Coastal erosion at Friog and its consequences

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Summary

Protection of the shingle spit at Friog is essential to any larger flood protection scheme for the village of Fairbourne nearby.

In the past 30 years, problems of coastal erosion have developed at Friog. This has led to a series of interventions to prevent ingress of seawater due to overtopping or breach of the shingle spit by storm waves, or inflow of sea water beneath the concrete sea wall at high tide.

The underlying cause of these problems has been the narrowing of the natural shingle spit along the coastal section from Friog cliff to the northern end of the adjacent caravan park.

An immediate solution to water ingress at the caravan park is to extend a line of sheet steel piles to reach the Cambrian bedrock of Friog cliff. Ideally, this work should be accompanied by restoration of the original inland profile of the shingle spit at this point, where sediment had been excavated to provide flat ground for construction of a row of huts.

A further suggestion is made to increase the thickness of the shingle spit by emplacing a near shore reef of boulders or concrete blocks on the beach. Sediment would build up naturally in the sheltered water behind this structure, or shingle could be transferred there from the end of the Ro Wen spit, where it is carried by longshore drift.

1. Background

In 2014, Gwynedd Council announced plans to abandon and demolish Fairbourne village as a precaution due to predicted sea level rise. This plan was shown by several scientists to be unnecessary (Phillips et al., 2017; Buss, 2018; Hall, 2022).

Gwynedd Council now state that they have no plans to abandon the village (Fairbourne Moving Forward project board, 2022). Sian Williams of Natural Resources Wales (2021) states 'We are committed to maintaining Fairbourne's flood defences until 2054', but gives no indication of what decisions might be made after that date. However, the Fairbourne residents' primary objective of removing the demolition date for their village has been achieved.

Fairbourne village has not flooded within living memory. The last recorded flood occurred in 1926. An old photograph shows knee-deep water around the shops and railway station. This was not sea flooding, but was due to a severe storm over the mountains which caused the Afon Henddol to burst its banks.

Works were carried out 10 years ago to protect Fairbourne from river and estuary flooding. The estuary embankment north of the village was raised and strengthened, and the Afon Henddol was re-routed along a new channel around the village (Morgan, 2013).

Sea flooding has occurred around Friog corner, when the old sea wall failed during a storm in 2014. The adjacent caravan park was flooded (fig. 1). A replacement section of sea wall was constructed and has been protected by rock armour.

Figure 1: Failure of the eroded section of the Ro Wen shingle spit at Friog corner during a storm, causing localised flooding.

As a result of these schemes, Fairbourne is currently at no significant flood risk. The village is protected from the sea by the Ro Wen shingle spit, which is so massive that there is negligible risk of it being breached during a storm (Phillips et al., 2017). Photographs taken during major storms show no significant overtopping of the shingle embankment by waves, despite flooding occurring at other locations along the Welsh coast (fig.2). However, problems associated with coastal erosion still exist at Friog, to the south of Fairbourne village, and will be addressed in this paper.

Figure 2:

Flooding in Barmouth. Fairbourne, in the middle distance, is well protected by the Ro Wen shingle spit which has not been overtopped.

2. The Ro Wen shingle spit

The origin of the Ro Wen shingle spit can be traced back to the closing phases of the Ice Age. An ice sheet covered much of Wales, with glaciers flowing westwards to the present coast and beyond. A marine survey by Larcombe and Jago (1994) has identified a large off-shore moraine deposit extending from Barmouth to Fairbourne and Friog. This represents the terminal moraine of the Mawddach valley glacier.

Further sand and gravel was washed out from the melting ice sheets at the end of the glacial period, with finer material deposited in the shallow waters of Cardigan Bay to form a coastal plain. A relic of the former coastal plain can be seen at very low tides in Borth, where remnants of a former forest are exposed (fig.3).

Figure 3:

Remains of the submerged forest at Borth, exposed during exceptionally low tides.

A rise in sea level submerged the coastal lowland with its moraine deposits. Formation of the Ro Wen shingle spit was probably initiated around 6,000 years before the present. Wave action along the Welsh coast is dominated by storms from the Atlantic, approaching from the south west. This results in a movement of beach sediment by long-shore drift, which occurs in a northerly direction along the coast between Aberystwyth and Porthmadog.

After the retreat of the Mawddach valley glacier, lagoons developed along the southern shore of the estuary in sheltered water behind a series of rocky islands (fig.4). These pools filled with vegetation, and a coastal lowland developed between the current locations of Arthog and Friog. As a consequence, sand and pebbles which were carried along the coast to Friog could not enter the estuary and were directed northwards towards the river outlet at Barmouth, and the shingle spit began its development.

