PORT DE QUEBEC

Quebec City, Canada

The Port of Quebec (French: Port de Quebec) is an inland port located in Quebec City, Quebec, Canada. it is the oldest port in Quebec after the Port of Montreal.

Owned by the Government of Canada and operated by the Quebec Port Authority, the port has been in exsistence since the early 17th Century.

In the 19th century, the Port of Quebec was one of the most important in the world. It played a major role in the development of both the city and of Canada. In 1863, more than 1,600 ships went through the port, transporting almost 25,000 sailors. It was during this era that the shipbuilding industry grew considerably in Quebec City.

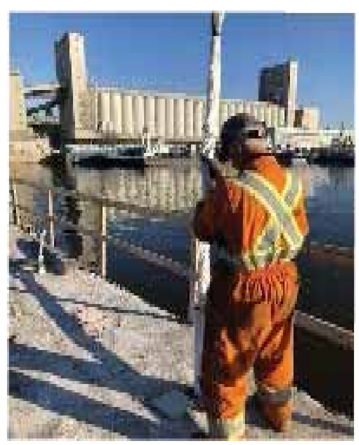
In the 20th century, the dredging of the Saint Lawrence River between Quebec City and Montreal moved major port activities upstream. Today cruise traffic has replaced much of the former freight traffic.

In the summer of 2019 Cintec was contacted by Jhon Páez, Senior Structural Engineer Ports, Marine and Coastal of WSP Global Inc – an international engineering firm with over 50,000 employees in some 500 offices serving in 40 countries worldwide.

The requirement was for vertical strengthening in two areas of Quai 5-14N of the Port of Quebec as shown in top photos. As determined, anchors were to be a 1 1/4” diameter, #30M 2205 stainless steel reinforcing bar with overall anchor lengths of 25 feet (7.5M) to 30 feet (9 M) long. 48 anchors were fitted with 4 inch (100 mm) sock and installed by use of a crane in drilled cored holes of matching diameter. Placement completed by injection of Presstec © grout.

Cintec anchors in protective shipping tubes

Cintecv anchors hoisted into place by crane



Cintec anchors being placed by installer

Cintec anchors in place prior to inflation

Case History

MORRIS ISLAND LIGHTHOUSE, SC

The Morris Island Lighthouse is located on Morris Island, off the coast of Charleston, South Carolina located on Sullivan's Island at the north end of the harbor.The lighthouse was opened in 1876 and decommissioned in 1962.The structure is 49M/161 FT tall. The lighthouse was placed on the national register of historic places in 1982. After the decommissioning, the circular stair case was showing advanced deterioration due to the salt air environment. There was a real fear that the stair case would collapse in on itself.

The stabilization on the stair case included the installation of CINTEC CEMENTITIOUS GROUT ANCHORS. The anchors were tied to the inner and outer walls of the lighthouse. A beam was tied to the anchors. The staircase was tied to the beam to support it. CINTEC AMERICA provided the anchor system to support the staircase. ICC- COMMONWEALTH based in Buffalo, NY were responsible forthe Engineering and installation.

Project Anchor specification was 1 3/8" (35mm) dia Stainless Steel rebar grade 2205 - 44" (1118mm) long socked 41"!(1040mm) with 3" (75mm) of exposed threads to attach bracket to beam.

Case History

Marco Island Sea Wall - Florida USA

March 1983 - Following a move from Germany to a new home on a Florida island, Civil Engineer Paul Pella was faced with a structural problem common to the region – subsidence and dislocation of the protective sea walls surrounding the homes built upon the island. Fortunately for Mr. Pella, his engineering experiences back in Europe provided him with an innovative new technology   ideally suited f or stabilizing these concrete structures – Cintec Anchors. The ground behind the walls consists essentially of sand, not considered an ideal medium for any form of anchorage. However the adaptability and unique features of the Cintec system overcame any potential difficulties associated with this soil type.

Consisting of a steel rod enclosed in a mesh fabric sleeve, the principle of the system is to inject a specially developed cementitios grout into the restraining sleeve of the anchor and so inflate it along its entire length. As well as providing an extremely strong mechanical bond, some liquid or 'grout milk' passes through the material membrane and bonds with the original substraight beyond.

Fig 1

In the case of Marco Island, an additional wide section of expandable sleeve, or sock as it is often called, was attached to the far end of the anchor. When the grout was injected, the additional section expanded to a diameter greater than the rest of the anchor. This created a bulb deep within the soil and ensured a truly secure point of anchorage.

Fig 2

As can be seen in the images (right) the individual boreholes were produced by diamond core drilling, in this case with a core diameter of 65mm (2 ½") and to the length of the anchor : 3.2 meters (15ft) – Fig 1. The anchors were then installed with a plastic half pipe to facilitate their intsertion – Fig 2. Finally the anchors were injected with 'presstec' cementitous grout expanding them from their far end to the front. Although not essential, a flange – plate was laso screwed to the exposed anchor end for additional securement – Fig 3.

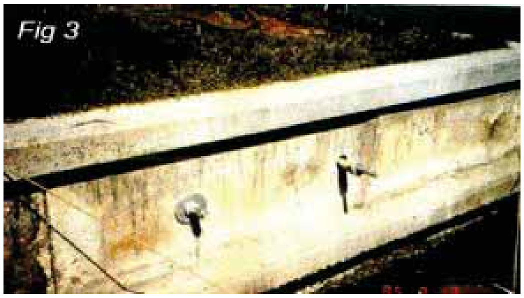


Fig 3

Case History

Lock Gates Clarendon Docks, Belfast, U.K.

Cintec anchors have been used to fix two 20 ton lock gates, as part of the 750 million pounds sterling, regeneration of Belfast's Laganside Development.

Clarendon Docks, where shipbuilding in Belfast first commenced, was severely affected by the river's tidal range. Construction of a temporary dam across the existing dock basin, and installation of a lock between the basin and the river, has created an aesthetically pleasing non- tidal water feature capable of facilitating small craft. Although the dock basin was pumped dry for the refurbishment of the waterfront site, it was vital that the fixing method selected was suitable for use underwater.

Each gate is supported by two hinges bolted into the 600mm concrete wall of the lock. One of the key reasons for selecting the Cintec system, was that although the top hinge for each gate is well above the water level, the lower hinge falls within the tidal zone, "explained Brian Campbell. Design engineer for the installers. During the installation, sea-water poured through at one of the anchor locations. We were concerned that alternative fixing methods would not be as successful in such wet conditions."

Following extensive testing, 48 Cintec anchors were embedded into the wall to support the two lock gates. Each lower hinge required 12 fixing anchors, 450mm in length and 102mm in diameter at 200 and 220 centers. The installation of the anchor bolts at the lock gates has been undertaken by ACE Fixings, the approved installers of Cintec anchoring system for Ireland.

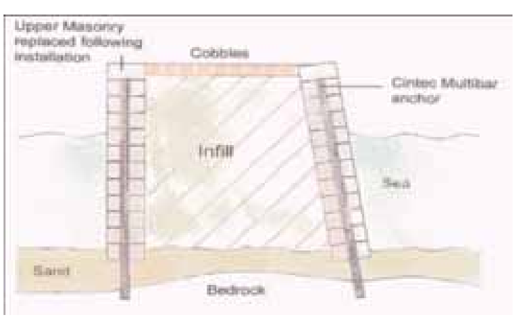
Hay's Dock Lerwick (Shetland Islands) - Scotland

Lerwick is the capital of the Sheltland Islands and in the early 1830's became a thriving centre for the herring industry. The foundation for this commercial success lay with the construction of Hay's Dock and a complex of warehouses and curing yards together with all the facilities for building and rigging sailing vessels. The fortunes of the herring industry fluctuated considerably during the 19th century and as vessels became larger and steam power became the norm, a new larger facility was required and subsequently built by the Lerwick Harbor Trust in 1906. The original dock continued to play an important commercial role adapting primarily to the timber trade.

Panorama of Hay's Dock with the Heritage Centre under construction in the background (right), the restoration of the old sail house on the quay (centre right) and Cintec stabilisation work (end of the quay left of sail house).

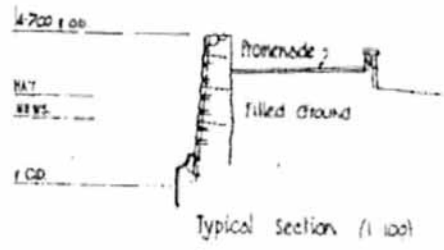
Today Hay's Dock stands as a monument to the town's industrial heritage and with the assistance of the Shetland Amenity Trust, Historic Scotland and a contribution of lottery funding, the dock area is being rejuvenated with the construction of the new Shetland Museum and Archives building as well as the refurbishment of the old docks itself.

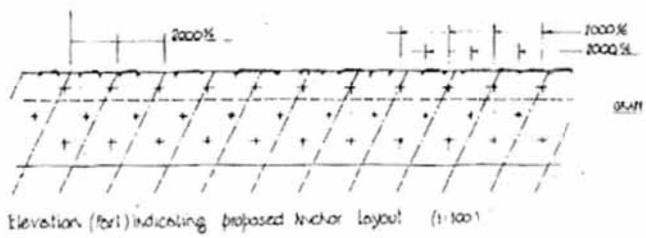
When originally constructed, technology for building underwater was limited. Consequently the foundations of the furthest and hence deepest part of the quay consist of large stone blocks resting upon a layer of relatively unstable sand and gravel. Inevitably, over the last two centuries, the structure has suffered from significant subsidence.



