Sea defences - friend or foe?

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Introduction: Water has been said to be the greatest enemy of the Permanent Way Engineer, even more so where a railway is alongside the sea. Although sea defences provide vital support and protection to the railway, there is a darker side! They are prone to failure, vertical walls in particular cause beach scour and hard defences prevent coastal erosion and hence in some instances have a negative environmental impact.

In this article John looks at various examples of sea defences, the problems they can have and some solutions which have been applied.

TYPES OF DEFENCE

1. Sea Walls: Built usually to form a bench for the railway between the sea and adjacent cliffs which are typically weathered and unstable. Constructed of masonry or concrete and either built vertically, inclined or concave to deflect waves. (See figure 1).

2. Revetments: Embankments, usually alongside estuaries that are protected from wave action erosion by stone pitching placed on the seaward side. An example of a revetment is the Capes Head embankment on the approach to Leven Viaduct in Cumbria, which was built by James Brunlees in 1855 and varies in height from 4.5 - 7.6 metres (15ft to 25ft). The viaduct carries the Carnforth to Barrow section of railway over the Leven river estuary. (See figure 2).

The construction of the revetment comprises sand which is covered on the seaward face with clay, rid and stone pitching not less than 1200mm, (4ft), thick. The pitching extends 915mm, (3ft), below the beach level and is 450mm, (18ins), thick at the bottom and 305mm, (12ins), thick at the top. (See figure 3). Revetments can be either open jointed or mortared. However, by sealing the surface the latter may do more harm by increasing wave-suction on the face of the revetment.Glan Conwy revetment, on the Conwy estuary has been larried, (plastering term), on the surface with concrete as have other defences in North Wales. This provides a good wearing surface but can eventually become detached in large slabs, which as well as exposing the underlying structure are unsightly and cause environmental problems.

3. Groynes: Post and plank walls perpendicular to the coast which prevent loss of beach materials caused by a phenomenon known as long-shore drift. Groynes are particularly effective on holiday beaches for retaining sand. They also provide a good depth of beach material, which reduces wave height and hence damage from wave action.

The railways used these extensively at one time constructed, (not surprisingly), of bullhead rail and greenheart timber. A number have fallen into disrepair as at Old Colwyn in North Wales, in most cases partly due to the problem of maintaining an asset which is usually on someone else's land, and partly due to the use of rock armour as a preferred method of protection. (See figure 4). There may also be issues around 3rd party liability. Groynes may come back into favour since by retaining beach material as a form of defence they offer a good environmental solution, though the use of greenheart timber as planking needs to be considered for sustainability. Alternative materials such as recycled plastic may be an answer.

4. Shingle Banks: These comprise a beach which is protected by pebbles or small-to-medium-sized cobbles, as opposed to sand. Size of the stones is likely to be in the range between 2mm to 200mm, (0.1 to 7.9 ins), diameter. The banks are usually steep as the waves readily flow through the coarse, porous surface of the beach. This reduces the effect of backwash erosion and increases the formation of deposited material to form a steep slope.

Figure 1: Nuclear flask train passing along the sea wall at Parton, Cumbria.

Figure 2: Revetment at Capes Head embankment.

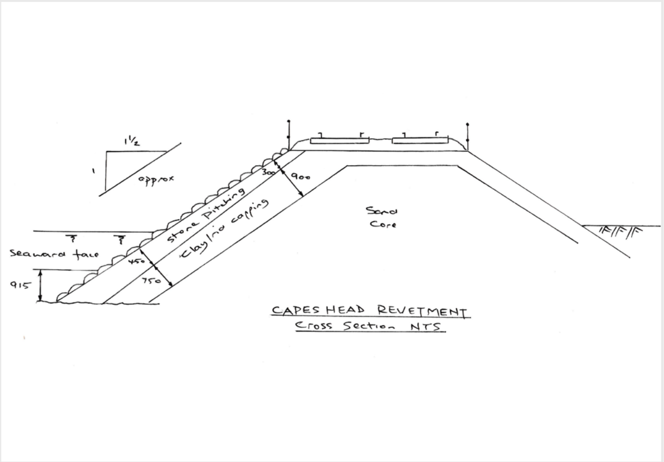

Figure 3: Cross-section through Capes Head embankment.