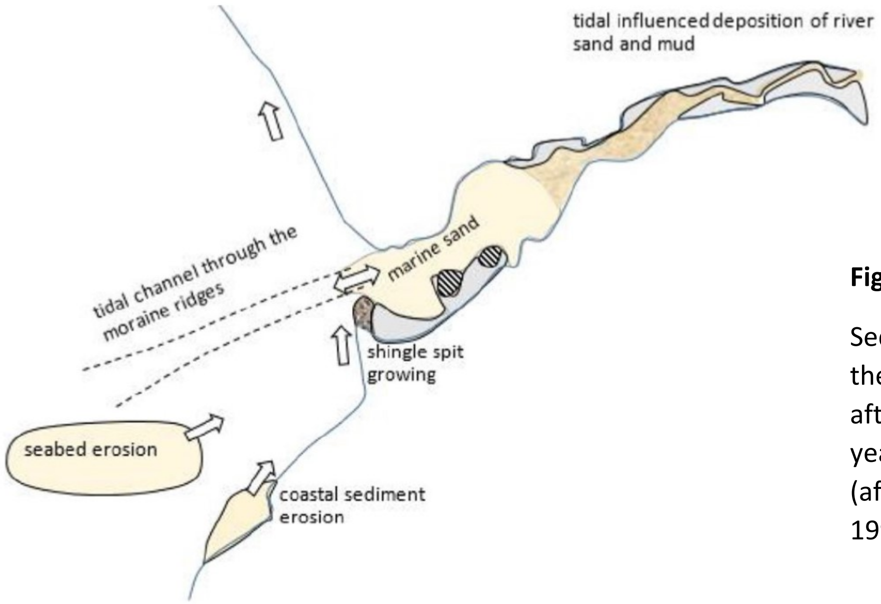

Figure 4:

Sedimentation around the Mawddach estuary after ice retreat, 6 000 years before the present (after Larcombe & Jago, 1994)

The source of shingle for the Ro Wen spit is the offshore terminal moraine, along with shingle transported by wave action from the low cliffs of glacial moraine at Llwyngwril. The spit was deposed on a base of estuary clay, lagoonal peat, and marine sand and gravel.

Figure 5: Structure of the Ro Wen shingle spit.

Sea defences

With the coming of the railways in Victorian times, holidays at the coast became increasingly popular. The entrepreneur Solomon Andrews was developing holiday resorts around Cardigan Bay and purchased land at the mouth of the Mawddach estuary to establish the resort of Fairbourne.

One of the works undertaken by Solomon Andrews was to excavate the crest of the shingle storm beach and emplace a concrete defence wall. This wall ran from the north of Fairbourne village to the cliffs at Friog, and was intended to stabilise the shingle spit before houses were constructed below the inland slope of the shingle embankment (fig.6).

Figure 6:

Photograph from about 1915 showing the sea wall constructed by Solomon Andrews to protect the newly established seaside resort of Fairbourne.

The wall seems to have been built by excavating a trench to a depth of around 5 metres, until the underlying sand, peat and clay was reached (fig.7). These deposits provided a more stable base for the wall than the storm beach shingle. The core wall is now covered by tarmac and forms the main walking route along the shoreline.

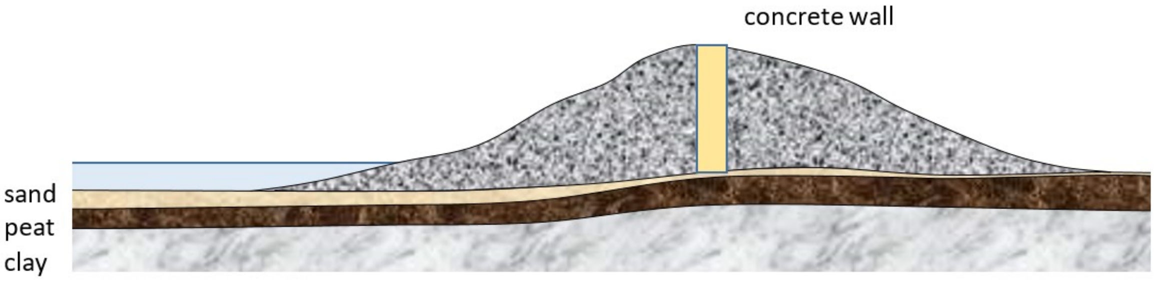

Figure 7: Core wall of the Ro Wen shingle spit.

Around 1975, problems occurred with wave overtopping during storms , and a side wall was added to raise the height of the storm beach crest (fig.8). The wall has had the beneficial effect of causing further shingle to accumulate on the top of the storm beach, where it is thrown by storm waves.