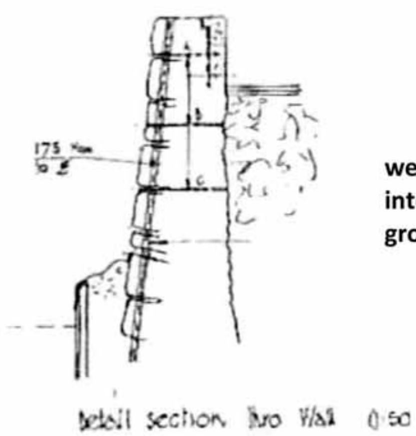
Goodrington Sea Wall, Devon, U.K.

The Sea wall at Goodrington Beach, in Devon, UK, was constructed of local stone and founded upon a concrete footing. The whole wall was gradually moving towards the sea by sliding off the concrete foundation

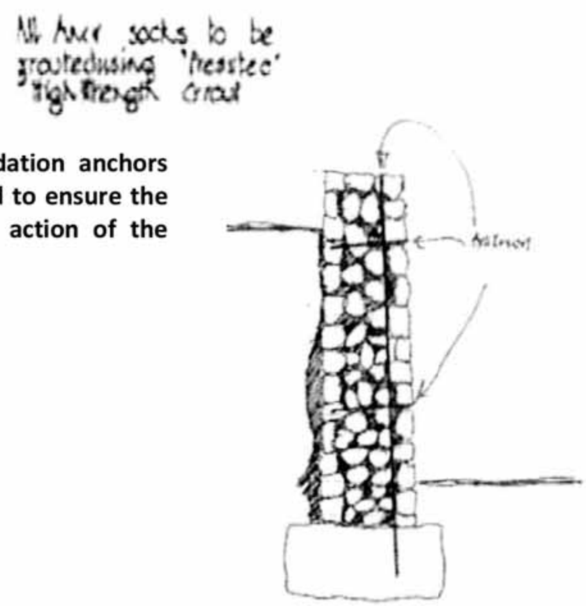




To overcome the problem, Torbay Borough Council proposed a design using Cintec anchors to pin the wall to the foundation. The anchors were inserted at an angle to mobilize the full length of the wall.



Additionally Cintec consolidation anchors were inserted on a regular grid to ensure the integrity of the wall and the action of the ground anchors on the wall.



‘Stitching up’ the past – The strengthening of three heritage marine structures in Jersey with needling technology

The three structures are the North Pier and South Pier of St. Aubin’s Harbour and the St. Aubin’s Fort Breakwater. Both structures are exposed to waves from the south west and act as breakwaters.
Both structures have suffered ongoing failures or unacceptable movements during the past decades, on the inner sheltered side of the breakwaters.

North Pier - cracks at deck level

In 2001 the North Pier was assessed as being in a state of instability due to movement of its internal wall and apparent settlement of the interior of the pier. The deck level of the North Pier is surfaced in asphalt which waterproofs the deck but also masks (to a certain extent) masonry movements. Large cracks however had developed and could be seen in the asphalt indicating a threat of impending wedge failure of a section of the inner wall

St Aubin’s Fort Breakwater has in turn suffered a re-occurrence of masonry movements and loss of pointing at its inner, lower deck wall.

In 2008 a bulge was also identified in part of this inner wall which prompted concerns about this part of the breakwater’s structural integrity.

Strategy for Repairs

Many options were considered in 2005 to protect and strengthen the North Pier. The basic engineering solution of constructing a foundation on the outside of the existing alignment and then rebuilding the

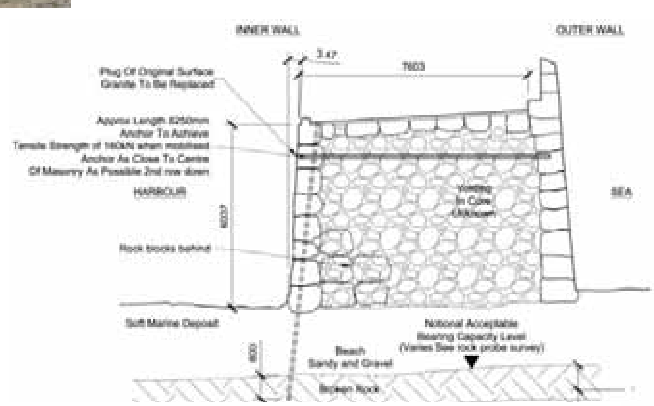


Figure 12 - Cross section of North Pier with stitching anchors

inner wall on this new foundation was the initial solution favoured. However, the rebuild proposals were not endorsed by the States of Jersey Planning and Heritage Departments, who asked for a 'tying in place' solution to be investigated for stabilising the inner wall. Environmental concerns regarding the endangered mollusc species further reinforced this argument.

The chosen 'stitching' solution used Cintec anchors consisting of a number of solid stainless bars contained within a fabric sleeve injected with cementitous grout after positioning. The bond of the grout that seeps through the fabric sock used in the anchor between the masonry and the reinforced anchor is very high tying areas of loose masonry blocks together. This 'stitching' methodology was also able to provide a foundation solution; the numerous small diameter vertical anchors become mini piles when drilled down through the granite wall stones, through the beach deposits and into the Jersey rock shale beneath. The natural arching of the masonry blocks between mini piles at beach level then provides significant underpinning support to the existing mass granite masonry wall over and above the sea bed level materials.

To resist the inner wall overturning, after pinning the base of the wall with vertical mini piles, requires a form of top restraint in the outward direction (Figure 12). The final design consisted of horizontal 'passive' ties from the inner wall to the outer face although inclined raking anchors through the core of the Pier tied into the Jersey rock shale were also considered.
The budget was focused upon dealing with the bulging section only. The engineering options considered were:

- Partial rebuild and removal of cementitious grout;
- Take down and partial rebuild in sections;
- Mini-piling to provide an effective inner foundation;
- Reduction of wave energy forces on the outside face of the breakwater – rock armour;
- The 'stitching' option repairs and strengthening.

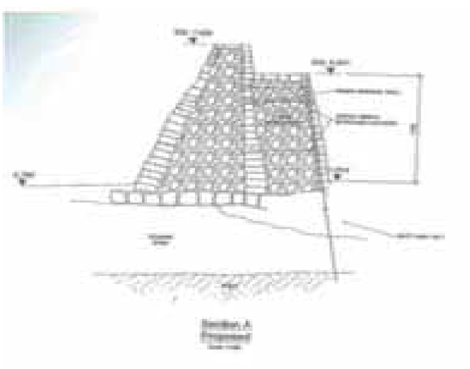
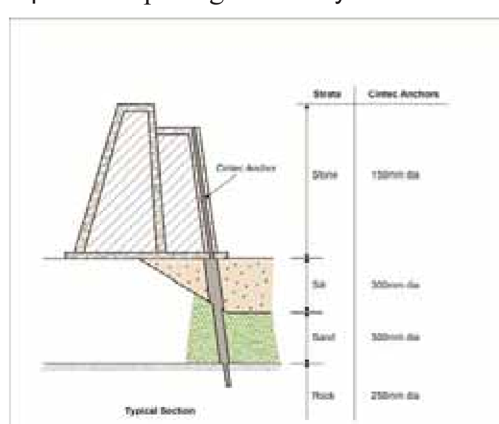


Figure 13 - St. Aubin's Fort inner wall ties and mini piles

The quality of the grout that was pumped into the end of the structure in 1972 was found (in 2009) to now be of deteriorating variable quality and consistency. However, it was not thought pragmatic or cost effective to dismantle this end of the lower deck structure and rebuild it in its original form, whilst the 'stitching' anchor solution provided clear benefits allowing the structure to be anchored and stitched together without changing its character and with minimal impact. In order to optimise the number of anchors, an iterative process was used, finding the optimum spacing to satisfy the onerous load criteria imposed by the sea conditions in such an exposed location. Horizontal ties were inserted through the inner wall of the main breakwater so that the inside face wall of the lower deck was not only tied to the inner bulk of the original wall but also had additional cantilevered 'beam' support.



Another design philosophy applied in the design of both structures repair works was that within the weaker strata such as sand, this grout injected anchor/pile system expands, reducing the potential for buckling and increasing skin friction.

Implementation

Not only did the final design solution comply with the planning authority requirements, it

Figure 15 - Anchors with coupler

Figure 16 - Pre-injection with masking tape

Figure 17 - Anchor expanded

furthermore mitigated pollution control concerns by the ‘sock’ principle of the anchor system where the grout is contained within a small radius of the sock diameter. Only a small surface area of grout oozes through the sock material to bond to the adjacent substrates and when cured, forms a concrete skin over the ‘sock’ material (Figure 16 before grouting injection/Figure 17 after grouting injection).

This way the repair works to the three structures were wrapped into one project, realising benefits in terms of cost and programme and lessons learnt from the trials.

Figure 18 - North Pier vertical drilling

At the North Pier the vertical drilling works for the anchors took place through the inner wall concrete up-stand used for vessel mooring. Plugs in the masonry were reinserted to enable invisible fix (such as that shown in Figure 20) once the anchor had been installed. The supplier utilised standard 2.5m anchor lengths for both structures, coupled together to achieve vertical and horizontal lengths as required (Fig 15).
Another valuable aspect of the installation process was that each individual anchor drilling provided its own borehole information. This allowed the length of the anchors to be reduced where, for example, the rock outcrop was found to be at a shallower depth.

