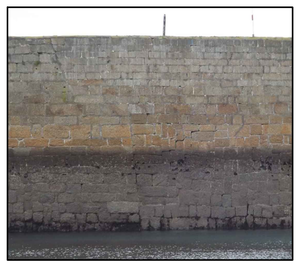

Photo 21 - Northern Section of the South Pier
2013 RHDHV Inspection

Photo 26

Photo 22 - Eastern Section of the Lighthouse Pier (Southern Face)
2013 RHDHV Inspection

Photo 27

Photo 23 Western Section of the Lighthouse Pier (Southern Face)
2013 RHDHV Inspection

Photo 28

Photo 24 - End Section of Lighthouse Pier
2013 RHDHV Inspection

Photo 29

Photo 25 - Northern Face of the Lighthouse Pier
2004 Hyder Report

Photo 30

Northern Section of the South Pier

The 2004 Hyder Report identifies various cracks and open joints along the the northern section of the south pier including an area of deep major open joints with depths of approximately 600mm - 900mm. A further two voids exist at the base of this section which are 1.2m and 1.6m deep.

It does not appear that any remedial works have been carried out on this section. Considerable cracks and voids still exist, with slight deterioration in places. A construction joint was also identified through this section, running from the base to the crest.

Eastern Section of the Lighthouse Pier (Southern Face)

This section of the Lighthouse Pier was in fairly good condition at the time of the 2004 Hyder inspection with very little in the way of cracks and voids. However, the remains of a line of badly corroded steel/iron staples running along the top of the Lighthouse Pier was identified.

Minimal deterioration of this section off wall appears to have occurred since the 2004 survey. However, the steel/iron staples have been replaced (see Photo 27).

Western Section of the Lighthouse Pier (Southern Face)

The 2004 Hyder inspection identifies several cracks and voids within this section, one of which is approximately 1.2m deep. The steel/iron bars providing structural support are highlighted as being corroded. However, it is recognised that they have not corroded away completely.

Although it is not obvious from the Photo 23, during the inspection it was clear that lighthouse end of the pier is subsiding. As a result there appears to have been a worsening in the cracks with maintenance work. However, the corroded bars have recently been replaced in parallel to those that existed in 2004.

End Section of the Lighthouse Pier

The 2004 Hyder reports identifies several significant open joints towards the top of this section. Two deep voids with depths of approximately 700mm and 1000mm are also highlighted, as well as impact damage to the corner of the wall.

It appears that the majority of the cracks and voids have been filled in, and the general condition of this section is good. The impact damage to the corner has not been addressed but is not considered to pose a threat to the stability of the structure.

Northern Face of the Lighthouse Pier

Despite its sheltered location, the 2004 Hyder report identifies several defects on the northern face of the lighthouse pier. Various open cracks with widths of between 40mm - 50mm as well as multiple voids with depths between 700mm - 1000mm.

The 2013 RHDHV inspection identified no remedial work to the north face of the Lighthouse Pier. This section appears to be in a similar condition as was recorded in the 2004 inspection.

NOTES

REV	DATE	DESCRIPTION	BY	CHK	APP

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CLIENT

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PROJECT

Penzance Harbour Inspection and Proposed Works

TITLE

Figure 3
Penzance Harbour Inspection
Part 2

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DRAWING No. 9Y0638/0003

REVISION D1

Penzance Harbour South Pier & Lighthouse Pier Serviceability & Review of Overtopping (Stage 2)

Cornwall Council

22 March 2013
FINAL REPORT
9Y0638

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Document title	Penzance Harbour South Pier & Lighthouse Pier Serviceability & Review of Overtopping (Stage 2)
Document short title	
Status	FINAL REPORT
Date	22 March 2013
Project name	Penzance Harbour
Project number	9Y0638
Client	Cornwall Council
Reference	9Y0638/RR001/304293/Exet

Drafted by	Eddie Crews	
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Approved by	Howard Rushton	
Date/initials approval	……	……

SUMMARY

This report forms an addendum to the Stage 1 History and Condition Report prepared by Royal Haskoning DHV on behalf of Cornwall Council and considers the current serviceability of South Pier and Lighthouse Pier in terms of overtopping.

The Department for Transport (DfT) is currently considering the business case for works at Penzance Harbour. A copy of the correspondence between Norman Baker MP (DfT) and the Leader of Cornwall Council (Councillor James Currie), dated 26th November 2012, contained the formal request for this business case and is included as Appendix A. The Minister specifically requested that the benefits of rock armour be shown separately.

This report discusses the scale and mechanisms of overtopping, considers in outline options for reducing overtopping and addresses the following questions posed by the brief:

- the current risk posed by overtopping of the South Pier and Lighthouse Pier, Penzance Harbour;
- identification of the scale of overtopping and how this may potentially impact on use and operation associated with the Piers;
- the options for addressing this risk considering different scale of work to provide different levels of protection; and
- the outline costs associated these options.

The Stage 1 report considers the condition of the piers and concludes that both the South Pier and the Lighthouse Pier are generally in fair to good condition. It highlights areas where defects exist and makes recommendations for maintenance and repair. Both piers have localised areas of missing mortar and in some cases, masonry. There is also evidence of voiding and settlement, and some repairs are considered urgent. Defects are described in more detail in the Stage 1 report.

In general the condition assessment concludes that problems identified are a result of overall deterioration and age, coupled to evidence of voids. While clearly wave exposure is one of the key causes of deterioration, the issues relating to the condition of the Piers would not be resolved by increased protection. Increased protection following full maintenance and repair would potentially slow further deterioration.

Over the final section of the Lighthouse Pier there is an area of concern as to the stability of the masonry face. Options to address the structural stability are suggested in the Stage 1 report. It is noted and relevant that the placement of rock armour to this section would not only serve to protect against further structural damage to the Lighthouse Pier but would also reduce overtopping.

This Stage 2 report summarises the reported overtopping at Penzance Harbour. The report goes on to compare the opportunities and constraints associated with three options: construction of rock armour along the Lighthouse and seaward section of South Pier, localised rock armour and an offshore breakwater. The focus of the options considered in this report is in the reduction of overtopping. These options will also have ancillary benefits by reducing wave action on the piers hence reducing wear and tear of the fabric of the piers.

Storm events that may cause overtopping impacting on the operation of the piers may be thought of as “frequent” storm events or “extreme” storm events. For example the Isles of Scilly Steamship Company requests permission from Penzance Harbour Master to temporarily move the Scillonian III’s berthing location to the Albert Pier on average once per month during the sailing period between March to October, this is regarded as a “frequent” storm event. An example of “extreme” storm events are those that might happen on average once every few years to say once in 100 years.

A continuous rock revetment over the length of Lighthouse Pier and the seaward section of South Pier (as consented by the 2009 Penzance Harbour Revision Order, refer Appendix C for works extent) would significantly reduce the risk of overtopping from waves during “frequent” and most “extreme” storm events. Such a scheme would most likely be necessary if it was intended to operate the Lighthouse Pier berth on a year round basis.

On “frequent” storm events overtopping occurs principally at specific locations. Examining why and where overtopping occurs offers the option of more localised placement of rock armour to address these key locations. The crest level of the rock armour for local placement would be lower than for the continuous armour and hence would offer a lesser level of protection. It would, however, provide improvements in the current use of the Pier under “frequent” storm conditions.

More major works have been suggested through the construction of a breakwater offshore of the piers. This report considers the benefit of such proposals but recognises the significant increased cost in relation to the two approaches outlined above.

Localised placement of rock armour could address some of the current operational issues of local overtopping and structural stability. A more comprehensive solution to overtopping could be provided through the construction of a continuous rock armour revetment but material costs would be higher than for localised rock placement. There may still be occasions where the Lighthouse Pier berth would be unusable.

An offshore breakwater solution would provide shelter to the harbour whilst maintaining access to the seaward face of the piers for repairs. The associated cost would be significantly higher than both of the rock armour options and no consents / permissions exist for such a structure. The breakwater considered in outline by this report would not be suitable to offer safe vessel berthing immediately behind (it is assumed that this was a feature of the Penzance Harbour Users Association (PHUA) proposal). Comparative costs for all options are included in Chapter 7.

CONTENTS

		Page
1	INTRODUCTION	1
2	CONDITION OF EXISTING STRUCTURES	4
3	INFLUENCE OF OVERTOPPING ON HARBOUR OPERATIONS	5
4	OVERTOPPING	7
5	DEVELOPMENT OF OPTIONS	11
6	COST ANALYSIS	14
7	CONCLUSIONS AND RECOMMENDATIONS	16
8	REFERENCES	17
9	BIBLIOGRAPHY	18

Figures

Appendix A – Letter form Norman Baker – 12th November 2012

Appendix B – Royal HaskoningDHV Technical Note December 2012

Appendix C – Full Length Rock Armour Protection, Plan View & Rock Armour Typical Section

1 INTRODUCTION

1.1 Scope of Work

The Stage 1 report provides an assessment of the current structural condition of the South and Lighthouse Piers. This Stage 2 report addresses the following issues:

- the current risk posed by overtopping of the South Pier and Lighthouse Pier, Penzance Harbour;
- identification of the scale of overtopping and how that may potentially impact on use and operation associated with the Piers;
- the options for addressing this risk considering different scale of work to provide different levels of protection; and
- the outline costs associated these options.