Figure 8:

Present day elevated crest wall constructed alongside the original sea wall to provide extra protection. Notice the accumulation of shingle against this structure.

3. Coastal erosion at Friog

A photograph taken in 1955 at Friog corner (fig.9) shows no evidence of coastal erosion. There is a wide expanse of storm beach shingle on both the seaward and landward sides of the crest line, which is marked by World War 2 anti-tank defences.

Figure 9: Photograph of the Ro Wen shingle spit taken in 1955. In the foreground is the row of huts at Friog corner, and the early development of the Friog Farm caravan park.

In the 1990s there was a breach of the embankment by the huts at the end of the sea wall. This was repaired by Natural Resources Wales and Railtrack, and the repairs appear at the time to have been very satisfactory (fig.10).

Figure 10: Repairs to the coastal defences at Friog corner, carried out in the 1990's. These works included the placement of rock armour along the line of the sea wall.

However, coastal erosion has continued at Friog corner, as seen from air photographs (fig.11).

2009 2021

Figure 11: Comparison of the extent of storm beach deposits at Friog corner (Google Earth).

Failure of the sea defences finally occurred at Friog corner during a storm in 2014. The Friog Farm caravan park was flooded to a shallow depth, along with neighbouring agricultural land, although Fairbourne village was unaffected (fig.12).

Figure 12: Flooding at Friog corner during a storm in 2014.

From the above photograph, it is possible to suggest the cause of the flooding:

There is little evidence of wave overtopping on a scale which could produce the volume of flood water seen.

In the foreground, water from breaking waves appears to be flowing horizontally ***between*** the cap wall and the core wall of the spit. Again, however, this would only occur for a relatively short period at high tide and would be unlikely to provide the volume of flood water observed at the caravan park and adjacent fields.

It seems probable that storm waves undermined the sediments forming the foundation of the core wall, causing this to subside and separate from the small crest wall. This movement could have provided a pathway for water to flow ***beneath*** the core wall, driven by a substantial hydraulic gradient at high tide (fig.13).

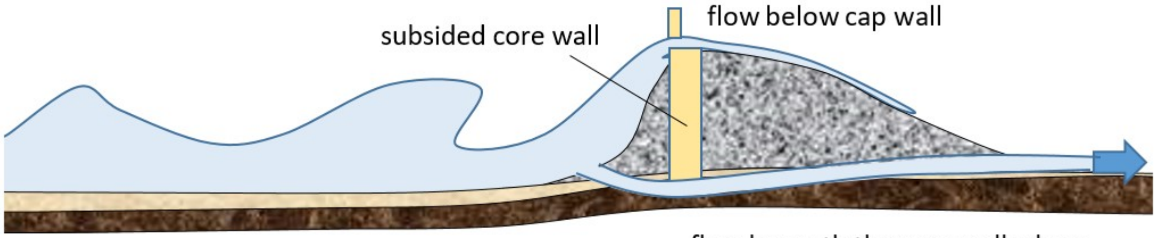

Figure 13: Suggested flood mechanism.

Causes of marine erosion at Friog

The primary factor leading to coastal erosion seems to be a reduction in the supply of shingle at Friog corner. This material is picked up by storm waves from the offshore glacial deposits, then carried onto the shore. It is possible that the available shingle source is now depleted, and insufficient shingle is reaching the shore to compensate for its northward transport along the spit by longshore drift.

Several years before the failure of the sea wall at Friog, measurements were made of the storm beach pebble sizes at points along the Ro Wen spit (fig.14). It was found that the pebble size at Friog corner was very substantially larger than at other locations.