F
drilling

From a large machine platform aided by localised, demountable scaffolding the horizontal anchors were drilled and fixed (Figure 19). The number of verticals and horizontals at the inner wall of the Fort Breakwater required careful setting out to avoid conflicts and also to allow for flexibility with respect to deck positioning of the rig on the

Figure 20 - Anchor with plug cap replaced, 'Secret Fix'

structure. In-situ vertical load tests took place on the anchors to confirm design assumptions, configuration and spacing of the anchors. The storm events at St. Aubin's Fort in December 2010 coincided with high tides, so the contractor re-focused upon the St Aubin's Harbour North Pier work, another advantage of having wrapped both works into one. In February 2011 they remobilised back out at the Fort Breakwater.

Conclusion

The 'stitching' method used to stabilise and strengthen these two marine heritage structures has proved to be effective on a number of fronts. The 'secret' or 'hidden' fix of the structure means that the heritage planning aspects of the strengthening works are achieved. The predicted wave pressure paths and loadings were analysed in an empirical way to maximise the effectiveness of the solution in areas of local maximum distress. Environmentally, the impact on the endangered mollusc species is now negligible and the risk of grout spillage is low. Economically, the costs budgeted for the original rebuilding of the inner wall of the North Pier on a new foundation, were of a similar magnitude to that for the 'stitching' techniques. There is a certainty with respect to the capacity of each anchor or mini pile as the drilling technique means that every element's bearing capacity is known and recorded. The technique therefore proved itself adaptable to the engineering judgements so necessary in this type of work; effective in terms of providing strengthening and repairs to threatened parts of heritage structures; and cost effective.

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WWII sea wall in St Aubin's Bay, Jersey: infrastructure improvements to alleviate flooding

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The sea defences constructed by the occupying Germans in 1943 are widespread in Jersey, and most still function today. The particular length of sea wall east of the slipway at Gunsite Café in St Aubin's Bay had experienced overtopping during high tides and storm events for many years, resulting in flooding inland at the main roundabout leading to the airport. The wall is subjected to 12 m tidal range. Engineering investigations into the causes of the flooding were started in 2014 to determine the nature of the flooding and how the mass concrete, original World War II (WWII) sea wall played a major part in it. The scope of the overall project included investigations into the flooding, the research into the original WWII mass concrete wall and design of a concrete capping beam with a recurve that allowed the top of the wall to be raised. Phase 1 of the construction work was completed in October 2017. Digital modelling together with innovative construction engineering methods enabled the project to be completed reducing the large wave forces which impact on this wall to be resisted even under storm conditions. This paper describes the investigations, research and design work involved in arriving at a design solution.

1. Description of the localised flooding problem

On many occasions in recent years, particularly at times of exceptional high tide and storms, overtopping at this relatively short section of sea wall in St Aubin's Bay on the south coast of the Channel Island of Jersey (see Figure 1) has resulted in significant flooding of residences and businesses at the main roundabout and highway immediately inland. As this roundabout is the main access leading from St Helier and St Aubin on the south coast up to the airport, the States of Jersey engineers for the Department for Infrastructure (DfI) decided that these significant flooding events needed to be addressed.

The States of Jersey engineers commissioned the consultants, Arup Rothwell, to investigate the flooding problems (see Figure 2) and put forward engineering concepts for a solution to alleviate the flooding which included the option of raising the height of this World War II (WWII) concrete wall. Other options considered at this location, such as rock armour and groynes, were not thought viable because this part of the St Aubin's Bay beach is a popular tourist spot, and the solutions impinging on the beach amenity use, coupled with the cost of such methods, precluded their use at this location.

2. Engineering constraints on the WWII sea wall

The sea wall in this section of St Aubin's Bay was constructed by the German occupation forces in 1943 under the instruction of Lt Gen. Graf von Schmettow, the military administrator of the island. He instructed nine Panzermauern (or antitank landing walls) to be constructed urgently on all of the large beaches in Jersey that presented an opportunity for the Allies to mount amphibious landings. The wall in St Aubin's Bay PMZ6 as reported by Hold (2016), was, like many other amphibious landing sea defences and fortifications, built by prisoners of war and forced labour (see Figure 3). In the current era, the cross-sectional geometry and shape of this particular section of the mass concrete sea wall was found to be of insufficient height to resist a combination of the high tides and storm waves and was inwardly sloping with a rounded top, both of which contributed to wave overtopping, allowing waves to ride up and over the top of the wall.

Directly behind the sea wall is the promenade walkway, which runs from St Aubin into St Helier around St Aubin's Bay. The walkway, which carries pedestrians, cyclists and a tourist minitrain, has been paved, but in this particular area of the promenade's surface, the paved surface also slopes inland. This combination of the wall geometry and the inland fall of the promenade meant that all significant overtopping water was channelled behind the promenade paved area and ran naturally to the lowest point inland. Access roads then channelled the overtopping water back to the main highway and surrounding buildings, which then had a fall towards the main roundabout junction on the island. The shape of the geometry of the sea wall being inclined inwards with a rounded top also meant that seaweed and debris contained in waves could run up and over the sea wall and also travel inland. During storms and heavy rainfall events, the subsequent build-up of debris (in particular seaweed) resulted in blocking the storm water drainage systems at the road and the roundabout, exacerbating the flooding problems.

Figure 1. Location map of Jersey and St Aubin's Bay

In 2015, at the start of the flood study investigations, Arup commissioned a light detection and ranging (lidar) survey of the area around this section of the esplanade, the roundabout and the beach in St Aubin's Bay to produce accurate levels and to model digitally the area around this part of the sea wall. The lidar modelling enabled the flow of water to be studied and understood, which confirmed the behaviour and direction of the flow of all overtopping. In addition, the lidar survey and model enabled accurate drawings to be produced of the whole area subjected to the flooding and allowed visualisations of the proposed raised wall to be assessed for both the effects of additional height on user benefit and visual impact changes to the beach and promenade.

Figure 2. Inland flooding – overtopping and flooding at St Aubin's sea wall near the Gunsite slipway

Figure 3. Shape of wall

3. The flood study

Arup undertook the flood study and assessed the volumes of water being produced by overtopping events and understanding where these volumes of water would be trapped and cause flooding. The objective of the study was to assess how high the existing WWII concrete sea wall had to be raised to prevent flooding or, at the very least, alleviate the flooding scenario inland, in particular at the roundabout. At the outset of the remediation design, the Construction Industry Research and Information Association (Ciria) guidance C674 on sea wall design (Dupray *et al.*, 2010) was used to provide an initial curved geometry and profile for a 'recurve' and capping beam that would be robust when subjected to the storm wave forces that impact on the existing WWII wall (see Figure 4).

The objective of the recurve is to ensure that the wave impacting on the wall is thrown backwards into the next oncoming wave, thus reducing the energy of the incoming wave and its wave energy at the wall together with its consequential overtopping volumes. The study looked at the relevant decrease in overtopping volumes that could be predicted, when the wall height was raised incrementally, accounting for sea level rise, storm increase and duration over a design life of a further 50 years. Various heights for raising the wall were analysed, and the relative reductions in overtopping volumes of these heights were predicted and plotted on the new cross-section (see Figure 5).

4. Scheme stage design

The geometry and the raising of the wall at scheme stage design was initially based on the above ordnance datum (AOD) levels that exist elsewhere in St Aubin's Bay for other parts of the esplanade sea wall parapet, particularly towards the St Helier end of the bay where the esplanade parapet top level is at 9·0 m AOD. This is not an all-encompassing magic figure but a reasonable 'engineering judgement' height for the new added section of the top of the sea wall at the Gunsite Café slipway area.

Figure 4. Typical shape of recurve' from Ciria C674 (Dupray *et al.*, 2010)

It is well documented that even this area of the esplanade in St Helier is overtopped with resulting flooding in St Helier as in 2014.

The original scheme design allowed for the further significant overtopping to be dealt with by utilising a secondary drainage channel at the rear of the promenade and a gated barrier defence across the entrance leading out to the highway. Previously, the States of Jersey engineers would place large sand bags at the roadway access to the highway in an effort to reduce overtopping flows getting on to the highway.

5. The research and further study

Refining the design of the shape and height for raising the sea wall, coupled with the change of geometry profile to produce a recurve had several iterations. A permanent secondary defence gate system at the entrance to the roadway has also formed part of the overall flood alleviation scheme proposed at this location.

6. Assessment of WWII concrete

The condition of the WWII concrete of this part of the wall was visually in a poor state, particularly on the seaward side. There were many areas where the wall surface had been abraded by gravel and marine debris and exposed the concrete aggregates in the mass concrete to a significant depth in some areas (see Figure 6). In addition to these defects, there were many inclusions of ferrous metal reinforcement that had originally been used to join together the joints in the mass concrete pours during the original construction in WWII which, being ferrous metal, produce corrosion problems within the porous concrete wall.