Figure 4: Groyne in degraded condition.

Shingle banks offer one of the best forms of sea defence by absorbing wave energy and reducing the depth of water and hence wave height on the upper beach. However, they do require significant maintenance involving replenishment of stone and reprofiling after severe storms. The residents in the chalets at Nethertown in Cumbria, shown in figure 5, have maintained a shingle bank defence to mainly good effect over many years. This has in turn provided protection to the railway.

5. Salt Marshes: Salt marshes form as estuaries alter course over the years ie Kent and Dee. The slower moving water on one side deposit silts and sands and this gradually builds up to force the estuary further away from that side. The mud banks thus exposed are not regularly covered in sea water and hence sea grass establishes itself. These areas form ideal defences as even in storm conditions the water depth on them is shallow hence the wave height is low. They also become very environmentally sensitive areas, usually SSSIs for the bird life they attract. They are, however, very fragile formations and can be quickly eroded when the estuary changes course again as discussed later in this article. Most estuaries oscillate from one side to the other over a period of maybe 100 years. Kents Bank frontage from 1964 to now has changed from a sandy beach to a full salt marsh as shown in figure 6.

THE ENGINEERS: SOME HISTORIC EXAMPLES, PROBLEMS AND SOLUTIONS

George Stephenson in 1837 proposed a route to Scotland via the Cumbrian Coast with a causeway across Morecambe Bay, a tunnel under the Furness peninsular and a viaduct across the Duddon estuary, (the start of the approach embankment is still visible near Askham). This would have been spectacular! He was therefore the ideal man to act as consulting engineer when the Cumbrian iron works and coal mine owners were promoting the Whitehaven Junction Railway from Maryport to Whitehaven.

Figure 5: Shingle bank sea defence at Nethertown.

It was towards the end of Stephenson's life but his experience, mining background and knowledge of the route would all be attractive to the promoters, but expensive. The line was incorporated in 1844 and opened in 1847 one year before Stephenson died. In addition to the extensive sea defence works another structure of note was a timber trestle viaduct across the creek at Harrington. This was heavily repaired in 1860 and reconstructed in 1888 in the form that existed until 2004. Timber trestle viaducts were common on early railways as they enabled the lines to be opened quickly and cheaply. They were also a form of construction early engineers would be very familiar with from early colliery days. (See figure 7).

The line was problematic from early days with the loco crews naming the Parton Sea Brows section 'avalanche alley'. In 1852 there was also a serous washout at 1MP when 23 metres, (30yds), of wall was lost. This was rebuilt with granite setts inclined at a steep angle.

Robert Stephenson In 1846 he was busy with the construction of the Chester – Holyhead Railway and particularly the sea wall at Llanfairfechan, 183 metres, (200 yards), of which failed following a storm in October of that year. He replaced that section with a viaduct initially with CI beams forming the spans. Brick arches were substituted in the late 19th century. (See figure 8). It was also found necessary to drive timber piles 4.5 metres, (15ft), from the wall to prevent scour to the foundations as the work progressed, a problem that exists to this day. It is interesting to reflect on Robert Stephenson's thoughts at this time as recorded in 'Lives of the Stephensons' by Smiles:

'Mr Stephenson confessed that if a long tunnel had been made in the first instance through the solid rock a saving of from £25k to £30k would have been effected. He also said he had arrived at the conclusion that in railway works engineers should endeavour as far as possible to avoid the necessity of contending with the sea. But if he were ever again compelled to go within its reach he would adopt, instead of retaining walls, an open viaduct, placing all the piers edgeways to the force of the sea, and allowing the waves to break upon a natural slope of beach'

He was ready enough to admit the errors he had committed in the original design of this work, but said he had always gained more information from studying the causes of failures and endeavouring to surmount them than he had done from easily won successes. Whilst many of the latter had been forgotten, the former were indelibly fixed in his memory. According to Smiles, Stephenson estimated the force of a wave as 144 to 190 kNm-2 (1.5 to 2 tons/sq ft), he also said that the lighthouse engineer Stevenson had measured a force of 290 kNm-2, (3 tons/sq ft) in the Atlantic at Skerrymore.