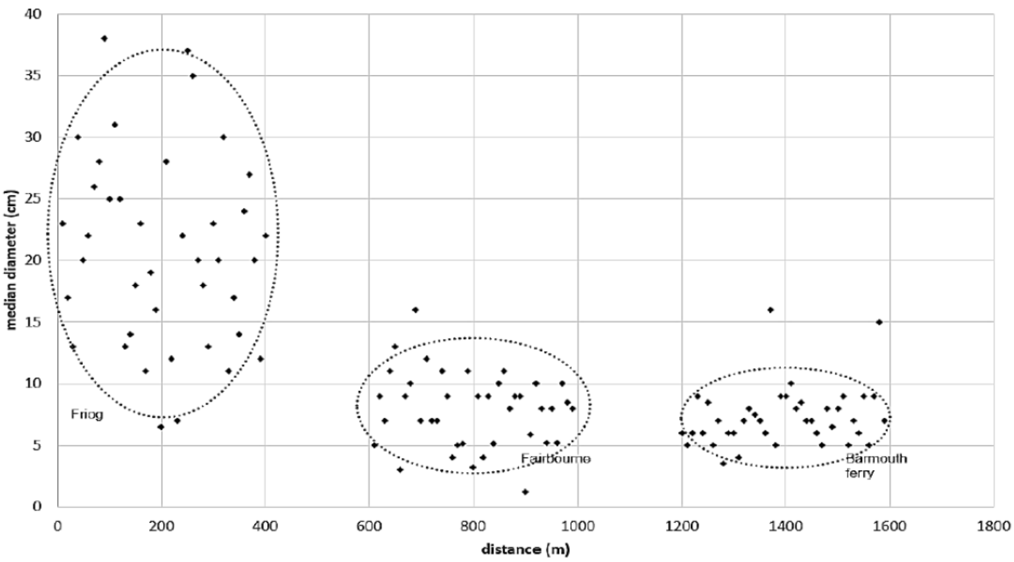

Figure 14: Sizes of random samples of storm beach pebbles at points along the Ro Wen spit.

Examination of wave action at Friog indicates that waves are refracted around the headland and approach directly towards the shore (fig.15). The geometry of the bay causes a strong water flow northwards parallel to the shore at this point. The powerful current is able to pick up and transport the finer shingle from the shoreface, leaving only the coarser cobbles in place.

Figure 15: Approach of waves at Friog corner, and redirection of the water mass along the spit.

The effect of sediment removal has been to steepen the angle of the remaining shingle storm beach at Friog corner.

It is known that waves break differently on gently and steeply sloping beaches (fig.16):

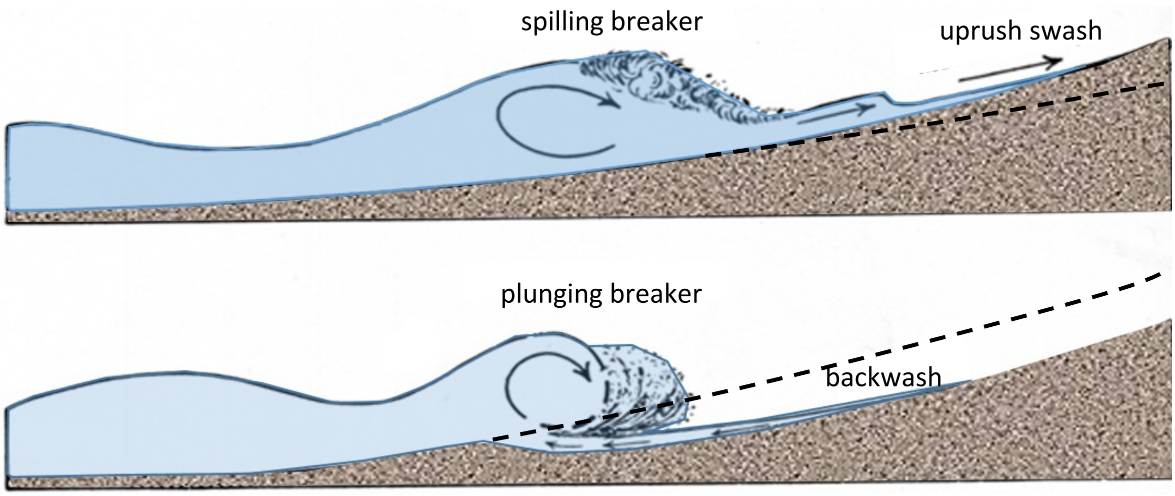

Figure 16a: (above) Constructive spilling breaker. **b**: (below) Erosional plunging breaker.

If the storm beach face has a gentle slope, rotational energy is removed gradually from the approaching wave and the motion of the water is predominantly in a forwards direction as the wave breaks. This produces a spilling breaker. The wave can pick up and transport sediment, encouraging deposition of sediment onto the storm beach.

If, however, the storm beach face slopes steeply, then waves will have lost less rotational energy by the time they break, creating a plunging breaker. The rotational energy of the water can carry sediment back down the storm beach face and erosion may occur.

As the storm beach became steeper, this encouraged further erosion by waves breaking by the plunging mechanism. In due course the base of the concrete core wall was exposed to erosion, leading to subsidence and water discharge beneath the wall.

4. Repairs carried out after the 2014 flood

Work was carried out by contactors Jones Bros, working to plans drawn up by Royal Haskoning civil engineers (Black and Veatch, 2019).

The first phase of the work involved replacement of the old sea wall with a more substantial concrete structure. This was then protected with rock armour placed at a surface angle of a little over 20^{o} (fig.17).