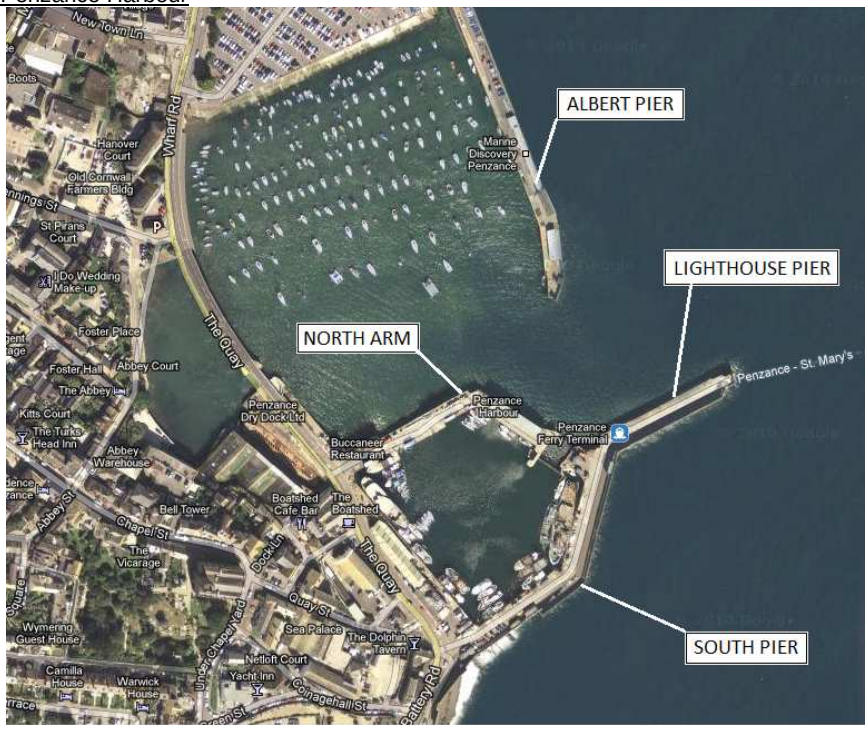
Information has been obtained from previous inspections and work undertaken by Hyder Consulting (2004) and by Halcrow Group Ltd (2008-2010) as part of previous development proposals. This report also incorporates Royal HaskoningDHV report /N0001/304293/Exet, a technical note submitted to Cornwall Council in December 2012 which includes an appraisal of previous overtopping calculations as well as further overtopping and wave run-up analysis. This is included as Appendix B.

1.2 Background

Penzance is a small port town on the south coast of Cornwall located approximately 65 miles west of Plymouth. The Penzance Harbour is located within Mounts Bay and comprises four piers (refer Photo 1):

- The Albert Pier
- The North Arm
- The Lighthouse Pier
- The South Pier

Photo 1 - Penzance Harbour



Imagery ©2013 DigitalGlobe, GeoEye, Getmapping plc, Infoterra Ltd & Bluesky, Map data ©2013 Google

The study focuses on the South Pier and the adjoining Lighthouse Pier which forms the first line of defence against waves travelling north from the English Channel and the Bay of Biscay. The two piers are currently protected by natural rock outcrops as well as sections of rock armour. However, these sections are in place to protect the toe of the structure and have a negligible effect in terms of preventing overtopping and reducing the impact of waves on the walls. The key features of Penzance Harbour are illustrated in Figure 1.

The South Pier is a Grade II* listed structure (upgraded from Grade II in 2011) and large parts of the rest of the harbour area and surrounding buildings are also listed. The Stage 1 report provides a more comprehensive review of the history of the piers and a more detailed description of the structural composition (Cahill 2009).

1.3 Harbour Revision Order 2009

The harbour has been identified as the preferred mainland location for a sea link to the Isles of Scilly since 1930. Several options for harbour improvements were developed, most notably the Route Partnership[1] project, which aimed to provide a reliable and sustainable sea transport link between Penzance and St Mary's. In 2009 a Harbour Revision Order (HRO) was granted permitting:

[1] A Route Partnership was formed in 2003 to address transport issues to the Isles of Scilly and comprised the former Cornwall County Council and Penwith District Council together with the Council of the Isles of Scilly, Duchy of Cornwall and the Isles of Scilly Steamship Company

- The construction of an extension to Lighthouse Pier to accommodate longer vessels and provide protection to current vessels using the quay;

- Provision of rock armour over the existing and extended Lighthouse Pier and approximately half of the South Pier to reduce overtopping to safe levels and potentially allow all year round berthing;

- Construction of passenger/freight facilities on an area of reclamation seaward of the remaining half of South Pier together with a new sea wall to an increased height.

The works described in the 2009 HRO may be undertaken at any time up to 2019 and the associated listed building consents, which were granted in 2010, remain valid until 2015.

It was intended that the rock armour would reduce overtopping and improve the structural integrity of the South Pier and Lighthouse Pier, providing protection to the existing Grade II* listed harbour wall and to users of the harbour through reducing run up/overtopping. This would increase the level of protection for both the stevedores working on the quays and passengers boarding ferries on the Lighthouse Pier. The project failed to secure DfT funding in 2011 and consequently the proposed work has not been carried out to date.

This present study provides a review of previous proposals and examines the potential need and benefits in undertaking various improvement works.

2 CONDITION OF EXISTING STRUCTURES

2.1 Previous Harbour Inspections

Several investigations have been undertaken at Penzance as part of various development proposals.

In 2004 an inspection of Penzance Harbour was carried out by Hyder Consulting. The report reference number is DV01104/RT/52/01 and the core findings are summarised in the Stage 1 Report.

A further inspection was carried out by Paul Carpenter Associates in January 2010 but does not provide the same level of detail as Hyder Consultings 2004 report. Neither report indicates any significant scour or instability in terms of overturning. The principle concerns appear to be with respect to local settlement and cracking and the potential washout of material from the core.

With regards to the latter issue of washout, it is noted that some pressure grouting work was undertaken to the Lighthouse Pier, although it is understood that there was significant loss of grout through open joints. The 2010 inspection report makes the valid point that reducing the internal permeability of the structure may in fact set up increased pressure within the structure that could result in damage to the stone face.

A more detailed summary of the previous harbour inspections is included in Section 2 of the Stage 1 Report.

2.2 Summary of 2013 Inspection

The Stage 1 Report concludes that the overall condition of the South Pier is generally considered to be fair to good with very little by way of cracks and voids on the section between the Jubilee Pool and the initial section of rock armour. However, in locations exposed to greater wave action there are areas which require repointing. There are also two locations where masonry has been dislodged.

The Lighthouse Pier is also generally in fair to good condition with the exception of the defects described in the Stage 1 report. It appears that the seaward end has subsided and there are some areas of cracks and voids associated with this subsidence. The inspection identified that maintenance and repair work has been carried out on the Lighthouse Pier in the form of filling in cracks and the replacement of the corroded staples. The report highlights, however, the vulnerability of the masonry seaward face of the structure to any further movement and concludes that the masonry face may have become detached from the main body of the pier as this has rotated back.

In general, the Stage 1 condition assessment concludes that problems identified are a result of overall deterioration and age, coupled to evidence of voids. While clearly wave exposure is one of the key causes of deterioration, the issues relating to the condition of the Piers would not be resolved by increased protection. Increased protection following full maintenance and repair would potentially slow further deterioration.

3 INFLUENCE OF OVERTOPPING ON CURRENT HARBOUR OPERATIONS

3.1 Existing Situation

A site visit was carried out by representatives of Royal Haskoning DHV and Team Van Oord on Monday 14th of January 2013. During the site visit a visual inspection was carried out in order to determine the current general condition of the South Pier and the Lighthouse Pier and any degradation since the 2004 Hyder Consulting report.

During the inspection, a discussion was held with the Harbour Master and other harbour employees confirming the location of overtopping along the piers. Photographs also provided evidence with regards to the location and magnitude of overtopping along the harbour walls.

It was confirmed by the Harbour Master that significant overtopping occurs during normal / "frequent" storm conditions and this was considered in relation to wave direction and areas of damage observed during the inspection of the structure. For further information with regards to modes of overtopping, see Chapter 4 of this report.

3.2 Implications of Overtopping

Storm events that may cause overtopping impacting on the operation of the piers may be thought of as "frequent" storm events or "extreme" storm events. For example the Isles of Scilly Steamship Company requests permission from Penzance Harbour Master to temporarily move the Scillonian III's berthing location to the Albert Pier on average once per month during the sailing period between March to October, this is regarded as a "frequent" storm event. An example of "extreme" storm events are those that might happen on average once every few years to say once in 100 years.

When overtopping occurs at the landward end of South Pier there is a health and safety risk to drivers and pedestrians driving/walking along the public highway (refer Photo 3) and Quay. It is possible that overtopping at the landward end of South Pier could prevent access to the pier even with the options described in this report. This is not within the HRO area, but should be a focus for future work.

Whilst significant overtopping occurs at the Lighthouse Pier, it is unsafe for ships to berth in this location

3.3 Future Operations

Assuming that dredging is continued to enable vessels to berth, Penzance Harbour is likely to remain the mainland port for the link to the Isles of Scilly. At some point in the future the existing vessels currently operating between Penzance, Cornwall and St Mary's, Isles of Scilly will reach the end of their economic life and require a replacement. The future vessel specifications and proposed sailing times are unknown, however, improving the protection provided at the Lighthouse Pier would provide flexibility in terms of vessel type and sailing timetable.

3.4 Global Warming

Current allowances for sea level rise and increased storminess mean that the frequency of events that cause overtopping will increase in the future. Sea level is predicted to rise by up to 86mm between 2010 and 2030 based on UKCP09 high emissions scenario. This will increase the risk of overtopping in the long term.

4 OVERTOPPING

4.1 Overtopping Calculations

Wave overtopping is a recurring issue at Penzance Harbour. This was examined as part of the development of previous proposals for rock armour protection, considering the improvements that might be achieved for “extreme” storm events. The results of this study are summarised below. This has been re-examined as part of this study, looking also at more typical operational conditions.

Halcrow Group Ltd (2008) Calculations

Halcrow Group Ltd produced a technical note in 2008 (Reference: DCSCDD) which presents overtopping rates that have been calculated using Eurotop guidance, undertaken as part of the design of the improved harbour facilities. The report presents a maximum overtopping rate of 40.2l/s/m for a 1 in 10 year return period, with a rate of 89.6l/s/m calculated for a 1 in 200 year return period.

The report goes on to quantify the expected reduction in overtopping resulting from the construction of rock armour for the majority of the South Pier and the entirety of the Lighthouse Pier. For a 1 in 10 year return period, reductions in overtopping rates for the current layout of 40.2l/s/m to 4.6l/s/m with rock armour protection were determined. For a 1 in 200 year return period a predicted overtopping rate for the current layout of 89.6l/s/m would be reduced to 44.7l/m/s by rock armour protection. A more detailed summary is contained in Royal Haskoning DHV Technical Note /N0001/304293/Exet which is included as Appendix B.