William Cubitt, Engineer to the South Eastern Railway was responsible for the Folkestone to Dover section, which was the first coastal railway completed. This was a heavily engineered section of railway 16 Km (10 miles) long, with 3.2Km, (2 miles), of sea walls, 3 tunnels totalling the same distance, and including the notorious slip prone Folkestone Warren.

The last section was built on a timber trestle viaduct 235m, (257 yds), long across the beach. The viaduct was remarkably resilient, lasting for 85 years until 1927 when the Southern Railway protected the structure with a sea wall and infilled it with chalk spoil.

On Christmas Eve 2015 sink holes were reported on the structure and the line was closed. Consultants Tony Gee and Partners looked at various options to remedy the problem which appeared to be caused by fill settling/ leaching from the structure. The preferred option was a piled concrete ground slab similar to a more recent scheme at Eden Brow on the Settle to Carlisle line and protected by sheet piles and rock armour. The £40m scheme had a 12-month construction phase.

Isambard Kingdom Brunel engineered his South Devon Railway as an atmospheric railway, and chose a coastal alignment to avoid heavy engineering works that would have been necessary for an inland route. From opening in 1846 the frontage at Dawlish has been subject to continual damage including four breaches by 1860. This has continued into this century with the recent well publicised failure in December 2015.

The sea wall is prone to overtopping and is backed by weathered sandstone cliffs, but has the added problem that it is fronted by a popular holiday beach which precludes standard sea defence solutions such as rock armour. The wall is also topped by a public footpath. (See figure 9).

Figure 6: Kent's Bank salt marsh.

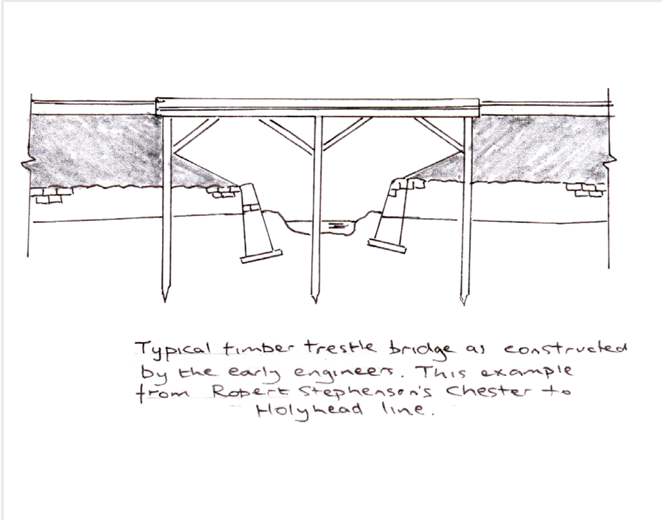

Figure 7: Example of a timber trestle bridge.

Figure 9: Reconstructed sea wall at Dawlish.

Figure 8: Viaduct at Llanfairfechan.

Figure 10: Wave action at Parton Sea Brows.

A budget of approx £600k a year is spent by Network Rail on continual maintenance, including underpinning the sea wall. Annual inspections are carried out together with periodic ones especially after storm conditions. This process of examination and maintenance of the sea wall was managed locally from Exeter where Peter Haigh was the engineer responsible for many years. There is a plaque commemorating Peter on the footbridge at the western end of Dawlish.

Following a recent feasibility study BAM Nuttall are now on site (Feb 2021) constructing the chosen option which is a partial reconstruction and raising of the sea wall with precast concrete units. Work has progressed from the west end to just beyond Dawlish Station.

CASE STUDIES

Parton Sea Brows: This section of coast is particularly prone to storm damage as seen from the failures soon after construction. The main causes of failure are wave overtopping forming sink holes in the cess, and erosion of the rock foundation allowing sea water to wash out fill material from behind the wall. (See figure 10). Historically, ad-hoc repairs have been carried out over the years usually involving filling sink holes and pouring concrete to seal the base of the wall.