Figure 17: Replacement section of concrete sea wall in the foreground, with rock armour.

A second phase involved the emplacement of similar rock armour from Friog corner to the northern boundary of the caravan park (fig.18).

Figure 18:

Extension of the rock armour in front of the caravan park.

The replaced section of concrete sea wall is in front of the huts in the foreground.

In order to carry out this work, existing storm beach deposits were excavated to produce a shortened 20^o seawards slope. The excavated material is seen to be shingle along with grit and sand washed into the cavities between pebbles as seawater enters the shingle bank at high tide (fig.19).

Figure 19:

Work in progress to prepare the seawards slope of the shingle spit for emplacement of rock armour.

It was considered necessary to excavate into the underlying peat and clay to provide a stable foundation for the toe of the rock armour slope (fig.20).

Figure 20:

Peat layer visible above clay in an excavation to stabilise the toe of the rock armour slope.

After placement of a geotextile sheet, rock armour was placed on the prepared slope (fig.21).

Figure 21:

Work in progress to place the rock armour on the prepared seaward slope of the shingle spit.

Problems arising from the repair work

In February 2019, significant flooding occurred at the Friog Farm caravan park. This was at the time of a particularly high tide, but under normal sea conditions with no wave overtopping of the shingle storm beach. It was evident that water was flowing beneath the sea wall and emerging as a spring below the road (fig.22).

Figure 22: Flooding of the caravan park in February 2019. Water can be seen emerging onto the grass area to the right of the entrance gateway.

It appears that the sea water under high hydraulic pressure was able to flow through voids in the rock armour and small amount of underlying storm beach deposits to reach the base of the concrete core wall. Hydraulic flows then carried away fine sand and clay material to create soil pipes, which increased in diameter as water flows continued (fig.23).

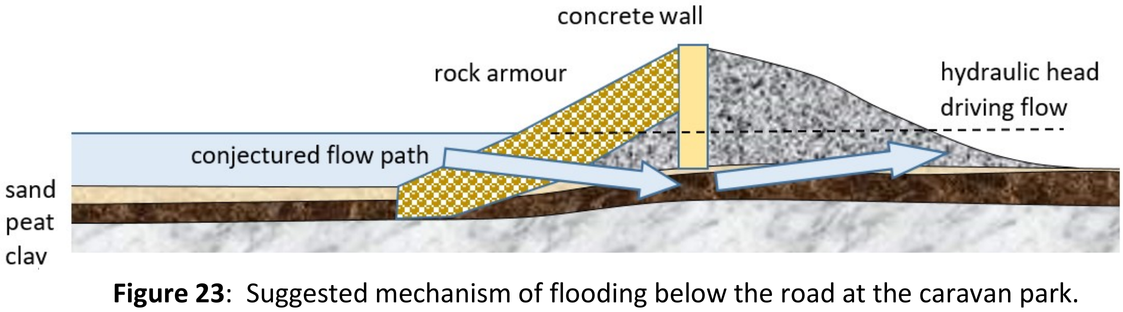

Figure 23: Suggested mechanism of flooding below the road at the caravan park.

A review was carried out by Black and Veatch (2019) to determine the design decisions which led to the flooding of the caravan park. It was concluded that it had been a mistake to remove such a large volume of natural shingle and underlying sediments (fig.24). There would have been less risk of throughflow if the rock armour had been placed on top of the existing shingle storm beach. It was stated that the Haskoning design did not consider the possibility of seepage occurring through the embankment.

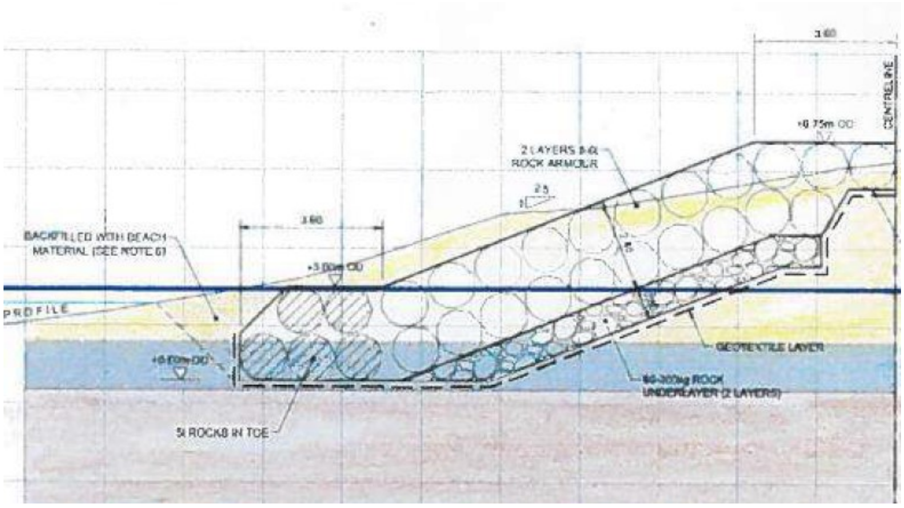

Figure 24:

Drawing showing the original beach profile (yellow), peat (blue) and clay (grey) , and the extent of excavation carried out before emplacing the rock armour.