It was therefore necessary to assess the integrity, the consistency and the physical properties of the original WWII concrete that was cast under the shadow of a blockade, which in turn meant that various other unseen defects were possible within the concrete. Not only was cement and aggregate reported to have been in limited supply during this part of WWII, but certain areas of the sea defences in the Panzermauern system were also subject to sabotage and deliberately poor construction. To address these quality unknowns, three horizontal cores were taken completely

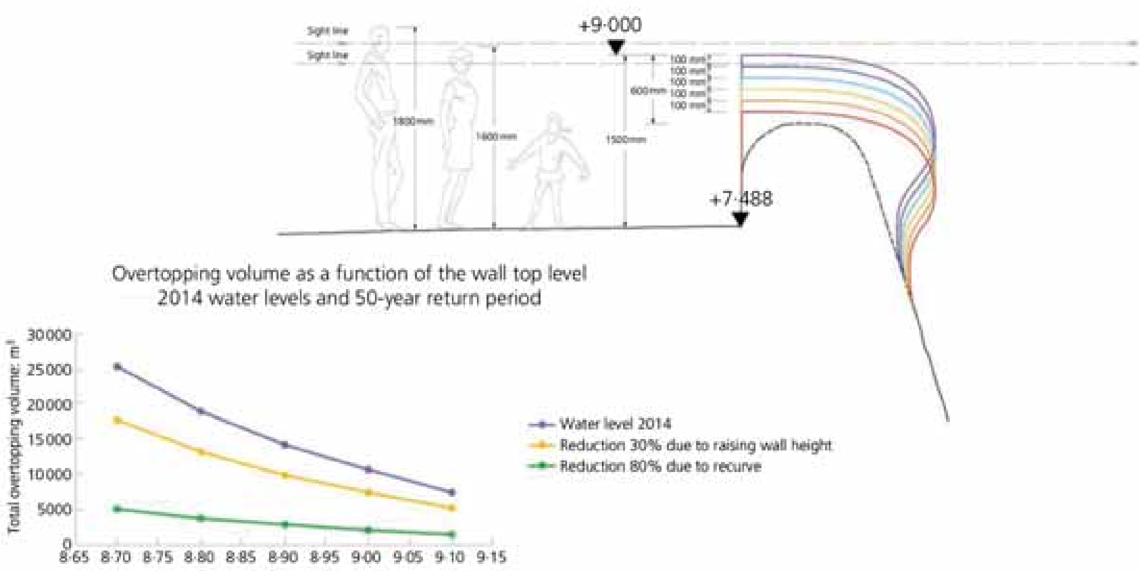

Figure 5. Overtopping options for various heights. m AOD, metres above ordnance datum

Figure 6. Poor surface of WWII wall with inclusions

Figure 7. Concrete core intact through wall

through the cross-section of the wall. These samples were to provide information on the consistency, compressive strength and tensile capacity of the original WWII mass concrete. For the design of the new concrete raised sections of the wall, it would be necessary to match this new concrete recurve capping piece with the in situ existing mass concrete to ensure that the new combined concrete sea wall arrangement acted as one.

The results of the horizontal cores indicated that the surface damage was to an approximate depth of only 20 or 30 mm, and, generally, the depth through the wall to 700 mm thickness was seen to be of consistent, reasonable quality concrete. The tensile strengths of concrete cores were in the 1·4–1·9 N/mm^2 region, and the crushing strengths were from 30 to 40 N/mm^2 (see Figure 7).

With these parameters in mind, design could then be directed at providing a new mass concrete capping beam to raise the height and to change the profile of the wall that would have similar characteristics to the original concrete that would be 'stitched and bonded' to the original mass concrete below.

7. Design parameters

The prime design objectives were to provide a further mass concrete capping arrangement that raised the level of the wall and incorporated a recurve to reduce the volumes of overtopping. The recurve would also mean that the wave energy from the next incoming wave was dissipated by the reflected wave and consequently had less energy when it impacted at the wall. Stitching new mass concrete to old mass concrete posed a few design problems, and the original concept of using numerous dowel bars was superseded by utilising 'Cintec anchors' which mobilise significant bond over a larger contact area and therefore require fewer drill holes to provide the tying action between old and new concrete and, therefore, larger spacings between ties could be used. The spacing of the anchors was chosen to be two anchors at the seaward side 1·0 m apart, with one anchor at the landward side of the cross-section in the compression zone. The site pull-out tests included in the contract specification proved an in situ tensile capacity of the Cintec anchor being able to produce a pull-out load of 75 kN.

Previous work by Arup Rothwell on sea defences in and around Jersey had concluded that a worst-case scenario design impact from wave loads at this location in St Aubin's Bay would be in the region of 24 kN/m^2. This impact force would have a significant upward component as the wave impact was being channelled up the wall due to the incline of the concrete face and would impose an uplift force at the junction between original and new concrete. It was therefore necessary to provide a 'tying or stitching' arrangement that could compensate for this 'uplift force' as well as other extreme impact circumstances from wave born debris. Early in the original design concept, it was deemed necessary to cut down the rounded and damaged top of the existing original sea wall to 'stitch and tie' in the new mass concrete beam with a recurve profile (Figure 8). The geometry of the cut surface to provide the tying action with the Cintec anchors meant that approximately 1 linear m of new concrete would be providing a downward dead load force of approximately 25·4 kN/m^3 – that is, 1 m^3, almost providing a safety factor of 1 to 1, with respect to the assumed worst-case uplift force per metre run of 24 kN/m^2. Also taken into consideration was information from the practical wave studies previously on the Jersey coastline that only in very rare circumstances would storm waves act orthogonally to the wall over a long length but would generally tend to impact on the wall in a rolling pattern, which imparts the maximum impact over a relatively small area of wall only. To achieve the required design safety factors, the additional bonding between the two concretes and tying them together was to be provided by the Cintec anchors within a unifying new capping beam arrangement on the top of the cut-down wall. Engineering judgements also concluded that at the junction between old and new mass concrete was also to be tied together in a continuous

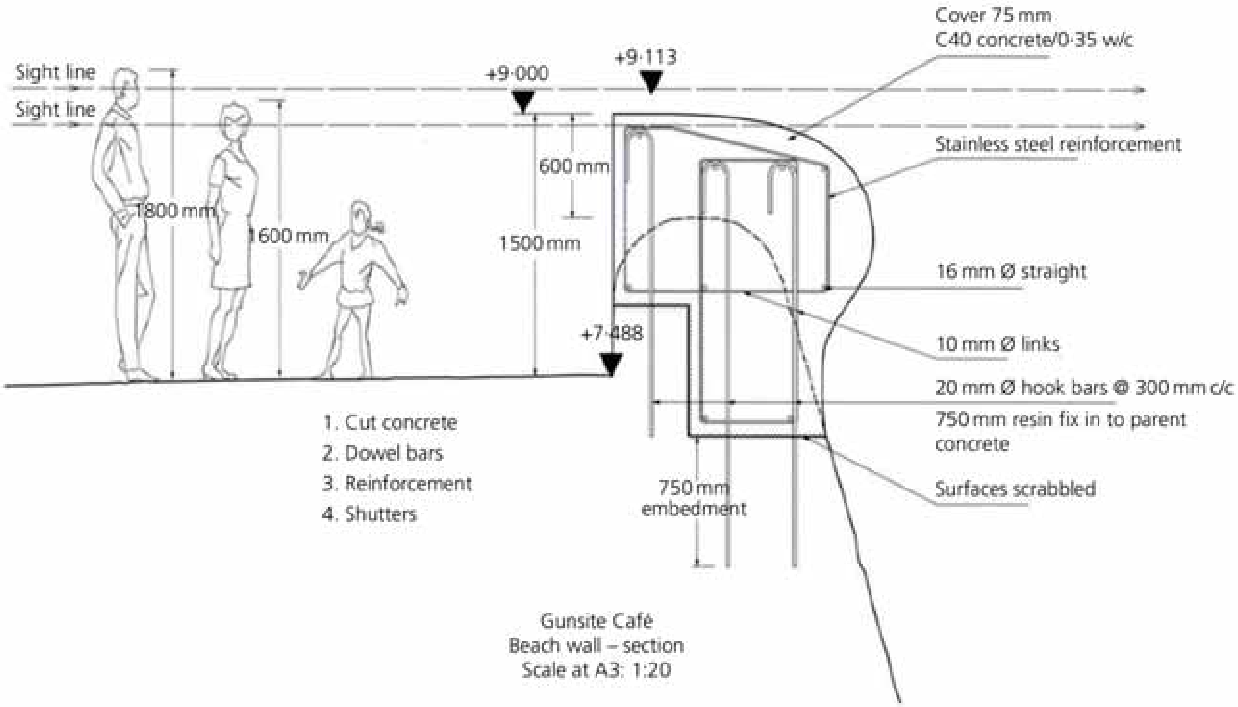

Figure 8. Initial design concept. c/c, centre-to-centre; w/c, water/cement ratio

beam. The intention is that the localised 'high forces' would be spread over a longer length of continuous new beam and better transferred and spread through to the mass concrete below by a 'designed' number of anchors which provide the estimated additional resistance required to comply with marine code safety factors.

8. The design of the capping beam

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10. Concrete repairs

The condition of the seaward surface of the original concrete wall was in a very variable condition (see Figure 6). In some areas, large surface loss has taken place, exposing aggregate and corroding reinforcement. The solution was to break out these areas of weakened concrete and repair with a fibre-reinforced spray concrete. Trial spray concrete areas were used to arrive at a satisfactory methodology for both the safe cutting out and replacement of material using spray concrete to achieve an appropriate concrete repair and an acceptable colour match.

11. Consultation processes

Prior to the production of detail design specification and tender documents for the works, DfI engineers had discussions with the Jersey public, the local politicians and minister responsible, who deemed that the new designed height of the wall of 9·0 m AOD at this part of the promenade walkway was unacceptable from a political standpoint as it reduced the viewing opportunities of people using the very busy and popular promenade.