This section of route was singled c1970 due to historical problems with the stability of the cliff face on the up side, which consists of sandstone inter-bedded with mudstone and dipping towards the sea. It is prone to erosion in this exposed location resulting in undercutting to and toppling failure of the sandstone blocks. The rock is also overlaid with glacial deposits supplemented over the years with spoil from industrial processes including mining. These continue to form slips resulting in earth flow down over the rock face to cess level.

The original singling scheme allowed for the construction of an H pile and sleeper rock trap wall which protected the remaining down (single line). This however needed regular possessions for the removal of debris from behind the stockade which was then tipped into the sea.

In the early part of this century, rock armour protection was put in place at this location and has prevented further failures. Major re-grading and drainage works above the cliffs have drastically reduced the number of rock falls and a recent extensive rock netting scheme has enabled the rock trap wall to be removed.

St Bees: The St Bees sea defence in Cumbria suffered many failures during the late 20th century. This was due to voiding beneath the stone pitching which had weakened the structure over time. It was always essential to start repairing damage at low tide before further loss of pitching on subsequent tides. In figure 11 the void is being filled with rock armour before sealing with concrete. However the solution was not always that neat, quite often scrap concrete units were used and on one infamous occasion redundant ‘brutes’ (parcel trolleys) from Carlisle station filled with concrete!

With the advent of Railtrack a decision was taken to tackle some of the longer running structural problems such as St Bees. Following a feasibility study a contract was let to Christiani Neilsen to reconstruct the defence with a low level rock armour defence and upper slope erosion protection. Access was naturally required along the beach which had belonged to BR but following privatisation now resided with BR residual who were just in the process of selling it by auction. It was therefore necessary for Railtrack to bid for it, and eventually ownership of the beach was secured for the benefit of the railway.

The rock armour was placed first and used as a platform for the upper works. There may have been a more cost-effective solution than concrete revetment blocks, but they provided a reasonable appearance and will last a very long time. (See figure 12).

Figure 11: Repairs to the sea wall at St. Bees.

Figure 12: Upgraded sea defences at St. Bees.

Figure 13: Lord Vivian’s Embankment.

Figure 14: Construction of rock bund at Micklam.

Lord Vivian's Embankment: This is an unusual location where a railway sea defence protects third-party property. Lord Vivian's Embankment in Flintshire, North Wales, pre-dated the railway and it is likely that as part of the agreement for allowing passage of the railway he transferred responsibility for the embankment to the Chester and Holyhead Railway.

Many years ago the salt marsh in front of the revetment was several hundred metres wide but as the River Dee altered course the salt marsh was eroded at an alarming rate. With the main channel so deep there was a serious concern that the estuary would eventually undercut the revetment and collapse it. (See figure 13).

To quantify the risk trial holes were dug to find the toe of the stone pitching, and fortunately the depth of it was such that undermining would be unlikely. This confirmed that the estuary had been hard up against this defence in past times, hence the need to build it. It also shows how fragile a salt marsh is, when accretion is taking place as at Kents Bank it reduces maintenance of sea defences, but erosion on the scale of the Dee at Lord Vivian's Embankment can quickly increase maintenance budgets and risk to railway infrastructure.

It is therefore important to monitor changes in salt marshes to understand, in advance, when preventative work is likely to be required.

Micklam Slip: The deep-seated slip at Micklam in Cumbria has been an on going problem for track engineers, who have frequently had to realign track distorted by ground movement. An historic solution was to weight the toe of the slip with scrap concrete units, mainly sleepers. This was reasonably effective, but the sleepers were not heavy enough to withstand the full force of the Irish Sea and over time ended up spread across the beach. This was undesirable for a number of reasons, being very unsightly and a risk to members of the public as the concrete eroded and exposed reinforcement strands, and the loss of the sleepers obviously weakened the defence.

Work was initially undertaken to contain the sleepers by constructing a rock bund along the frontage. (See figure 14). This proved to have additional benefits by trapping beach material behind it, forming a raised platform in front of the defence which absorbed and reduced the effect of wave action.