To remedy the flooding problem at the caravan park, sheet steel piling was installed along the length of the caravan park on the landward slope of the shingle embankment (fig.25), approximately 1.5 metres up from the road and extending downwards into the peat layer. The piles were emplaced to a depth of approximately 4m below the level of the road.

This intervention has been partially successful. The severity of tidal flooding has been reduced. However, water appears to build up behind the piling at high tide and is deflected to either the northern or southern end of the line of piling, where it again emerges as springs which threaten the caravan park.

Figure 25: Location of the line of sheet steel piling, and observed water flows at the northern and southern ends.

At the northern end, water discharges into a drainage ditch which has been dug to receive it. At times of exceptionally high tide, the flow can be significant (fig.26).

Figure 26: (left) drainage ditch constructed in front of the caravan park to intercept groundwater flow through the shingle spit at high tide. (right) culvert discharging into the Friog drainage ditch network.

Groundwater can be seen to flow out of soil pipes under significant hydraulic pressure, as at the points marked in fig.27.

Figure 27: Groundwater seen to be flowing out of soil pipes (ringed in red) into the drainage ditch at the northern end of the caravan park..

The southern end of the line of piles stops just before a line of huts. Water appears to discharge around and below the huts, causing regular flooding of the adjacent parking area (figs.28 and 29).

Figure 28: typical extent of water discharge onto the parking area by the huts at Friog at high tide.

Figure 29:

More extensive flooding of the parking area at a high spring tide, with a risk of water entering the caravan park.

Flooding of the parking area becomes severe on occasions, and can overflow into the caravan park. The photographs were taken on days with no recorded rainfall, so cannot simply be the result of rainwater runoff.

During October 2023, after completion of the sheet steel piling, further flooding occurred in the central area of the caravan park (fig. 30). It is uncertain whether groundwater reached this area around the northern or southern ends of the line of piling, or whether goundwater was able to flow beneath the piles in the central area of the site.

Figure 30:

Tidal flooding of the central area of the caravan park, October 2023.

5. Engineering solutions

The objective of this paper is to propose engineering solutions on two time scales:

- Firstly, to address the immediate flooding problems at Friog Farm caravan park.
- Secondly, to work towards long term protection from flooding at Friog and reduce the risk to the whole Friog-Fairbourne area.

Flooding problems at Friog Farm caravan park

The problem of water resurgence at the northern end of the site has been partially resolved. The recently constructed drainage ditch collects groundwater, which is discharged into the Friog drainage ditch network. This then flows via the Afon Henddol to the Mawddach estuary. It is recommended that the line of sheet steel piling be extended northwards by about 20m to reduce the amount of groundwater flow into the caravan park, and redirect water directly into the Friog drainage ditch network outside the site.

The situation at the south end of the site around the line of huts is more serious, where the structure of the natural shingle spit has been severely compromised at Friog corner on both the landward and seaward sides.

Figure 31:

Rear of the huts at Friog, showing the substantial excavation of the landward slope of the shingle spit at this point.

It is understood that the huts were built before the Second World War to provide accommodation for railway workers. To do this, a substantial amount of shingle was removed to create a flat area for the hut foundations (fig.31).

Coastal erosion and subsequent repairs have led to a situation where nearly all the natural storm beach shingle has been removed and replaced by rock armour.

The consequence of these two factors has reduced the shingle spit to less than a quarter of its original width, providing short pathways for sea water to pass beneath the sea wall under a large hydraulic pressure during periods of high tide (fig.32).

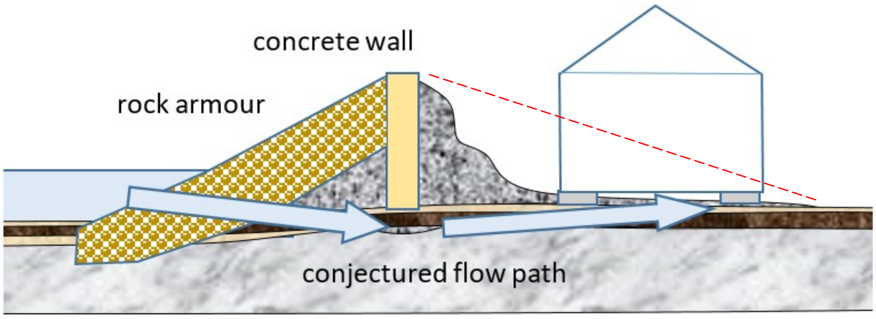

Figure 32:

Suggested pathways for sea water ingress beneath the sea wall in the area of the huts at Friog corner. The original landward profile of the shingle spit is shown in red.