Consequently, the top of the new section of the wall was instructed to be some 300 mm below the new designed level of 9·0 m AOD and that a provision for 'future-proofing' the height of the wall so that it could be raised to 9·0 m AOD at a later time was to be included in the detail design. As a result, the design and tender drawings had a reduced height of wall and a threaded bar with a cover cap at the top of each of the Cintec anchor bar at the surface level to enable a coupler to be fixed and then additional beam height could be added to the current level at an unspecified date in the future. This coupling capacity would also allow for an even bigger height sea wall than the notional 9·0 m AOD to be possible depending on climate change and sea level rise in the future. Another significant fundamental design change instigated by the States of Jersey Manager of Highways and Infrastructure was to create a recurve design for the capping beam that mirrored the angular shape at the top of the wall in the WWII concrete defences that was designed to resist tank assaults climbing the concrete defence walls (see Figure 9). The recurve shape for this project is therefore not designed as a modern recurve, which is generally rounded, but angular with an overhang, which effectively produces a similar wave deflecting capacity. The wave deflecting characteristics by raising the wall to 9·0 m AOD could produce a 30% reduction in overtopping volumes, but with a recurve, this figure was increased to a 70% reduction in wave energy and consequent overtopping at the wall (see Figure 5).

12. Additional contractor's input from tendering

The successful contractor from the tendering process, Geomarine (Jersey) Ltd, had allowed for applying quiet concrete-cutting methods and a specific steel shutter design that conformed to the new angular recurve profile. The Gunsite Café and St Ouens WWII sea wall PMZ3 antitank top wall have an angled, outward-leaning sections and then a vertical beam section, and the contractor's design shutter proposal utilised a metal shutter bolted to the wall which conformed to the new recurve profile design (Figure 10).

The contractor also received credit in the tender assessment process for his use of modern techniques for concrete splitting using a hydraulic device which greatly reduced site noise and made removing the top of the wall concrete much easier as well as being more efficient when handling the waste concrete pieces for disposal (see Figure 11).

13. Attention to public interface

The location of this project directly adjacent to a well-used promenade behind the sea wall with a busy, popular sandy beach meant that the interface with the public was of vital importance. The contractor had to deal with the use of the promenade for cyclists, pedestrians, runners and so on and a tourist minitrain that regularly passed up and down the route from St Aubin's into St Helier and back along the promenade. Therefore, public awareness and interfacing with the public from both the contractor's and design team's points of view was given much thought, planning and programming. The temporary works involved minor redirection of the train in particular and isolation of the working area from the public, which meant that access of materials and machinery at the wall as well as safe transportation of concrete, formwork and so on required careful planning, supervision and execution.

Figure 9. Gunsite angular recurve at the slipway

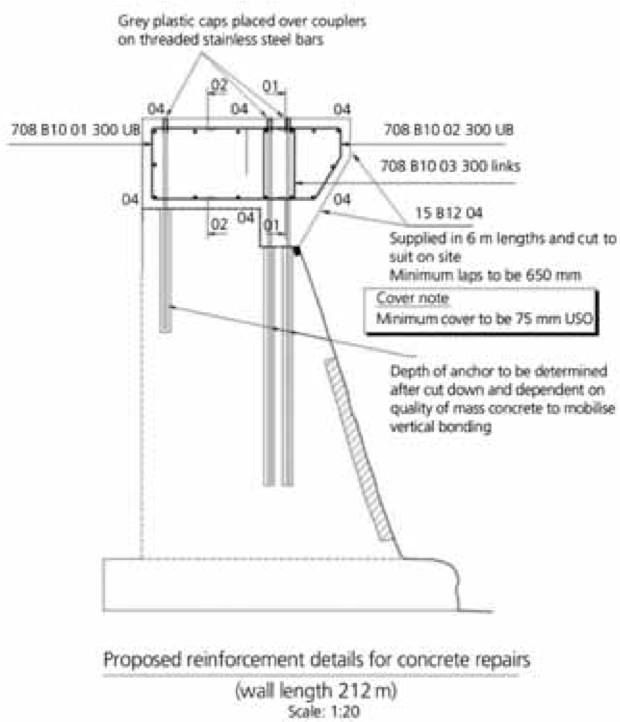

Figure 10. Angular modified recurve design

Figure 11. Concrete splitters removing the top of rounded wall

Figure 12. View of sequential construction of capping beam, raising the height and providing a recurve

14. New modern engineering techniques used during the project

In addition to utilising lidar for the surveying and modelling of this project, Cintec anchors provide the main tying and bonding connection between the old WWII concrete and new concrete. The new seaward-facing surface concrete was to be produced incorporating formwork using Zemdrain fabric on the shutter. Zemdrain produces a surface, which is hard wearing, has few surface defects, is more robust to wave impact and is more abrasion resistant. In addition to sand debris in the waves, a gravel bank is formed at the base of the sea wall and the gravel is then taken up in the waves and this has a very abrasive action. The Zemdrain-coated formwork was also used in 2006 for the St Ouens sea wall overlay and produced a very good antiabrasive result which has stood up well in an even more extreme environment than the one in St Aubin's Bay. The almost flat top of the capping beam has a shallow fall towards the sea and needed a 'non-smooth' surface so has been given a light 'rough brush' finish on top. The landward- or promenade-facing concrete has a normal F1 finish. Some minor volumetric and shrinkage cracking took place during the early work which was carried out in the hotter drier summer months. Leaving formwork in place for a longer period resulted in reducing this minor cracking during the progress of the works. The sequencing of the works is shown in Figure 12.

15. Contractor's programme

The contractor chose to deal with the breaking out of the concrete and the casting of the new concrete in successive phases in a rolling programme working backwards from Le Perquage car park to the Gunsite Café slipway. The new methodology of using concrete splitters provided a less noisy, less dusty and more easily handled removal operation. There were a few anomalies of additional cracks and voids found within the body of the WWII mass concrete when cut. These areas were made good by using concrete hand repair methods, which was the most economical way of dealing with these breakouts.

The seaward face concrete repairs were hand cut out and then spray concrete applied, using Sika I35F, to complete the major part of the phase 1 flood alleviation works.

16. Finished arrangement of phase 1

Since the construction and completion of the top of the wall to Gunsite Café slipway, two major storms coinciding with high tide have demonstrated the ability of the new geometry of the wall and its recurve to reduced overtopping. Storm Brian tested the ability of the new geometry of the wall, and studying the changed wave action and responses have produced excellent results.

It is interesting to compare the wave action of the original WWII lower height wall with the performance of the raised new recurved profile wall because the new wave behaviour illustrates the reflected wave impact on incoming waves reducing the wave energy at the wall (Figure 13). The arrangement has yet to be tested against the maximum of storm surge, high tide and heavy rainfall, but it is anticipated that with the secondary defences at

Figure 13. Performance of the wall reflecting waves

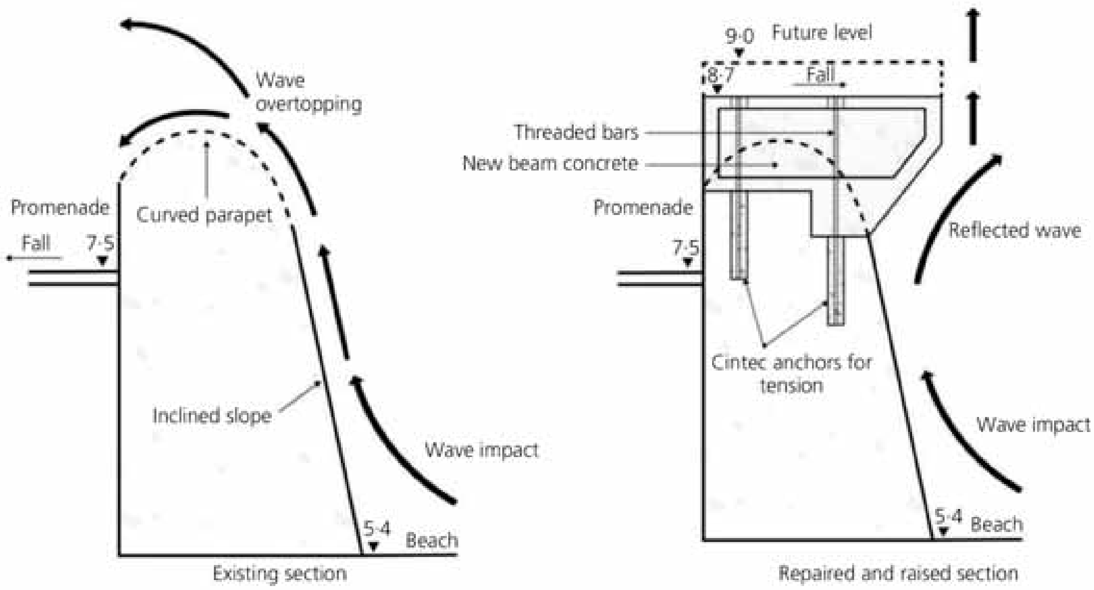

Figure 14. Scheme stage design concept before and after cross-section

the entrance to the access road, the measures have significantly minimised the risks of further flooding.

However, high tide and wave conditions that occurred in January and February 2018 at the site provided an excellent practical demonstration of the theory of improvement to the wall being demonstrated on-site. Figure 14 shows the theory behind the scheme, but the very good photograph in Figure 15, taken by the site engineer from DfI, Ross Fernley, captures nature behaving as the engineer intended. The split and change in direction of the wave is at the junction of the completed phase 1 work with the next section of the wall to be remodelled in phase II to match the phase I concept.

Figure 15. Storm wave action at new wave return wall and existing

Acknowledgements

The authors thank Ross Fearnley, Angela Brant and the States of Jersey Department for Infrastructure Engineers.