Further Overtopping Analysis

As part of this present study, the potential overtopping under more typical operational conditions (“frequent” storm events) was also investigated and is also reported in full in Appendix B. Overtopping of the existing harbour wall during an operational wave condition was estimated as being 9 litres/sec/m. Furthermore, the wave run-up during operational conditions was calculated to exceed the crest level of the harbour wall by approximately 0.45m.

A calculation was also carried out to determine the effect that rock armour would have on overtopping at the harbour wall. It was confirmed that the construction of rock armour should reduce overtopping of the harbour wall to acceptable levels during typical operational conditions.

4.2 Locations at which Overtopping Occurs

The scope of this present report does not allow for detailed modelling of wave conditions and overtopping rates / volumes. However, it has been possible to draw upon previous studies and assess this information in the context of observations made and discussion held during the site visit. This has been supplemented by an internet search for photographs of overtopping of the two piers, as well as anecdotal evidence provided by the Harbour Master.

The dominant wave direction, as reported in the SMP, is from the south west. However, as reported by the Harbour Master, the most significant inshore wave direction causing overtopping is from the English Channel and the Bay of Biscay in the southeast. It should be noted that wave refraction within Mounts Bay has not been considered in this study. It is thought the refraction will cause waves to travel in a more westerly direction, which is consistent with the orientation of the beach in front at the landward end of South Pier. A typical angle of wave approach is shown on Figure 2 to assist in the subsequent discussion of overtopping.

In general it is understood that the worst overtopping is experienced in the three following locations:

1. At the rock armour in front of the South Pier (where the crest level is raised);
2. The corner between the South Pier and the Lighthouse Pier; and
3. At the end of the Lighthouse Pier.

These are highlighted in the discussion below along with an overview of how waves interact with the harbour wall along all sections.

Lighthouse Pier Seaward End

A number of factors lead to the end of the Lighthouse pier being one of the worst affected locations. The Pier itself is situated in deep water at the point most exposed to a southeast wave conditions. The pier also changes width in the vicinity of the lighthouse creating a V-shape at which wave energy can focus and leading to explosive overtopping. It is not considered likely that the overtopping and wave slam is directly responsible for the movement that has been observed in the end of the Pier. However, given the potential for separation between the seaward masonry face and the body of the pier behind, the end of the Pier is vulnerable to this high degree of wave overtopping. Wave overtopping at this location is illustrated in Photo 2.

Photo 2 – Wave Overtopping at the Lighthouse Pier
(Courtesy Dave Simpson, Cornwall Council)

Lighthouse Pier

The critical point for overtopping appears to be at the landward end of Lighthouse Pier, where it changes direction and turns in to the South Pier. Waves would typically run along the face of the Lighthouse Pier, concentrating into the corner. The present extent of rock armour along the toe may be a previous attempt to reduce scour caused by the oblique wave angle but does little to reduce overtopping.

Access to the Lighthouse Pier is restricted when overtopping of the pier is experienced (the Harbourmaster closes gates across the access to the piers).

The Seaward Section of the South Pier

The seaward section of the South Pier is in relatively deep water, however minimal overtopping has been reported. This is likely to be due to the fact that incident waves will tend to approach the wall quite normally. Wave run-up will tend to be quite uniform along the section of wall, without concentration of wave energy as that seen at the corner with the Lighthouse Pier.

Corner to the North of the Concrete Toe

Significant deterioration was observed to the north of the concrete toe in the 2013 inspection in the form of the missing concrete block. It is evident this section is subject to considerable wave action. However, minimal overtopping has been reported. It is considered that this is due to the incident wave arriving at an angle to the corner, with waves effectively being shed to either side and particularly down the towards the landward end of South Pier. The action could result in increased turbulence at the ends of the concrete toe.

Section between Concrete Toe and the Beach

Waves would typically be expected to run along the section of wall, potentially increasing as they run up the area of rock outcrop, but essentially being squeezed in to the corner of the wall as the wall curves around the back of the beach.

At the Rock Armour in front of the South Pier

The overtopping at the rock armour occurs where the crest level has been raised. This is seen as a result of waves running up the beach and being focused by the curve of the wall at the back of the beach. Wave overtopping at this location is illustrated in Photo 3.

It is understood that during storm conditions overtopping spills onto Battery Road behind the sea wall. During a storm in January 2010 the closure of a section of Battery Road was required. It is therefore considered that the existing protection at the sea wall is not sufficient in this location.

Photo 3 - Wave Overtopping at the Rock Armour in front of South Pier
(Courtesy Dave Simpson, Cornwall Council)

5 DEVELOPMENT OF OPTIONS

5.1 Description of Options

As set out in the previous section, during storm conditions the worst affected areas are at the landward end of South Pier, at the transition between the Lighthouse Pier and the South Pier, and at the seaward end of Lighthouse Pier. Three options aimed at addressing the issue of overtopping are set out within this section.

Local use of Rock Armour

The local use of rock armour would seek to address normal operational overtopping and would have a crest level approximately 2 metres lower than proposed for the full rock armour option. The local armour is focused on key areas of concern, to address locations where intense overtopping occurs and provide support for critical sections of the wall. It is proposed that rock armour would be strategically located in the following locations which are also illustrated in Figure 3:

- The head of the Lighthouse Pier;
- The transition between the Lighthouse Pier and the South Pier;
- The corner just north of the concrete toe; and
- An extension to the existing rock armour located at the toe of the raised crest section to provide a local bastion at the landward end of South Pier (not within the footprint of the current HRO).

The use of local rock armour is lower cost than a full rock revetment. Furthermore, this option maintains access to much of the wall allowing a progressive programme of improvements and repairs. Structural support will be provided critically to the end of the Lighthouse Pier, reducing wave impact loadings at this key location. The issue of overtopping will be addressed at the critical locations for some operational conditions ("frequent" storm events).

The local use of rock armour does not provide a comprehensive solution to the issue of overtopping over the whole length of the structure, particularly during "extreme" storm conditions. Access to the harbour wall would be limited once construction is complete. It will therefore be necessary to ensure that investigations and repairs are undertaken in advance. This option could affect any future proposals to extend Lighthouse Pier. As with the full rock revetment there will be an impact on the visual appearance of the structure.

The design of the local rock armour is at present based on a scaled down adaptation of the rock armour set out in the Halcrow Group Ltd 2009 report (section included in Appendix B). The height of the of the rock armour would typically be 1m above mean high water spring, a height of approximately 6.5m CD, (Compared to the crest height of the full rock revetment which was designed to a level of 8.3m CD (Halcrow 2009)). As with the Halcrow Group Ltd design, the gradient of the rock armour will be approximately 1 in 2.25. A typical cross section and an indicative plan view are illustrated in Figure 3.

The final shape and position of these structures would need to be considered in further detail to optimise the reduction in overtopping and structural performance if this option were

taken forward (however the volume of rock per metre run would be less than for the full rock armour option).

Full Rock Armour

A continuous rock revetment over the full length of Lighthouse Pier and the seaward section of South Pier (refer Appendix C for works extent) was set out within Halcrow Group Ltd's Appraisal of Alternatives at Penzance Harbour Report (Halcrow 2009). This report appraised three options and all included full rock armour for the entire seaward face of the Lighthouse pier as well as part of the South Pier.

In terms of construction on the seaward face there were two variations. Option A proposed a rock armour to be constructed in conjunction with an area of reclamation between the Jubilee Pool and the South Pier. Options B & C did not include an area of reclamation but did recognise the potential need for additional rock armour to improve the protection of the wall in that area (not consented in the HRO 2009).

The benefit of the continuous rock revetment was to increase the structural stability to the whole structure but primarily to reduce overtopping to a level acceptable for the redevelopment of the harbour. There would be a reduction in overtopping to acceptable levels along the whole structure. However, it was recognised that this was a partial solution and there would still be occasions where the Lighthouse Pier berth would still be unusable.

If the continuous rock revetment option were to be implemented a programme of maintenance to the piers across the affected sections would have to be carried out prior to construction (The programme of works has Listed Buildings Consent, including a schedule of repair works).

The design of the rock armour would be in line with that set out in the 2009 Halcrow Group Ltd report. A plan view and cross section of this option are included in Appendix C.

Offshore Rock Breakwaters

Although a more expensive option, an offshore breakwater could also be an effective method of reducing wave impact loadings and overtopping at the harbour wall. It is also the only option which offers the benefit of retaining access to the harbour wall for maintenance and repair work. Depending on the option selected there may be additional wider benefits such as flood and coastal defence, additional berthing areas or contributing to wider regeneration plans.

Two previous proposals for an offshore breakwater have been set out by the Penzance Harbour Users Association (PHUA). The more extensive of the two proposals comprised a large area of reclaimed land in the north of the harbour, to be used for substantial development and also included a breakwater and a marina. A second option isolates the breakwater element of the original proposal as an interim protective breakwater. The previous proposal options are illustrated in Figure 4.

Having reviewed the proposals it is considered that the previous breakwaters may still not have addressed the issue of overtopping at the landward end of the South Pier as this remains significantly exposed to the predominant storm wave climate.

Outline or detailed design of an offshore breakwater was not included within the remit of this report. However, it is considered that an offshore breakwater would have to originate offshore of the Jubilee Pool and extend approximately 400m in an easterly direction to dissipate waves from the southwest/southeast. This option is also illustrated in Figure 4. The design of any breakwater option would have to take account of its proximity and visual impact on the setting of the Listed Jubilee Pool, war memorial and the piers and the impact on views from the seafront.

Typical water depth contour for construction would be around 3.5m below CD, with the structure typically having a crest height around 1.5m to 2m above MHWS to provide suitable wave protection at Lighthouse and South Pier and a crest width of 5m. The crest height of this breakwater would not be suitable to offer safe vessel berthing immediately behind (it is assumed that this was a feature of the PHUA proposal).

While the construction of a breakwater extending from the western side of the harbour would provide protection along the whole length of the South and Lighthouse Pier (length and position to be confirmed by modelling) it would not provide additional structural support to the end of the Lighthouse Pier. The position of such a breakwater would need to be considered in relation to navigation other possible development within the area of the harbour.

5.2 Summary of Options

Table 1 provides a comparative / qualitative assessment of each of the options in terms of the residual risk of overtopping and the future operational flexibility.