Two possible solutions to the flooding at the south of the caravan park can be suggested:

(i) Relocation of the huts and emplacement of sheet steel piling.

The most satisfactory solution, which would have long term benefits for the flood security of the whole Friog and Fairbourne area, would be to move the huts back from the sea wall and reinstate the original landward profile of the shingle bank.

The huts are of light wooden construction (fig.33). They could be moved either by jacking up the base and moving the structure on rollers or trucks, or lifted with a crane. The huts could be repositioned on the existing parking area near the railway bridge.

Figure 33:

Huts at Friog corner.

After removal of the huts, the profile of the shingle bank can be reinstated using either beach shingle or locally available slate waste. This work is likely to reduce the flow of water under the sea wall by lengthening the hydraulic pathways. The increased mass of the embankment would also have the benefit of supporting the sea wall and protecting it from mechanical damage by storm waves.

It is recommended that the line of sheet steel piles is then extended along the newly created embankment to reach the Cambrian bedrock of the Friog cliff. The steel piles should be grouted into the rock to ensure a watertight join.

(ii) Simple emplacement of sheet steel piling

If arrangements cannot be made to move the huts, a less satisfactory alternative plan would be to extend the line of sheet piling across the car park in front of the huts, at a height of about 1.5m above the current ground surface (fig.34).

Figure 34: Huts at Friog corner after emplacement of sheet steel piles.

After emplacement of steel piles (fig.35), the steelwork can be concealed by a low stone wall, and the ground between the pile line and the huts made up with slate waste or gravel.

Figure 35:

Sheet steel piles of the type proposed for use at Friog corner.

Once one of these schemes has been carried out, there should be no further problems of groundwater flowing around the coastal defences at the southern end of the caravan park.

The area of most concern is the newly emplaced rock armour in front of the caravan park.

It is evident that sea water can easily enter voids between the large boulders (fig.36). At times of south westerly gales at high tide, waves are likely to reach the top of the rock armour slope and will fill interconnected channels through the boulder pile, producing about 5 metres of hydrostatic pressure in excess of the tidal level.

Figure 36:

Boulders forming the rock armour in front of the caravan park.

Hydraulic overpressure is demonstrated by the active flows of water leaving the base of the rock armour as the tide falls (fig.37).

Figure 37:

Substantial water flow from the base of the rock armour as the tide falls.

A significant observation is that tidal flooding of the caravan park requires a strong onshore wind to push waves high up the rock armour slope (personal communication: David Platt).

The conjectured mechanism for the continued tidal flooding is that high hydraulic overpressure generated within the rock armour is driving the flow of groundwater beneath the original sea wall and then around or under the line of sheet steel piles. The water discharges at lower hydraulic head inland of the road embankment. Continued flow carries away finer material to create soil pipes, making routes with less resistance to throughflow.

The strategy employed by the designer of the rock armour defences was to ignore and largely remove the natural protection provided by the storm beach shingle accumulation, and replace this with an engineered solution (see fig.24). The result has been to provide hydraulic connectivity from the top of the rock armour slope, through pathways between the boulders, down into the underlying sediments.

Investigations were carried out by Gwynedd Archaeological Trust (2010) in the Friog area. Excavated pits found typical estuarine deposits of peat, sand and clay. These materials are roughly layered, with organic peat content reducing with depth. The deposits have a greater sand content near the surface, being replaced by clay below a depth of one or two metres.

Figure 38: Sediments sampled at Friog. The excavated material shows a mixture of orange-brown sand and grey clay.

The environment of deposition of the sediment sequence is typical of the Mawddach estuary at the present day. The dynamic depositional environment creates a pattern of moving channels, interspersed with salt marsh vegetation which can provide an organic peat input to sediments. Sinuous zones of sand and mud occur alongside, above and below one another.

Figure 39:

Present day depositional environments in the Mawddach estuary. Salt marsh vegetation is cut by a complex pattern of channels through sand, with mud deposited on the channel floor.

The significance of these observations is that pathways of higher hydraulic conductivity can be intertwined through estuarine sedimentary deposits. Once water under pressure enters the sediments, it can move significant distances to a discharge point.