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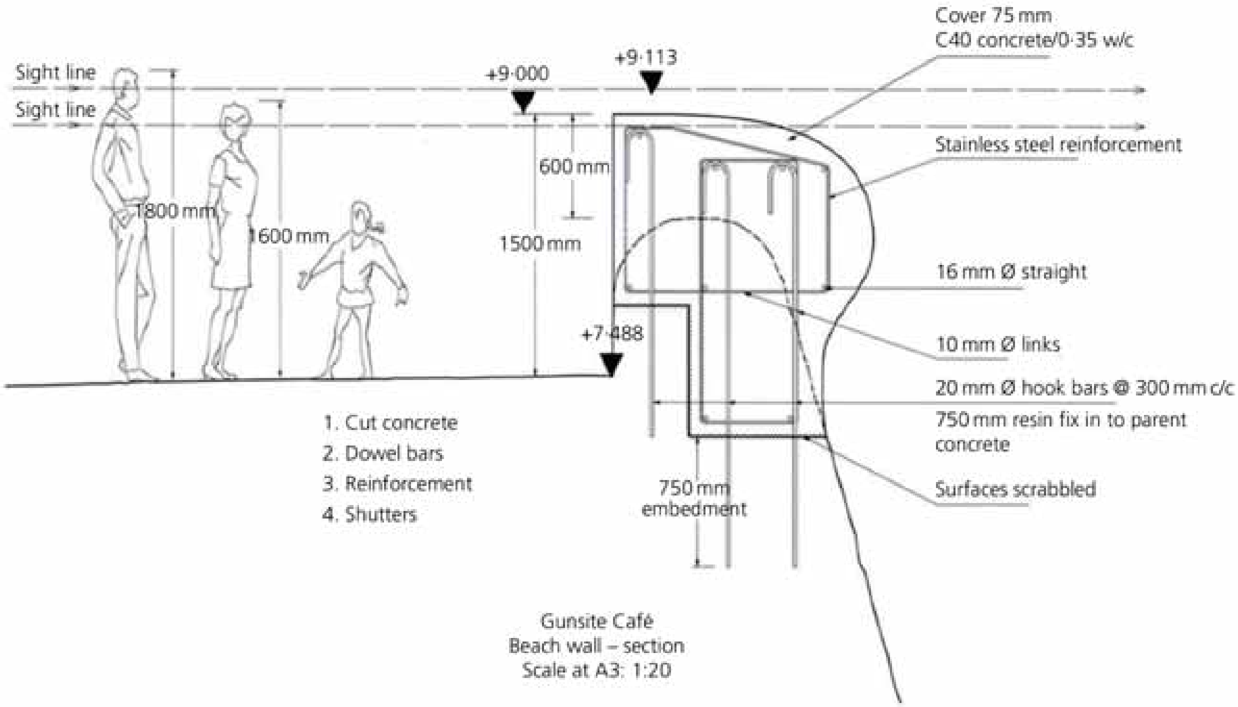