Table 1 - Summary Table of Options

Scenario	Overtopping Risk	Future Operational Flexibility
Do nothing	High	Low
Localised Rock Armour	Medium	Low / Medium
Full Rock Armour	Low	Medium
Offshore Breakwater	Low	Medium / High

6 COST ANALYSIS

6.1 Overview

This chapter summarises the costs associated with the three construction options described above. The costs are outline estimates for comparative purposes and a more detailed costing exercise would be required following outline design, should an option be selected (with the exception of Full Rock Armour where design and consenting is significantly progressed and Cornwall Council have obtained advice from a marine contractor). Table 2 provides a summary of the costs.

Table 2 - Summary Table of Costs

Scenario	Capital Cost
Do nothing	N/A
Localised Rock Armour	£1.5-2.5m
Full Rock Armour	£6m
Offshore Breakwater	£15-25m
PHUA Detached Breakwater (ex. Birse 2010)	£45m

Full Rock Armour

The full rock armour option would be constructed as set out in the Halcrow Group Ltd 2009 report, a plan and cross section of the design is included in Appendix C. This assumes protection along the whole length of the two Piers (as far as the current HRO permits). Cornwall Council have prepared a cost estimate for these works with advice / input from a marine contractor, the current estimated cost of this option is in the order of £6m.

Local Rock Armour

The design of the local rock armour is illustrated in plan and typical cross sectional in Figure 3. The costing of the local rock armour has been based on equivalent rates used for the full revetment above but with reduced quantities of rock. With a contingency to reflect the uncertainty of the works (further modelling and investigation would be required to optimise the design) the overall cost estimate for the works would be in the order of £1.5m - £2.5m.

Offshore Breakwater

The cost of the offshore breakwater option has been estimated based on a basic rock structure 11m high with a crest width of 5m, extending some 400m. It is considered that a structure of this size could provide comprehensive protection to the Lighthouse Pier and the South Pier. Works to support the seaward end of Lighthouse Pier would also need to be undertaken (as discussed in Section 5.1).

The length and geometry of the structure would be developed during outline and detailed design. In considering an offshore breakwater, significant care would need to be taken in ensuring that if a more localised approach were adopted, wave redirecting would not become an issue. There is a risk that a smaller breakwater may cause localised wave focusing that could exacerbate the problem of overtopping.

The estimated cost of the structure would be between £15m - £25m. As indicated by the range of costs, there are significant further uncertainties with this option, including the need for a more detailed assessment of wave climate and a full ground investigation. There would be significant costs (included above) and implications on programme related to environmental assessment and consenting requirements, as this option does not fall within the current HRO.

The cost of an offshore breakwater is obviously significant, to put the figures in context, the costs for a number of recent projects are listed in Table 3. This table illustrates the high costs (and variability) associated with constructing marine structures.

A new breakwater is also proposed at Cowes (also included in Table 3 below) it should be noted that this breakwater is proposed to be constructed in shallower water depths than Penzance, with a smaller tidal range and less wave exposure.

Table 3 - Summary Table of Costs

Borth Coastal Defences, 2011
Project Cost £12m 70,000m^3 rock 2 offshore breakwaters 4 rock groynes Shingle nourishment
Weymouth & Portland Sailing Academy 2008
Project cost £7m 200m long breakwater, 4000m^3 revetment 45,000m^3 reclamation Also slipways & ramps
Portland Marina, 2007
Project Cost £27m 860m long breakwater 160,000m^3 Also slipways, boat hoists and marina
(Proposed) Cowes Breakwater
Project Cost £6.5m 350m long breakwater

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

In general it is understood that the worst areas of overtopping are experienced at the landward end of South Pier (where the crest level is raised), at the interface between the South Pier and the Lighthouse Pier and at the Lighthouse Pier head. Even under “frequent” storm conditions an unacceptable amount of sea water overtops the harbour wall. On more “extreme” conditions more general overtopping occurs over the whole length of the structure.

It is possible that overtopping at the landward end of South Pier could prevent access to the pier even with the options described in this report. This is not within the current HRO area, but should be a focus for future work.

The study has considered potential management approaches in dealing with the above issues. It concludes that while rock armour to the full length of the piers would reduce the risk of overtopping significantly, there is not in general a need for such a structure to provide support to the integrity of the Piers. This option would provide future operational flexibility in terms of berthing against Lighthouse Pier.

As an alternative approach, the study has considered use of local rock bastions to address the more operational issues of overtopping under “frequent” storm conditions, while also in the case of the end of the Lighthouse Pier, providing increased stability to the Pier Head. This approach presents cost savings but has limited future flexibility in terms of berthing against Lighthouse Pier.

The third option considers the potential construction of a major breakwater structure seaward of the existing Piers. It is concluded that while this would reduce overtopping, reduce wave heights in the harbour and maintain access to the seaward face, the cost would be high and there would be not substantial improvement to the stability or condition of the Piers. This option would provide the highest degree of future flexibility in terms of berthing against Lighthouse Pier as it provides the greatest reduction in overtopping.

7.2 Recommendations

This report has assessed three options aimed at reducing the level of overtopping at Penzance Harbour. The preferred option will be a balance between cost, acceptable overtopping risk and future operational flexibility. This report should be used as the basis for further discussion in determining the most effective course of action.

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FIGURES

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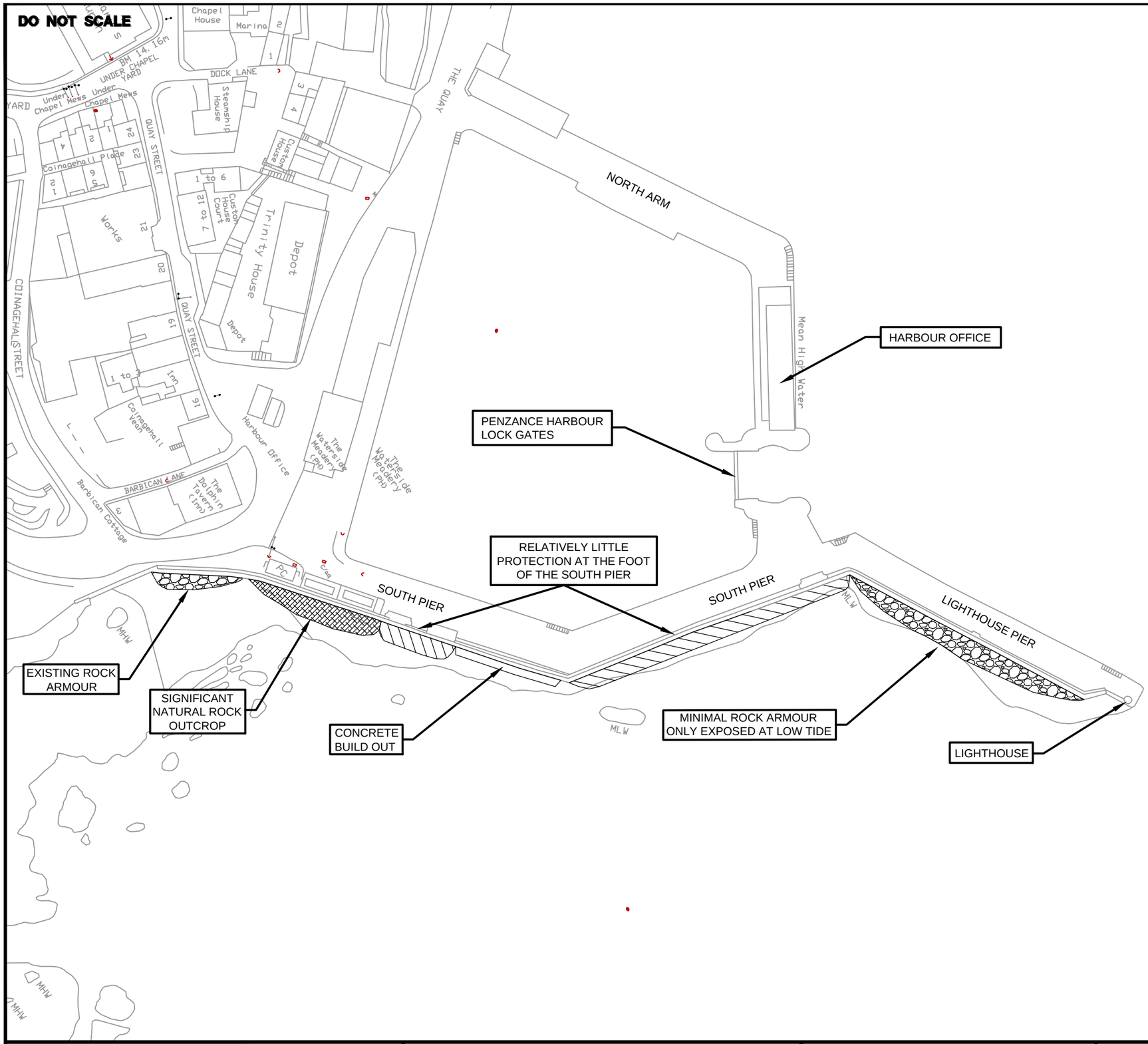

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3. ALL MATERIALS AND WORKMANSHIP WILL BE AS DEFINED IN THE SPECIFICATION UNLESS NOTED OTHERWISE.
4.