To reduce the occurrence of flood events at Friog caravan park, it is recommended that an attempt is made to return the rock armour to a more natural state. This could be done by tipping a layer of beach sand onto the top of the boulder slope, followed by a layer of shingle. This material should stay in place, as the unsupported rest angles for sand and shingle slopes are both higher than the 20^{o} slope of the rock armour.

The objective is to allow waves to wash sand and shingle into the voids between the boulders, gradually reducing the capacity for water flow through the boulder pile. By blocking the flow routes, this would reduce the build-up of hydraulic overpressure during storms, and would consequently reduce the driving force for water flow below the storm beach.

It is perhaps significant that Sian Williams of Natural Resources Wales (2021) has commented: “[There] is an increasing challenge as we work against the forces of nature to help reduce flood risk."

This seems to be entirely the wrong approach, replacing natural flood protection with engineered solutions. Flood protection agencies should be working ***with*** nature where possible, not against it.

6. Future protection of the shingle spit

The extreme narrowing of the Ro Wen shingle spit at Friog corner makes this a vulnerable point in the flood defences of the whole Fairbourne area. Whilst the sea wall repairs with rock armour are currently adequate protection against storm waves, further protection is really needed.

It is suggested that an inshore reef of rocks or concrete blocks is constructed at Friog (fig.40). This would deflect waves and reduce damage to the new sea defences during major storms.

Figure 40: Proposed artificial reef to deflect storm waves at Friog corner.

An area of calm water would be created between the reef and the shore, where shingle could be deposited for further coastal protection. This shingle may accumulate naturally, or may be brought from the end of the Ro Wen spit where it is carried by longshore drift.

Inshore reefs of boulders have been emplaced at the nearby coastal town of Borth (fig.41) as part of a coastal flood protection scheme. It is seen that shingle is accumulating behind the reef structures. In time, it is likely that shingle ridges will extend all the way to the reefs.

Figure 41:

Inshore boulder reefs constructed at Borth.

Shingle banks appear to be developing in the sheltered areas behind the reefs, as marked by the red dotted lines.

Vink (2023) carried out interviews with residents in Fairbourne as part of a study into the consequences of climate change. She observed ‘the lack of trust that most inhabitants have in the decision-making process at Gwynedd Council.’

It is perhaps time that Gwynedd Council restored the faith of the residents of Fairbourne by showing a commitment to the future of their village. Up to this point, coastal defence works have been largely ***reactive***, responding to problems which have arisen, rather than being ***proactive*** in putting in place defences to increase the future security of the village. Constructing stronger coastal defences at Friog would be an appropriate proactive scheme.

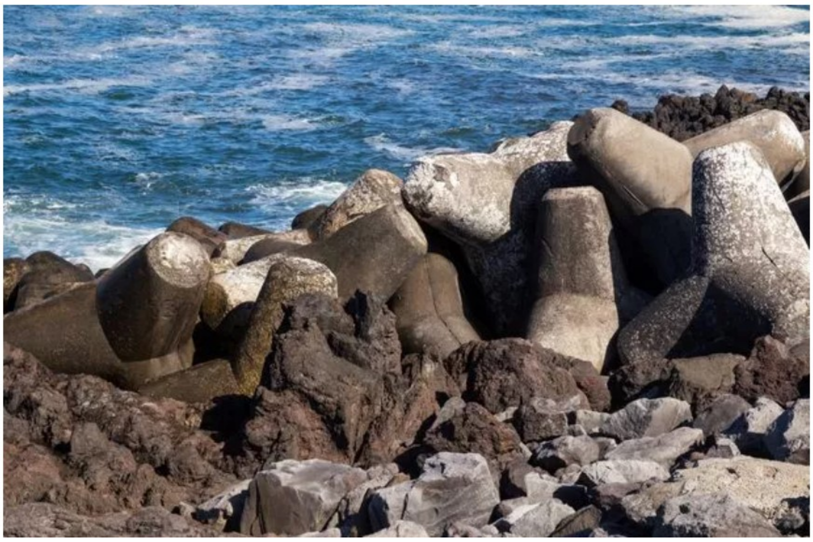

Figure 42:

Concrete tetrapods used in coastal defences.

It has been reported in the press (Forgrave, 2023) that local resident Stuart Eves is willing to organise the construction of an inshore reef at Friog using concrete tetrapods (fig.36), if Gwynedd Council and Natural Resources Wales are unable or unwilling to undertake the work.

If Mr Eves goes ahead with this scheme, a wave impact and sediment transport model, produced using industry standard coastal engineering software, can be supplied to accompany an application to the relevant authorities for permission to undertake the work.

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