Figure 8. Initial design concept. c/c, centre-to-centre; w/c, water/cement ratio

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Pier Road Record of Photos

Fig 1. View of Pier Road parapet

Fig 2. CH. 0+00

Pier Road

Fig 3 CH. 0+00

Fig 4. View looking up

Pier Road

Fig 5 View looking up

Fig 6. Staircase

Pier Road

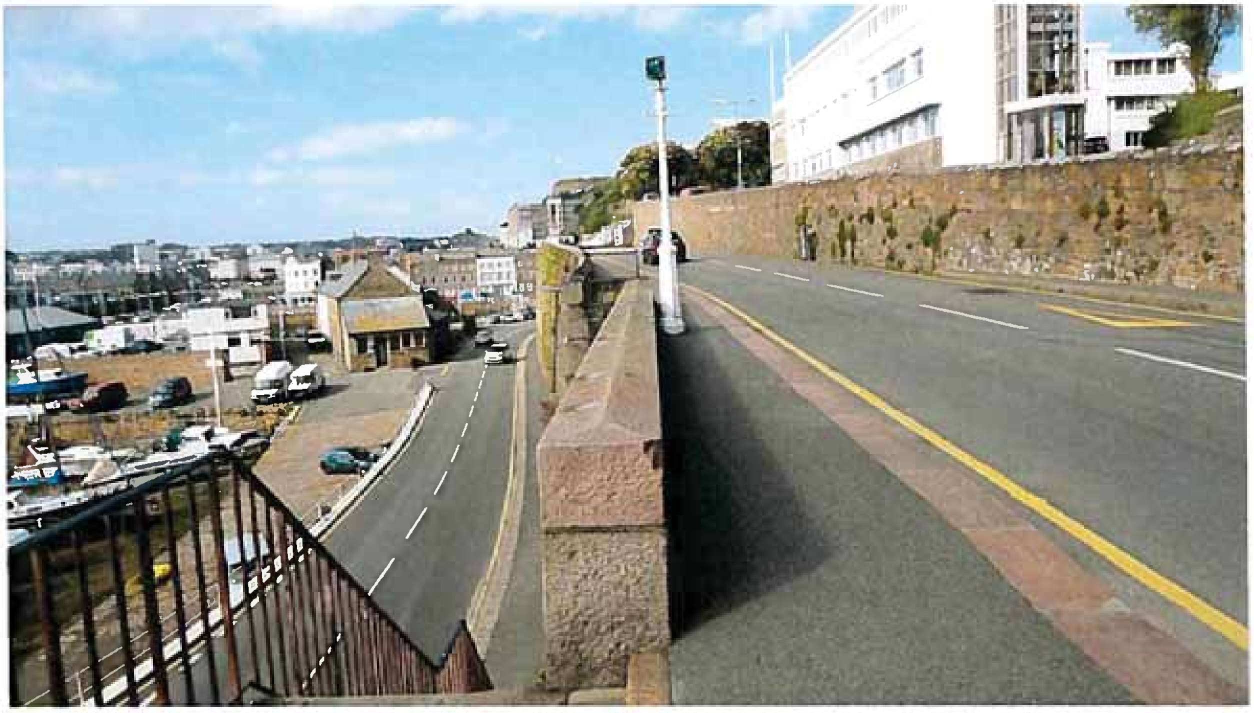


Fig 7 Return

Fig 8 . Drop

Pier Road

Fig 9 Low wall rail

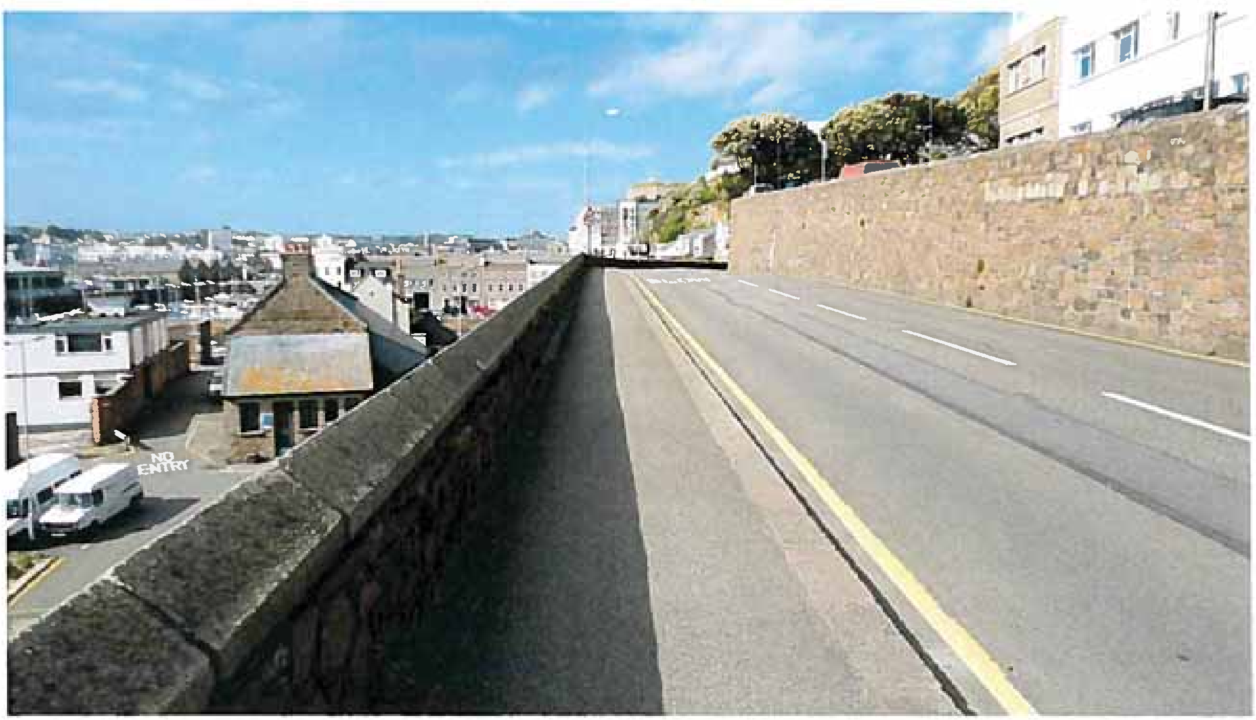


Fig 10 Looking up

Pier Road

Fig 11 Large drop

Fig 12 Thinner wall

Pier Road

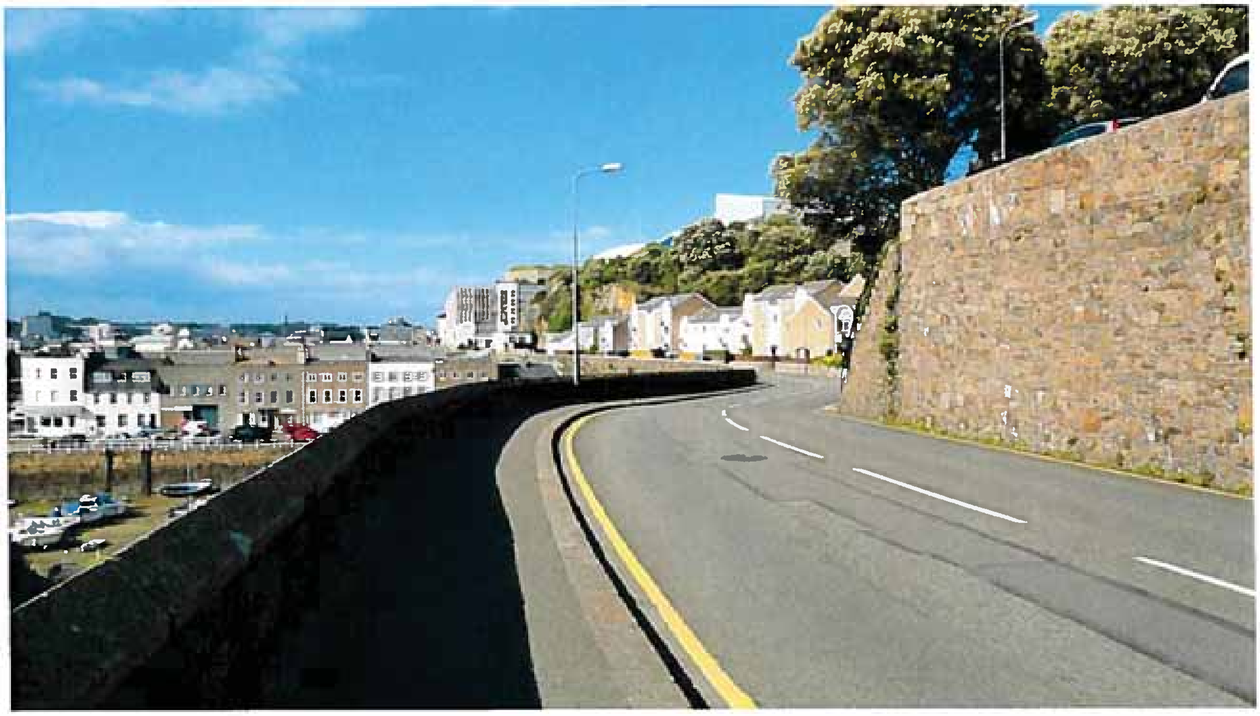


Fig 13

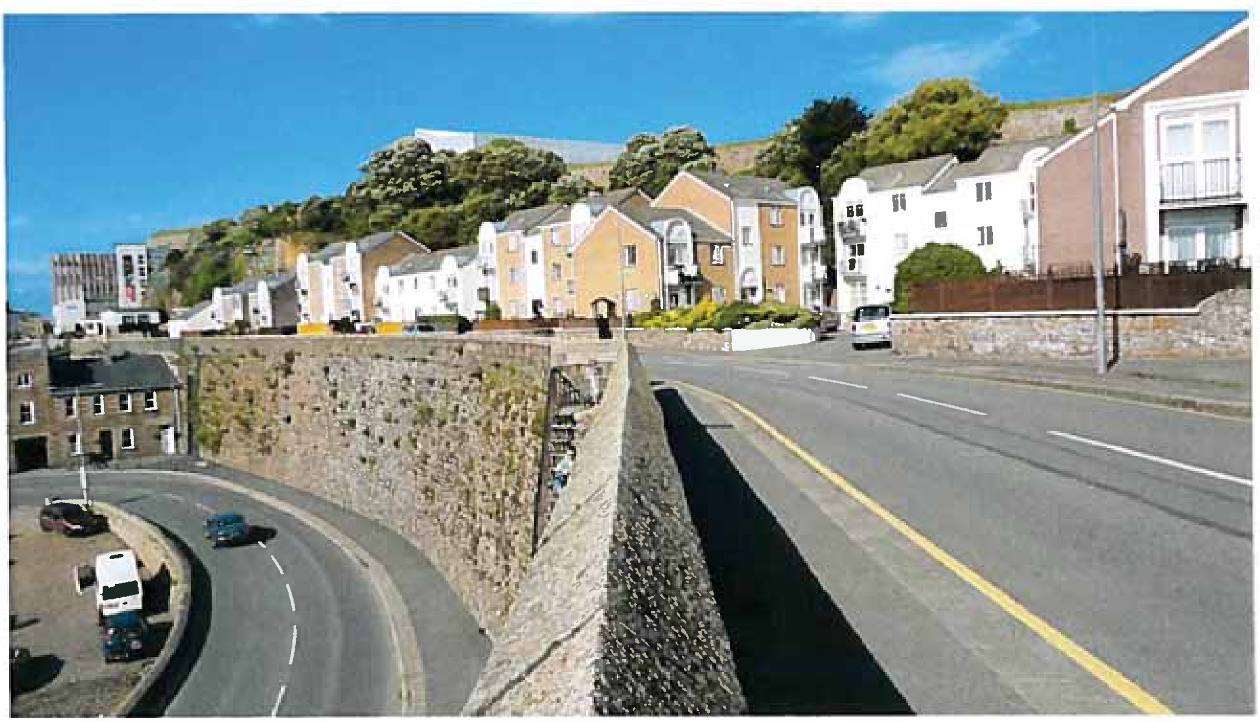


Fig 14

Pier Road

Fig 15

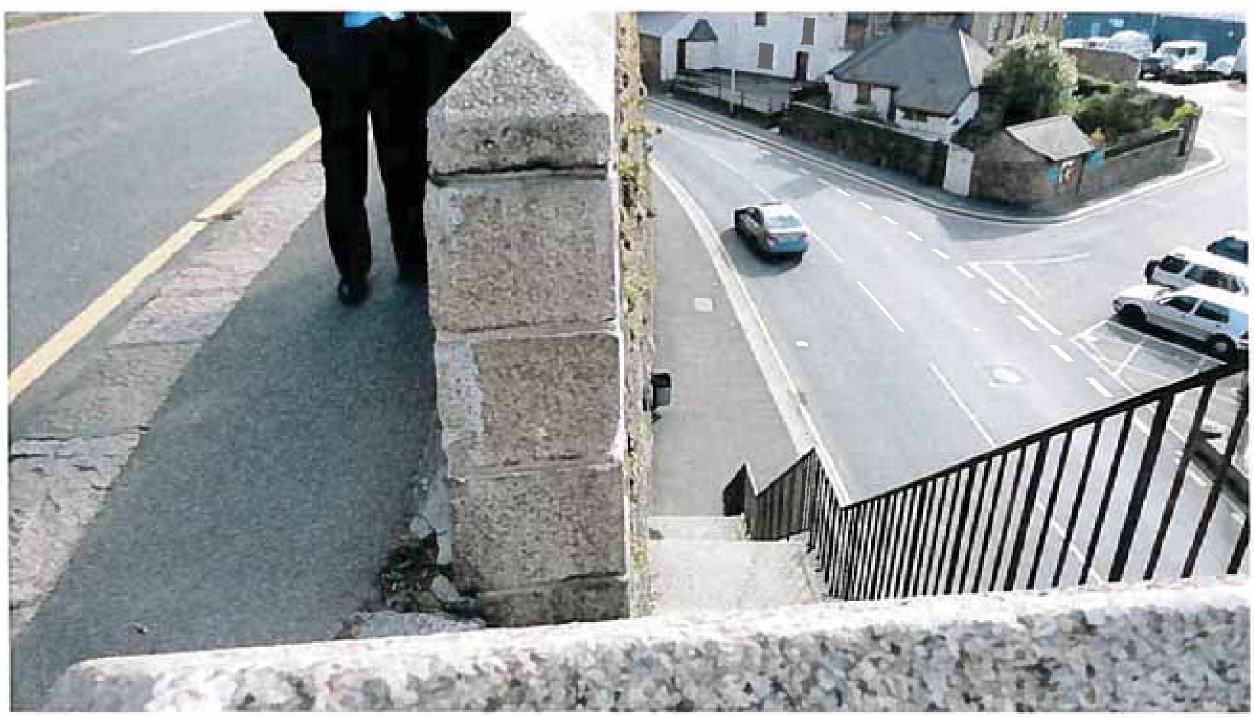


Fig 16

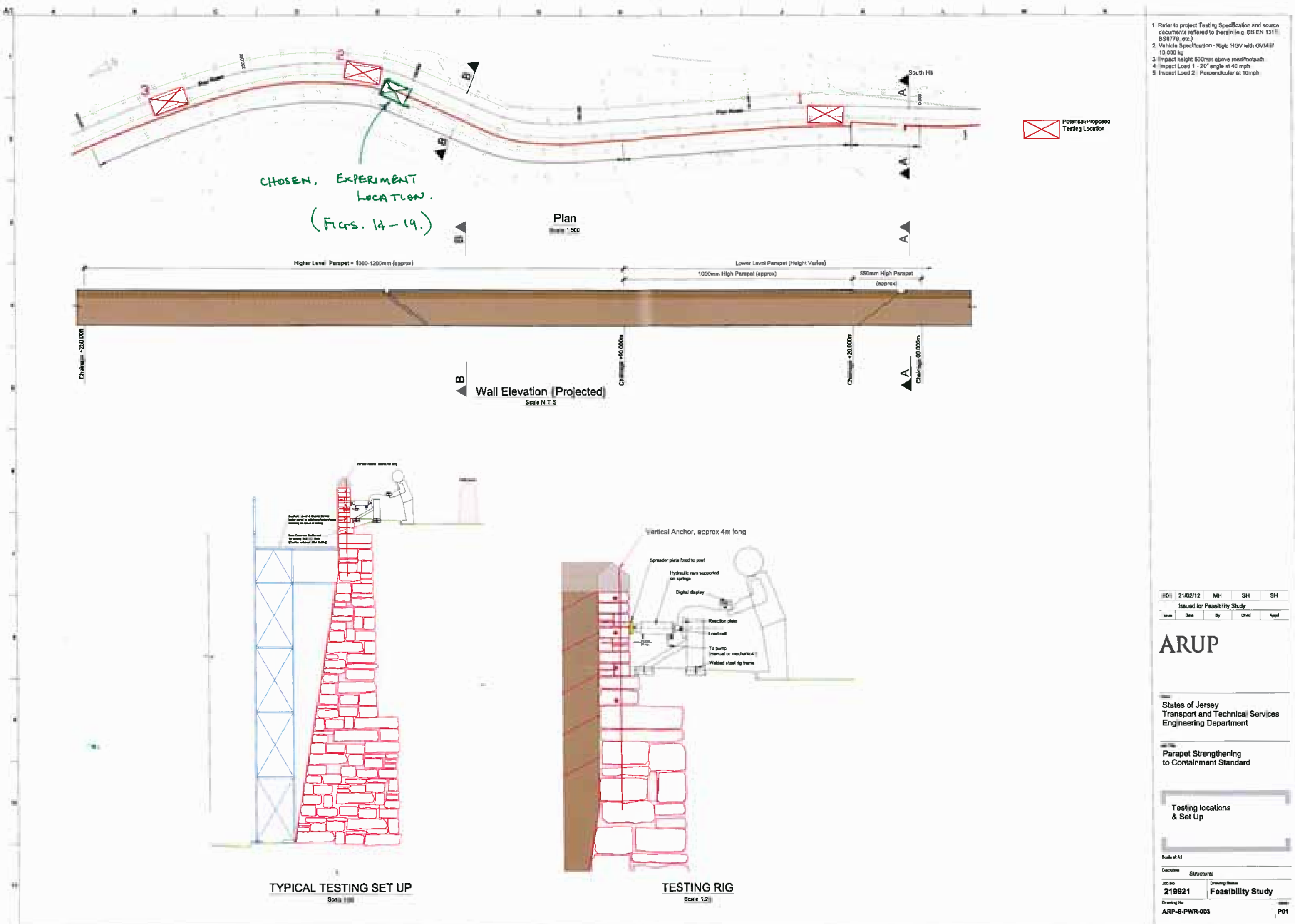
Pier Road

Fig 17

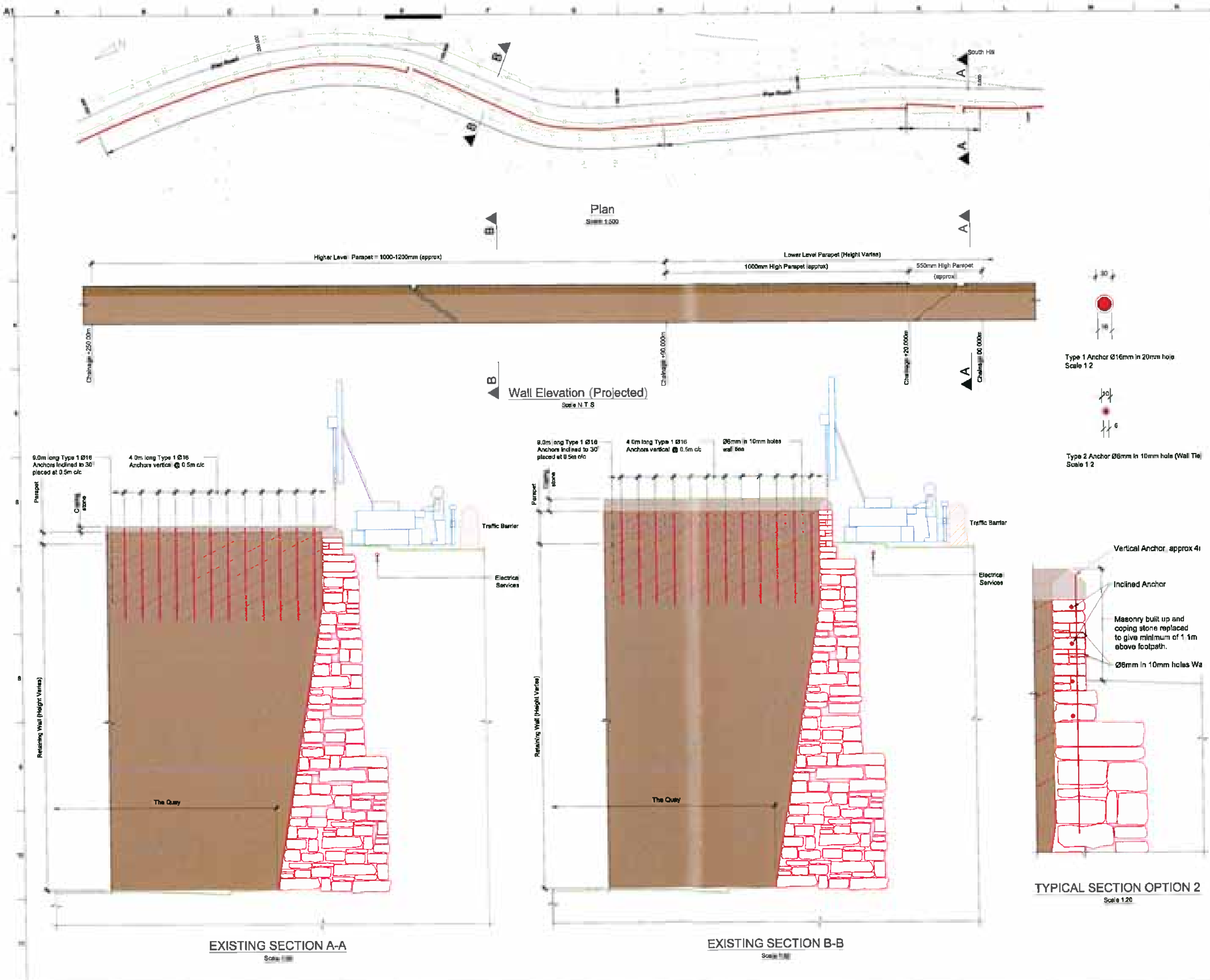
Fig 18

Pier Road

Fig 19



1 Refer to project Testing Specification and source documents reffered to therein (e.g. BS EN 1317, BS6779, etc.)
2 Vehicle Specification - Rigid HGV with GVM of 10 000 kg
3 Impact height 600mm above road/footpath
4 Impact Load 1 - 20° angle at 40 mph
5 Impact Load 2 Perpendicular at 10mph
South Hill
Potential/Proposed Testing Location
CHOSEN, EXPERIMENT LOCATION. (FIGS. 14 – 19.)
Plan
Higher Level Parapet = 1000-1200mm (approx)
Lower Level Parapet (Height Varies)
1000mm High Parapet (approx)
550mm High Parapet (approx)
Wall Elevation (Projected)
Scale N T S
Vertical Anchor, approx 4m long
Spreader plate fixed to post
Hydraulic ram supported on springs
Digital display
Reaction plate
Load cell
To pump (manual or mechanical)
Welded steel rig frame
TYPICAL TESTING SET UP