TITLE
Site Location Plan & Harbour Features

PROJECT
Penzance Harbour Inspection and Proposed Works

Royal HaskoningDHV
Enhancing Society Together
Stratus House, Emperor Way
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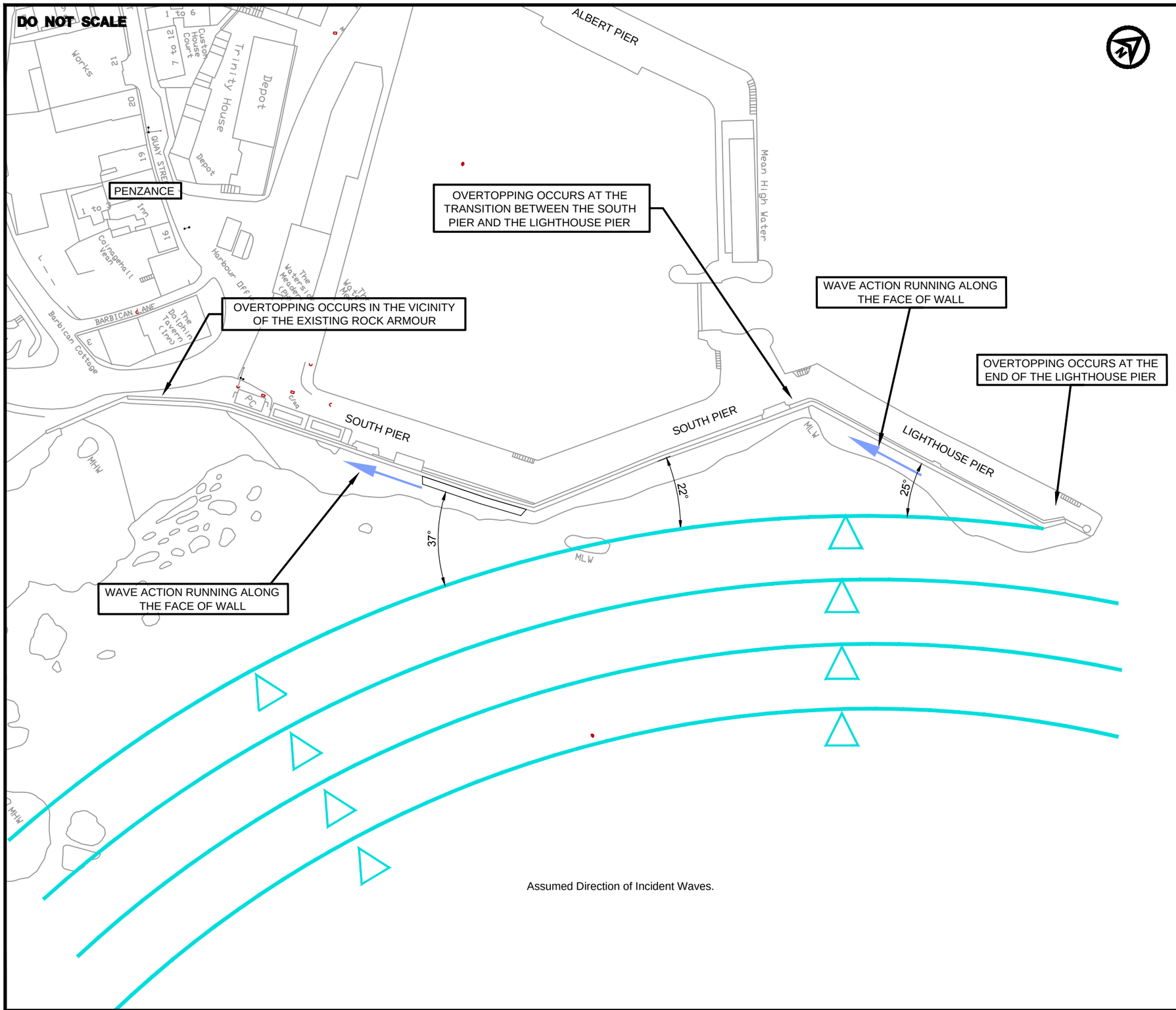

Assumed Direction of Incident Waves.

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4.

TITLE
Plan Illustrating Wave Direction and Areas of Overtopping

PROJECT
Penzance Harbour Inspection and Proposed Works

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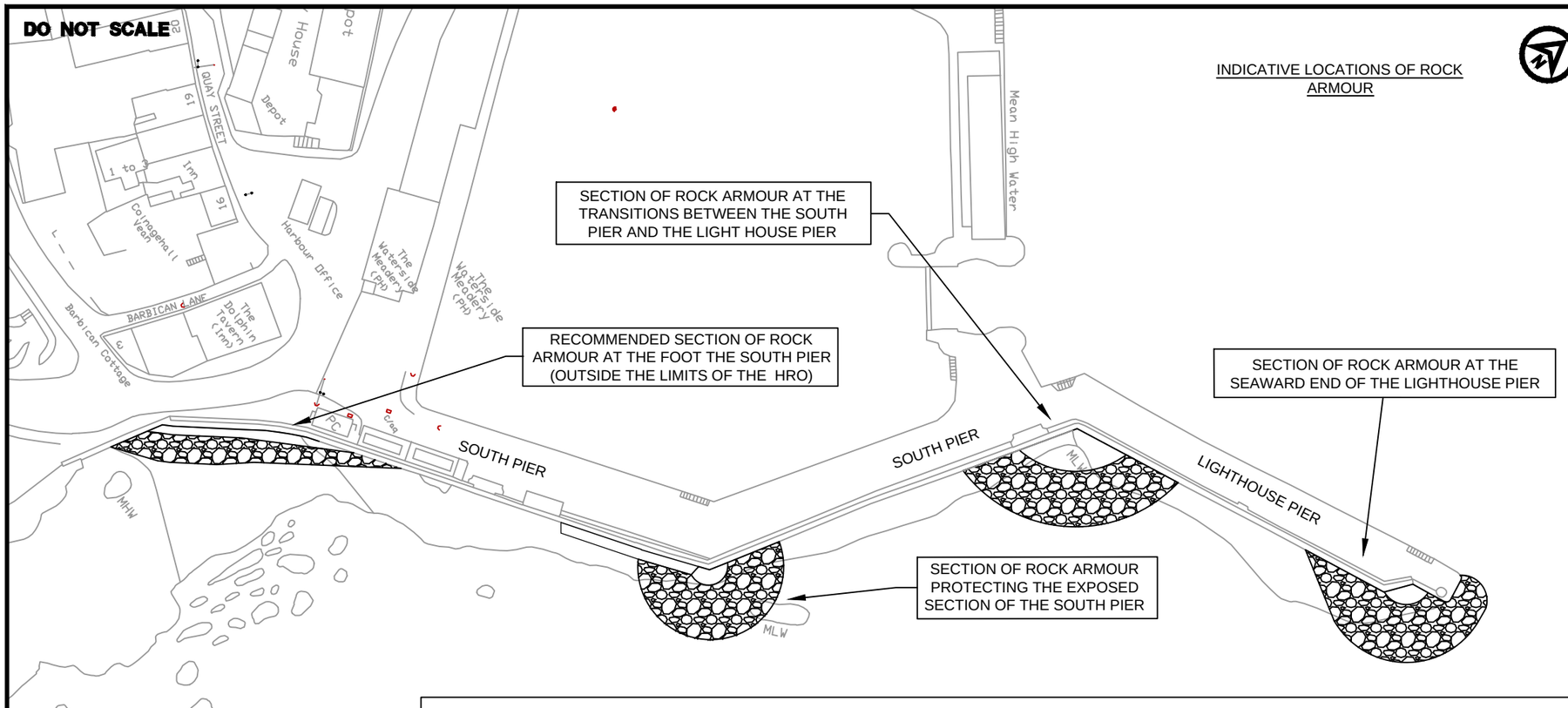

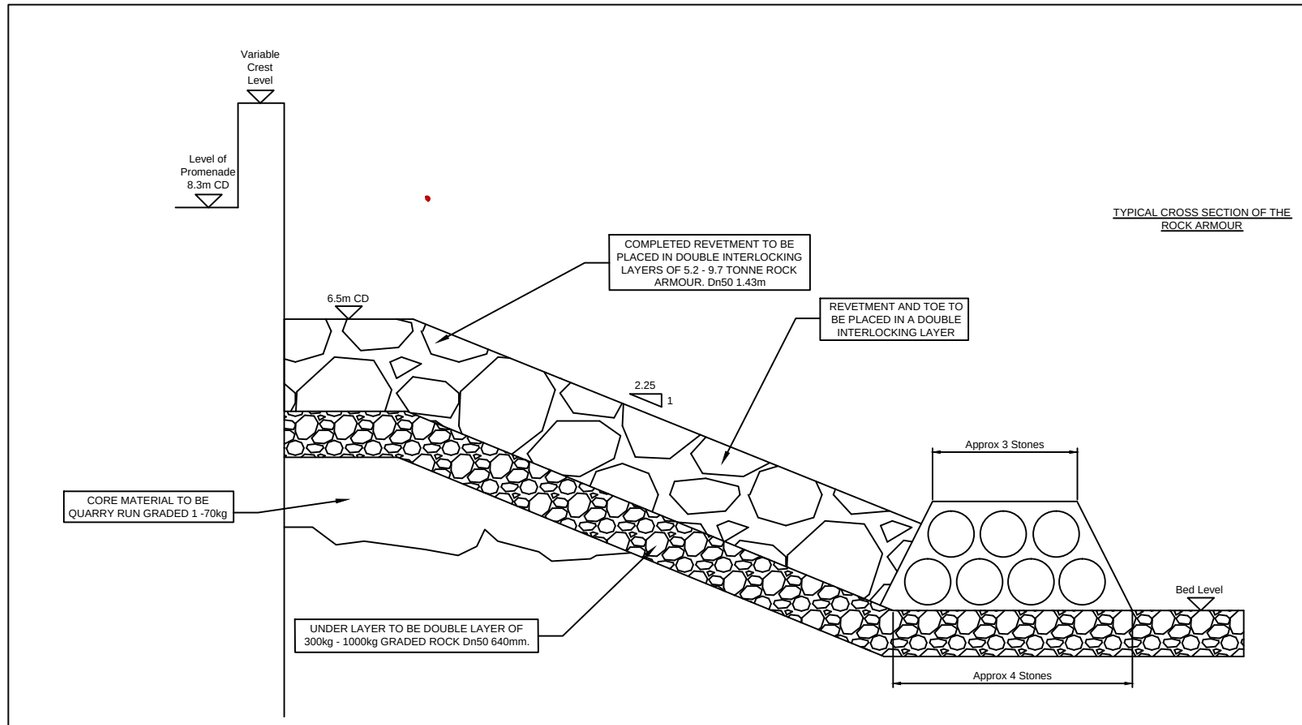

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TITLE: Proposed Locations of Rock Armour	PROJECT: Penzance Harbour Inspection and Proposed Remedial Works	Royal HaskoningDHV Enhancing Society Together	Stratus House, Emperor Way, Exeter, EX1 3QS Tel +44 (0)1392 447999 Email info.exeter@rhdhv.com Website www.royalhaskoning.com