The whole frontage has since been rebuilt and strengthened using material from the recycled sleepers and rock armour. The use of scrap concrete and building materials to strengthen sea defences is not new. A scrap concrete beam from West Allerton forms part of the sea defence near Askam. This was from demolition work done as part of the West Coast Main Line modernisation works in the 1960s.

Another example is where rubble from bomb damage in Liverpool during WW2 was used by the local authority to strengthen the coast near Formby.

Siddick: The railway here is on a level coastal strip near Workington in Cumbria, and historically no defence was provided. The stony beach was regularly supplemented with waste from coal mining and the steel industry which formed a protection from the sea. With the decline of industry and a more environmentally aware society this practice stopped. (See figure 15).

The frontage was then subject to fairly rapid erosion resulting in the substantial damage in 1977 detailed in Mike Chorley's paper 'The Great Washout', which was published in the PWI Journal in 1984, (Vol 102 part 2). Initially a gabion defence was provided, and as this deteriorated concrete was cast to protect the gabions. In this exposed location the scour effect of the sea undermined the defence and made it necessary to construct a rock defence in early 2000s. However, erosion continues to the north along this very open and level stretch of coast which extends all the way to Flimby. This is an example of a defence growing in a reactive way.

It is interesting to note that the weathered blast furnace slag on the Cumbrian beaches is now considered of historic interest and should not be removed!

Nethertown: The toe of a railway embankment can have adequate protection from coastal erosion provided by rock armour held in place on the rock shelf by steel pins. However the upper slope can still be vulnerable to erosion by wave over topping or run off from the fields on the higher ground inland of the railway. A cost effective solution is to grade the upper slope, place 150mm of Type 6G stone and retain it with rock netting, (See figure 16). This solution could have been used at St Bees but the design life is probably only 30 years due to corrosion of the netting and settlement of the stone.

To close on a high, I once said that looking out over the lagoon at Nethertown on a sunny day was as good as anywhere. A colleague remarked I should get out more, which was probably true!

CONCLUSION

High risk sea defences should be identified by examination, monitoring and viewing historical records; in fact the history of a structure can often reveal more than mere observation. A management strategy can then be put in place.

Lower risk defences should be examined annually and additionally after severe weather as necessary. Any noted defects, especially loss of masonry blocks and voiding, should be rectified quickly to avoid rapid deterioration which can happen after consecutive tides when structures are exposed to wave action.

Finally, the words of Robert Stephenson are as true today as when he said he leant far more from his mistakes than his successes. Lessons can always be learnt to improve the outcome of future projects.

Figure 15: Exposed location at Siddick showing continual erosion.

Figure 16: Upper slope with 6G stone and rock netting at Nethertown.

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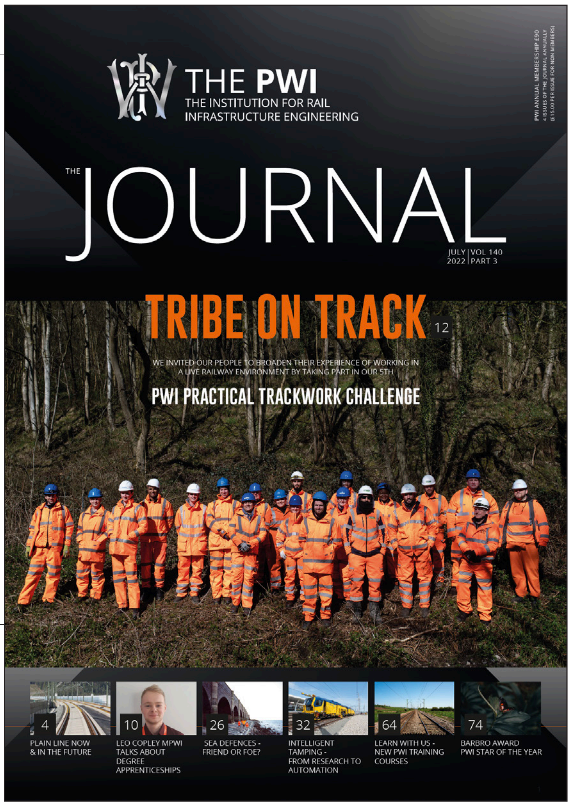

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