TESTING RIG
P01 21/02/12 MH SH SH
Issued for Feasibility Study
Issue Date By Chkd Appd
ARUP
States of Jersey
Transport and Technical Services
Engineering Department
Parapet Strengthening
to Containment Standard
Testing locations
& Set Up
Scale at A1
Discipline Structural
Job No 219921
Drawing Status Feasibility Study
Drawing No ARP-S-PWR-003
P01



Notes:

1. Coping can be removed for main drilling exercise & coping hole drilled seperately
2. Masonry must be built up prior to drilling

Issue	Date	By	Chkd	Appd
P01	21/02/12	MH	SH	SH
	Issued for Feasibility Study			

ARUP

Client
States of Jersey
Transport and Technical Services
Engineering Department

Job Title
Parapet Strengthening
to Containment Standard

Proposed Option 2
Paratec Strengthening
Anchors

Discipline: Structural

Job No: 219921

Drawing Status: Feasibility Study

Drawing No: ARP-S-PWR-003

Issue: P01

1. Contract Sum Analysis

1.1. Drawings Received

- Parapet Strengthening to Containment Standard – Proposed Option 2 Paratec Strengthening Anchor – Job No. 219921 - Drawing No. ARP-S-PWR-003 – Issue P01
- Parapet Strengthening to Containment Standard – Testing Locations and Setup– Job No. 219921 - Drawing No. ARP-S-PWR-003 – Issue P01

1.2. Bill of Quantities

Our bill of quantities can be found below:

Item Number	Description	Rate	Quantity	Unit	Total
1	Mobilisation, setup and Traffic Management		1	Sum	
2	Supply and Installation of CINTEC anchors (11nr 200mm wall ties, 12nr 4m anchors, 11nr 9m anchors)		1	Sum	
3	Static Load Test		1	Sum	
4	Masonry works (Coping works/repointing)		1	Sum	
5	Additional CINTEC ties to fix coping stones			Per anchor	
				TOTAL	