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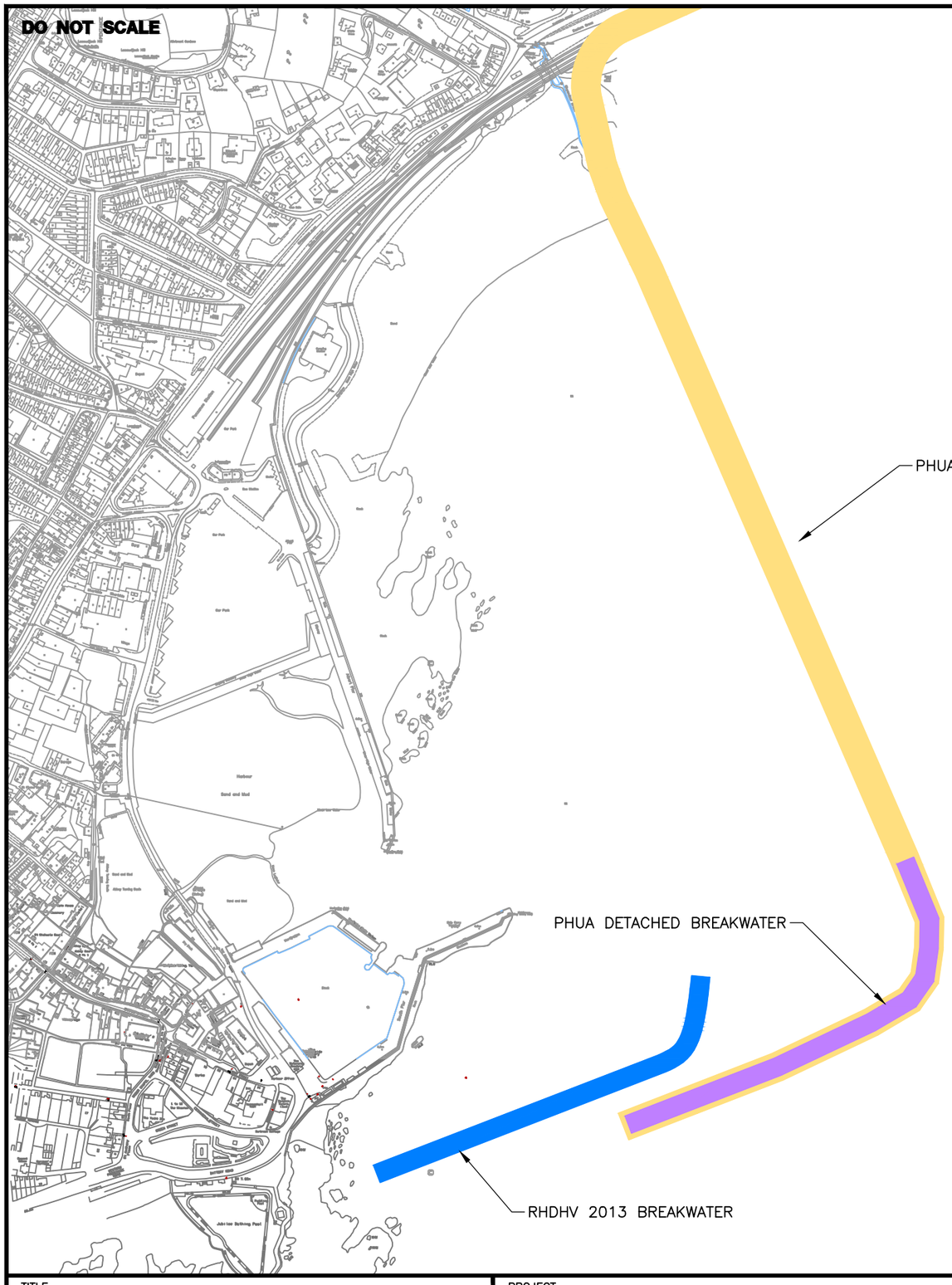

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TITLE
OFFSHORE BREAKWATER PROPOSALS

PROJECT
PENZANCE HARBOUR INSPECTION AND PROPOSED WORKS

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APPENDIX A

Correspondence between Norman Baker and James Currie
Dated 26th November 2012

Department for Transport

From the Parliamentary
Under Secretary of State
Norman Baker MP

Great Minster House
33 Horseferry Road
London SW1P 4DR

Tel: 020 7944 2566
Fax: 020 7944 4309
E-Mail: norman.baker@dft.gsi.gov.uk

Web site: www.dft.gov.uk

Our Ref: MC/59266
Your Ref: JC/BB

Councillor James Currie
Leader of the Council
Cornwall Council
County Hall
Truro
Cornwall
TR1 3AY

26 November 2012

Dear Councillor Currie

Thank you for your letter of 2 November about St Mary's and Penzance Harbour Proposals.

I an very pleased that Cornwall Council is prepared to take the lead in developing and, if approved, delivering the scheme to improve St Mary's and Penzance Harbours, building on the work already done by the Council of the Isles of Scilly and Penzance Town Council.

Clearly there are elements of the Town Council's preferred scheme that are undeliverable within the timescale for EU Convergence Funding. However, as I made clear, in my letter to them of 28 September, I am keen that the elements of the project that can be delivered are now progressed with urgency.

I would therefore welcome a business case from you that comprises the proposed works at St Mary's, along with dredging and rock armour at Penzance. I am aware that the latter element – rock armour – is controversial locally and therefore I would like to see the costs and benefits of that element separately identified in the business case. I will then be able to take an appropriate judgement about the case for its inclusion in full possession of all the relevant evidence. I have also asked the Town Council for their views.

I am also content to consider any modest and deliverable improvements to Penzance Harbour within the business case, provided there is a strong case for doing so and their inclusion does not slow down the overall timetable.

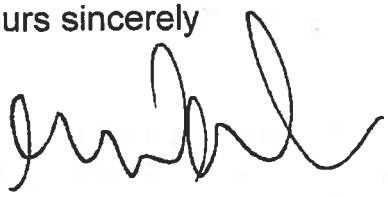
I am pleased to say that I have approved funding for the further development of this scheme and I therefore look forward to receiving your business case by the end of December if possible. We will aim to make a decision by the end of March, as your letter suggests.

You also asked about future projects at Penzance. The funding that I have set aside is specifically for a scheme that can be delivered quickly and subject to additional funding contributions being sought from the current round of the EU Convergence programme. Beyond that, the Department's budget for local transport major schemes is fully committed to 2015 and will be devolved for future spending review periods. Therefore funding for any future Penzance scheme, or indeed any other local major transport scheme, will need to be sought from the devolved major schemes budget or other funding streams such as the Growing Places Fund.

I am copying this letter to Andrew George MP.

I hope this is helpful.

Yours sincerely



NORMAN BAKER

APPENDIX B

Royal HaskoningDHV Technical Note, December 2012

Note

HASKONING UK LTD.
WATER TECHNOLOGY

To	:	Greg Guthrie
From	:	Eddie Crews
Date	:	21 December 2012
Copy	:	
Our reference	:	/N0001/304293/Exet

Subject **:** Penzance Harbour Proposal Advice

---

1. INTRODUCTION

Scope

This technical note has been prepared by Royal Haskoning on behalf of Cornwall County Council considering the condition and structural stability of elements of Penzance Harbour. In particular the study reviews the need and justification for rock armour along the South Pier and the Lighthouse Pier in terms of improving the long-term structural integrity of the piers and reducing the volume of overtopping.

The study focuses on the South Pier and the adjoining Lighthouse Pier. Information has been obtained from various sources including inspections that have been carried out over the last decade as well as preliminary work that was undertaken by Hyder and Halcrow as part of development proposals.

This report provides a preliminary desk based assessment and will be followed up by an inspection of the two Piers to further develop the assessment.

Background

Both the South Pier and the Lighthouse Pier are constructed of an inner core with an outer facing of granite blocks (*PDC 2004*). An inspection of the inner core has not been undertaken, however, it is thought it consists of a variety of stone of varying sizes together with a range of other fill materials. The South Pier is a Grade II listed structure (upgraded in 2011) and large parts of the rest of the harbour area and surrounding buildings are also listed.

Penzance Harbour is recognised in the Cornwall and the Isle of Scilly Shoreline Management Plan (SMP) and is situated within Policy Unit 21.1. The SMP outlines that a hold the line policy is to be adopted in and around Penzance Harbour. The key features of Penzance Harbour are illustrated in Appendix A (taken from PDC 2004).

Over the last decade the harbour has been the subject to several proposals for development, including 200m of rock armour for the extent of the Lighthouse Pier and approximately half of the South Pier (the other half being protected by an adjoining land reclamation scheme.) An extension to the Lighthouse Pier, also to be protected by rock armour was proposed. The rock armour along the two existing Piers was intended to

improve the structural integrity of the South Pier and Lighthouse Pier, providing protection to the existing harbour wall as well as reducing run up/overtopping. To date, none of the aforementioned proposals have been carried out.

2. BASELINE DATA

Tidal Ranges

At mean high water spring the majority of the harbour wall is submerged, whereas during mean low water spring the outcrop of hard igneous rock on which the harbour is founded, is exposed. Table 1 provides tide levels at Penzance, sourced from the Admiralty Tide Tables (2013).

Tide	Water Level Relative to mODN
HAT (Highest Astronomical Tide)	2.85
MHWS (Mean High Water Spring)	2.45
MHWN (Mean High Water Neap)	1.25
MLWN (Mean Low Water Neap)	-1.05
MLWS (Mean Low Water Spring)	-2.25
LAT (Lowest Astronomical Tide)	-3.05

Table 1 – Extreme Tidal Ranges

Extreme tide levels for Penzance are reproduced from *Coastal Flood Boundary Conditions for UK Mainland and Islands report,* SC060064/TR2: Design Levels, February 2011, published by the Environment Agency. The Extreme tide levels are contained in Table 2 below:

Return Period	Water Level Relative to mODN
1:1	3.08
1:5	3.23
1:10	3.29
1:25	3.37
1:50	3.43
1:100	3.48
1:200	3.53
1:500	3.60
1:1000	3.65

Table 2 - Extreme Tidal Ranges

Wave Climate

The coast of Cornwall experiences one of the highest energy wave climates in the UK, due to its Extreme Westerly mainland and its predominantly south-west, west and north-westerly facing shorelines. Despite the dominant westerly wave direction, there is a significant south-east and south component to the wave climate on the south coast of Cornwall. Large wind waves can be generated by strong east and south-east winds blowing over the English Channel.

The annual 10% exceedance significant wave height for the south coast west of Lizard Point is 2.0m – 2.5m. Lizard Point is approximately 30km southeast of Penzance Harbour is a location is more exposed to Atlantic swell. A significant wave height of 2.0m-2.5m is therefore considered to be a worst case scenario.

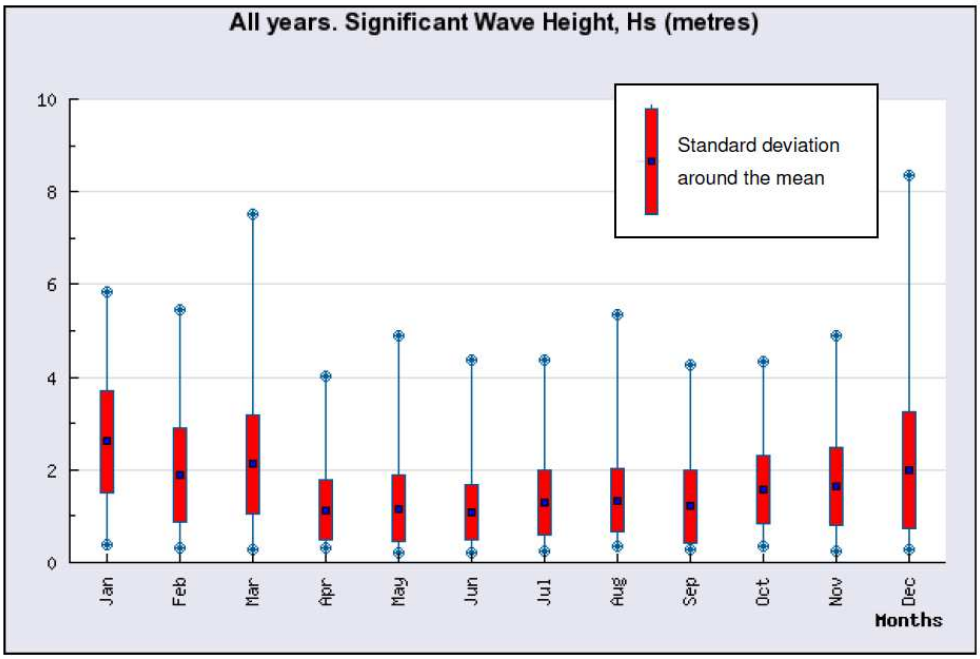


Figure 2 – Significant wave heights Recorded at Penzance 2007 – 2009 Source: South West Coastal Monitoring Programme

Figure 2 displays the wave climate recorded for the Penzance area, during the period 2007 to 2009, by the waverider buoy deployed by the South West Coastal Monitoring Programme. Although this is a relatively 'young' time series, the seasonal trends, particularly relating to the late winter months are already clear (SMP 2009).

Although Figure 2 provides an indication of the shore wave climate, it is recognised that the harbour is in a more sheltered location. The Mounts Bay Pilot Study (2012) suggests the height of typical storm waves against the harbour to be in the order of 2.21m.

At Penzance the waves are relatively narrowly banded and approach from between 150 and 180 degrees (from south-southeast). Here the largest waves are greater than 5.75 metres and can have periods of longer than 17 seconds.

3. CONDITION OF THE STRUCTURE

An inspection of the Penzance Harbour was carried out by Hyder Consulting in July 2004 and the significant finding are summarised in this section.

South Pier

With regards to the South Pier, the 2004 inspection report states:

"The overall condition of the seaward face of the wall is good with some areas of open joints where mortar has been lost, and some voids in behind open joints, with depths from less than 200mm to more than 2700mm."

The Lighthouse Pier

With regards to the Light house Pier, the 2004 inspection report states that:

"The overall condition of the seaward face of the wall is good, with some areas of open joints where mortar has been lost and some voids behind joints, with depths from less than 200mm to more than 2000mm, From Ch236 to 270m the rock armour to the toe of the wall has been reinforced with rough in-situ mass concrete."

The report goes on to say:

"On the inside Face, the overall condition is poorer, with a large number of open joints, probably due to constant abrasion from vessels moored against the wall."

Although the report identifies many local areas where mortar is missing, it is only in quite specific areas where there is seen to be deeper voids running into the structure. There are two areas on the South Pier around chainage 100m and chainage 130m, either side of the concrete blockwork toe where there appears to have been significant loss of mortar and potential movement of stonework. There is a further section between chainage 180m and 200m where there are signs of movement and cracking to the structure.

On the Lighthouse Pier, although there is reported to have been some general settlement, much of the defects appear to be quite local in nature.

Further Information and Benefits of Rock Armour

A further inspection was carried out by Paul Carpenter Associates in January 2010 but does not provide the same level of detail as the 2004 report. In February 2010 a Schedule of Conservation repairs was submitted by Jonathan Rhind Architects. It is not known whether the works contained in the Schedule of Conservation have been carried out and a harbour inspection by Royal Haskoning DHV is planned for January to confirm.

Neither of the reports indicates any significant scour or instability in terms of overturning. The principle concerns appear to be with respect to local settlement and cracking and the potential washout of material from the core.

With regards to the latter issue of washout, it is noted that some pressure grouting work was undertaken to the lighthouse Pier, although it is understood that there was significant loss of grout trough open joints. The 2010 inspection report makes the valid point that increasing the internal impermeability of the structure may in fact set up increased pressure within the structure that could result in damage to the stone face.

The main benefit of rock armour would typically arise from a reduction of scour to a structure and in providing stability form overturning failure. Neither of these failure mechanisms seem to apply to the structures at Penzance. Rock armour can also reduce the instantaneous pressure loading to the face of the structure under wave action. Since the design philosophy proposed by the 2010 report is to maintain the overall permeability of the front face, this is seen as being less of an issue. Indeed, rock armour, in dampening initial wave loading may establish a different loading pattern which could result in exposing different weaknesses within the structure.

It is not, therefore, considered that the structural integrity of the harbour wall will be significantly improved by the construction of rock armour.

4. OVERTOPPING AND RUN-UP

Halcrow have produced technical notes in both 2008 and 2010 which present the results of overtopping calculations which were undertaken as part of the design of the improved harbour facilities. Overtopping calculations were carried out at the sections illustrated below in Figure 3.

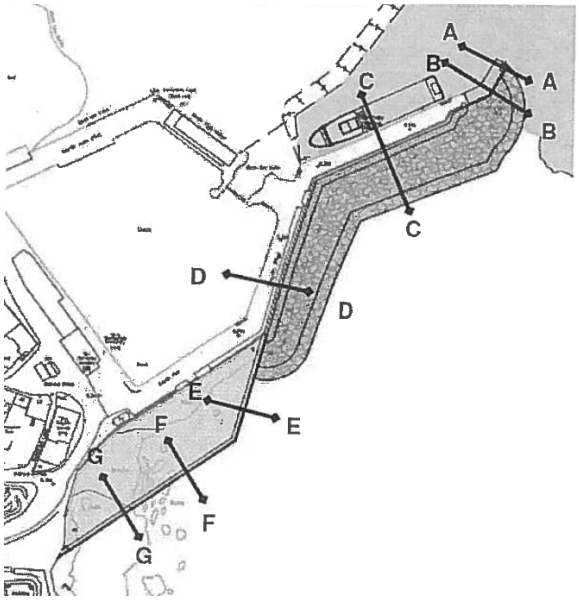


Figure 3 – Location of Overtopping Calculations (Source: Davidson 2008)

The 2008 note sets out overtopping rates that have been calculated using Eurotop guidance and the results are included below in Table 3.

Cross Section	Existing Crest (mCD)	Current (Yr0 Overtopping Rate (l/s/m)		
		1 in 10	1 in 50	1 in 200
A	-			
B	-			
C	10.3	40.2	33.3	87.4
D	10.5	2.9	4.9	89.6
E	10.65	4.4	5.2	7.8
F	13.1	1.0	1.5	2.1

Table 3 – Current Rates of Overtopping at the Existing Structure

Table 3 contains the rates of overtopping that would be expected based on crest levels proposed in the improvements. When comparing the overtopping rates at the existing and proposed structure there is a clear reduction. However, comparisons can only be drawn from sections C-F as Sections A and B are situated on the proposed extension.

Cross Section	Proposed Crest (mCD)	Yr0 Overtopping Rate (l/s/m)			Yr50 Overtopping Rate (l/s/m)		
		1 in 10	1 in 50	1 in 200	1 in 10	1 in 50	1 in 200
A	10.5	13.7	13.5	80.1	15.1	56.0	76.8
B	10.5	4.6	15.1	44.7	7.8	21.9	47.4
C	10.5	4.6	15.1	44.7	7.8	21.9	47.4
D	10.5	1.8	6.8	23.1	3.2	10.2	24.5
E	15.0	0.3	0.6	1.1	0.4	0.6	1.1
F	15.0	0.5	0.8	1.3	0.6	0.9	1.4

Table 3 - Overtopping Results based on Revised Crest Levels

Following the overtopping predictions, the 2008 technical note outlines the limits for overtopping for pedestrians. Recommendations for improvement work are then outlined as part of the conclusions. The new levels of overtopping is describe as being acceptable at the quay extension, inner harbour and the passenger terminal and the harbour wall is described as providing adequate protection within the berthing area and the reclamation/waiting area.

It should be noted that Royal Haskoning's remit only extent to appraise the construction of a rock armour defence (Sections A-D). Built in isolation, the rock armour does not provide a solution for overtopping in the whole harbour. It is clear from Table 2 that considerable overtopping is occurring at sections E and F and this will also have to be addressed if the south pier/lighthouse pier is to remain operational during storm conditions.

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Overtopping Existing (Operational Wave Conditions)

The work undertaken previously considers more extreme overtopping conditions. In part as a review of this information, but also to look at the more operational conditions, this study has undertaken a brief indicative overtopping/wave run-up calculation for existing and with rock scenarios.

Equations have been taken from Wave Overtopping at vertical and Steep Seawalls (Allsop *et al.* 2005). For simple vertical breakwaters in deeper water, Fanco et al. developed the following single empirical formula which is valid for $0.03 < R_c/H_s < 3.2$.

$$Q_n = 0.2exp\left(-\frac{4.3}{\gamma_s}\frac{R_c}{H_s}\right)$$

Where:

Q_n	Dimensionless Discharge		
R_c	Crest freeboard of structure, relative to still water level (m)	-	3.97m
H_S	Significant Wave Height	-	2.21m
γ_s	Seaward face geometry reduction factors	-	1

Based on the equation above the dimensionless discharge for the Penzance harbour wall is 8.87×10^{-5}. The mean overtopping discharge can be obtained by resolved using the following equation.

$$Q_n = \frac{q}{\sqrt{gH_s^3}}$$

Where:

g	Acceleration due to gravity	-	$9.81 m^2/sec$
q	Mean overtopping discharge per metre structure width		
	= 9.31×10^{-3} $m^3/sec/m$		

9.31×10^{-3} $m^3/sec/m$ is considerably lower than the overtopping rates calculated by Halcrow. This is expected, as conditions used in the Halcrow calculation are thought to represent a more extreme case, whereas a significant wave height of 2.21m reflects a more operational wave condition.

Typically, run up elevation on a vertical wall being impacted by a wave is around two times the significant wave height. With a freeboard of 3.97m and an expected run up elevation of around 4.42m (2 x 2.21m), the level of run up will typically exceed the crest level by around 0.45m. This seems reasonable given the low overtopping rate of 9.31×10^{-3} $m^3/sec/m$ calculated above.

Run-Up Calculation (operational)

A calculation has been carried out to look into the run-up that is likely to occur after the construction of the rock armour is complete. The Coastal Engineering Manual (CEM 2002) has been used as guidance for the following calculations. The parameters have been taken from the Cornwall Coastal Flood Risk Modelling: Mounts Bay Pilot Study (July 2012).

α	Slope Angle (of the Rock Armour)	-	23.96°
H_o	Offshore Wave Height	-	6.52m
T	Wave Period	-	9.25 seconds
L_o	Offshore Wave Length	-	133.6m

$$L_O = \frac{gT^2}{2\pi}$$

S_o	Deep Water Wave Steepness	-	0.0488

$$S_o = \frac{H_o}{L_o}$$

ξ	-	Iribarren Number	-	2.01

$$\xi_{op} = \frac{\tan\alpha}{\sqrt{S_{op}}}$$

An Iribarren Number of 2.01 defines the wave as a plunging breaker. Due to the steepness of the rock armour, this would appear to be reasonable. The Iribarren number is considered when calculating $R_{d2\%}$ (run up level which is exceeded by 2% of waves).

$$\frac{R_{d2\%}}{H_s} = 0.33\xi_{op} \text{ When } \quad 0 < \xi_{op} \leq 4$$

Based on a significant wave height of 2m, $R_{d2\%}$ has been calculated as 1.47m. Table VI-5-3 in the CEM provides a surface roughness reduction factor Y_R. The guidance states that for a slope surface comprised of 2 or more layers of rock, the reduction factor is 0.5 – 0.55 which reduces the run up to 0.81m (as a worst case scenario).

A design water level of +6.53m CD (based on a 1 in 200 year return period) and a wave return crest level of +10.5m CD have been used. Based on the above calculation, the maximum wave run up at this section will be +7.34m CD which in theory will not overtop.

It is therefore concluded that, the construction of a rock armour would minimise overtopping at the harbour.

5. PRELIMINARY CONCLUSIONS

The initial conclusions of this report, based on a review of existing information, are as follows:

1. Previous inspection reports identify that is only local structural damage to both the South Pier and the Light House Piers. An inspection is due to be carried out by Royal Haskoning DHV in January which will confirm the key areas in which repairs are required.

2. The construction of rock armour is unlikely to directly improve the structural integrity of the harbour walls.

3. Both the preliminary calculations carried out by Halcrow and the calculations contained within this technical report show that there would be a significant reduction in overtopping. (It should be noted that a reduction in the overtopping is likely to preserve the piers against damage caused by overtopping.)

4. It is recognised that the orientation of the pier varies. The way in which waves approach the structure in different storm events will also vary. This will be examined in the site inspection in January.

5. It is possible that strategic placement of rock amour at critical location could reduce the amount of overtopping.

6. REFERENCES

Reference

PDC 2004 – Penwith Distric Council 2004, Penzance/Newlyn/Penlee Technical Investigation, Report on Condition Survey of Penzance Harbour, July 2004, Report No:DV01104/RT/52/01

Halcrow, Davidson 2008 – Halcrow, Adam Davison (September 2008), Isles of Scilly Link Harbour Work, Penzance Overtopping, Preliminary Results, Ref: DCSCDD

SMP 2009 – Ridgewell, J & Walkden, M (May 2009) Royal Haskoning, Cornwall and Isle of Scilly SMP2, Review of Coastal Processes and Geomorphology, Cornwall Council for CISCAG (Cornwall and Isle of Scilly Coastal Advisory Group), Draft Report

CEM 2002 – US Army Corps of Engineers (April 2002) - Coastal Engineering Manual

W.Allsop Bsc, MICE Ceng, T Bruce Msc, J. Pearson BEng, PhD and P.Besley BSc, PhD - Wave overtopping at vertical and steep seawalls, Maritime Engineering 158, September 2005 Issue MA3 Pages 103 -114.

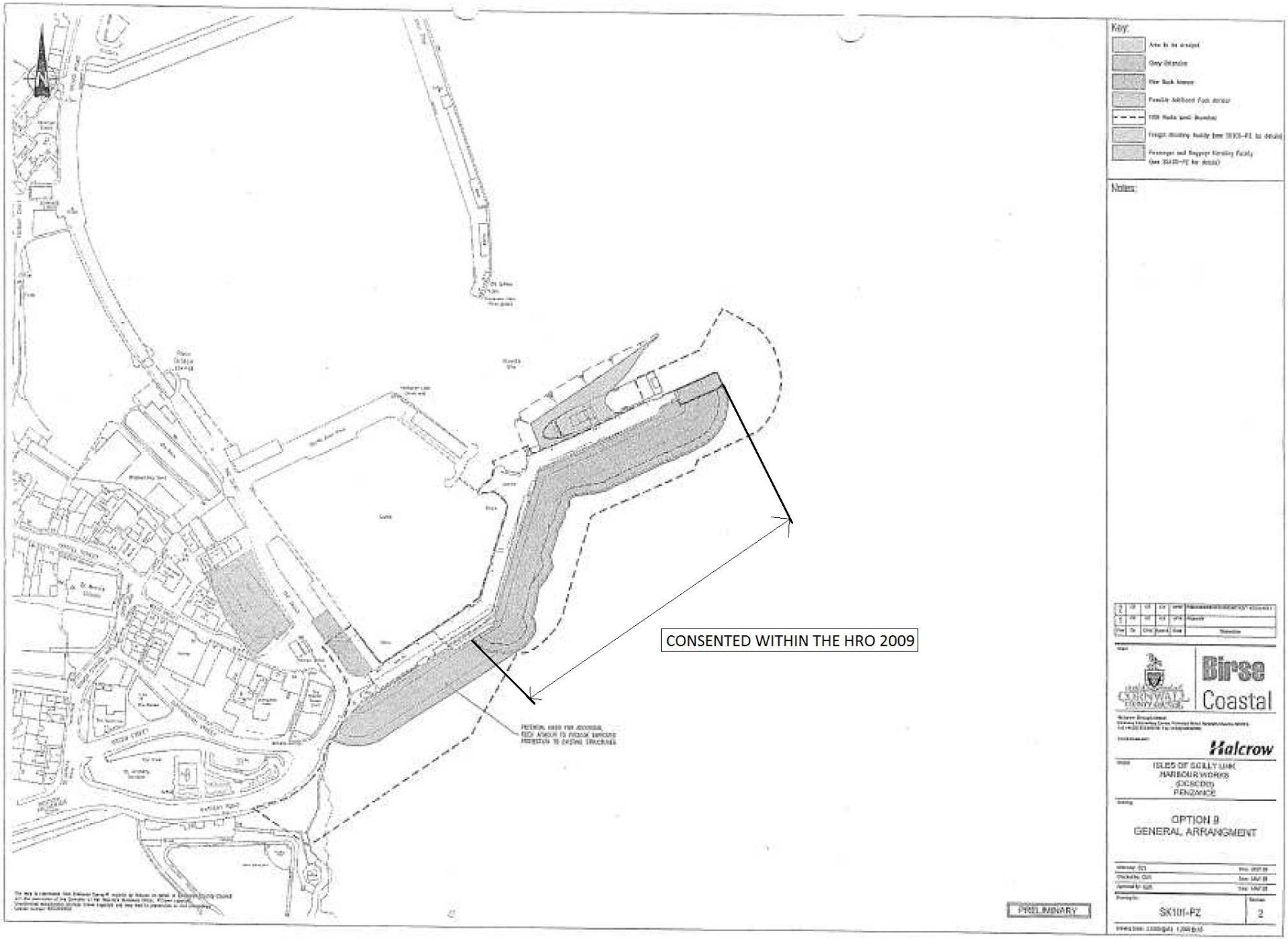
Admiralty Tide Tables – United Kingdom and Ireland (including European Channel Port) Vol 1 NP201-13 2013.

APPENDIX C

Plan View of a Full Rock Armour
Ref: Penzance Harbour - Appraisal of Alternatives Halcrow (2009)

&

Typical Cross Section of Rock Armour
Ref: Penzance Harbour Technical Briefing, Gareth Robertshaw Presentation (February 2010)



Key:

Area to be dredged

Quay Extension

New Rock Armour

Possible Additional Rock Armour

HRO Works Limit Boundary

Freight Handling Facility (see SK101-PZ for details)

Passenger and Baggage Handling Facility (see SK101-PZ for details)

Notes:

Birse Coastal

Halcrow

ISLES OF SCILLY UHK
HARBOUR WORKS
(OUTLINE)
PENZANCE

OPTION 9
GENERAL ARRANGEMENT

SK101-PZ

2

Rock Armour – Design