Friog corner, where work has recently been carried out to repair and strengthen the sea defences.

Stability of the Ro Wen shingle spit, Fairbourne

Graham Hall May 2022

Summary

Gwynedd Council has made a decision to abandon and demolish the village of Fairbourne. The main argument supporting this decision is that devastating flooding of the village is inevitable, either from breaching of the Ro Wen shingle storm beach or overtopping by waves during a storm. The objective of this paper is to examine the validity of this argument.

Development of the Ro Wen spit began around 6,000 years before the present, as sand and shingle were carried northwards along the coast by longshore drift. The source of this material was from sea bed glacial moraine deposits and from the erosion of boulder clay cliffs.

Maps, photographs and survey data collected over the past century indicate that the profile of the Ro Wen spit has remained remarkably constant during this period. The majority of the shingle spit is stable and at no risk of failure during a worst case storm at the present day. The only area of concern is a small section at Friog corner where coastal erosion is taking place. Recent repair and strengthening of the sea defences at this point have been very effective, and there is currently no risk of failure. Recommendations are made for precautionary works which would eliminate the risk of any future failure of the sea defences at Friog.

The overall conclusion is that the shingle spit is at no risk of being breached during the next 100 years, and maintenance costs will be small.

A set of computer models presented in the document 'Fairbourne Preliminary Coastal Adaptation Masterplan' (Fairbourne Moving Forward Partnership, 2019) are shown to be based on false assumptions and are inaccurate. The modelling presented is invalid, and it should not be accepted as evidence for the necessity to decommission Fairbourne village.

Contents

1. Introduction

Fairbourne is a coastal community at the mouth of the Mawddach estuary in Cardigan Bay. The village is built on land reclaimed during Victorian times from salt marsh and reed beds behind the large shingle spit of Ro Wen.

Based on computer modelling, Gwynedd Council has made a decision to abandon and demolish the village of Fairbourne due to a perceived flood risk. The main argument for this decision is that devastating flooding of the village is inevitable, either from a breach of the Ro Wen shingle storm beach or overtopping by waves during a storm.

Schemes have been proposed which would protect Fairbourne village from flooding and would make decommissioning unnecessary. However, contrary to the opinion of Gwynedd Council, these schemes assume that the Ro Wen shingle storm beach is stable and will not be at any risk of failure during the coming century. The shingle storm beach will continue to provide adequate protection for the village during storms.

Regarding the safety of the Ro Wen storm beach, the opinions of the proponents of demolishing and of preserving Fairbourne are diametrically opposed. It is clearly essential to evaluate the scientific evidence concerning its stability.

The origin of the Ro Wen shingle spit in the period following the Ice Age is discussed. Evidence for the stability Ro Wen during the past century is then examined. Coastal processes relating to the formation and maintenance of the storm beach structure are considered, and interventions necessary to protect the Ro Wen shingle spit in the coming century are discussed. Finally, an evaluation is made of a series of computer flood models published by Gwynedd Council as evidence for the need to abandon Fairbourne village.

2. Origin of 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. During the Devensian maximum glaciation, an ice sheet covered much of Wales, with glaciers flowing westwards to a confluence with ice sheets moving southwards from Scotland (fig.1).

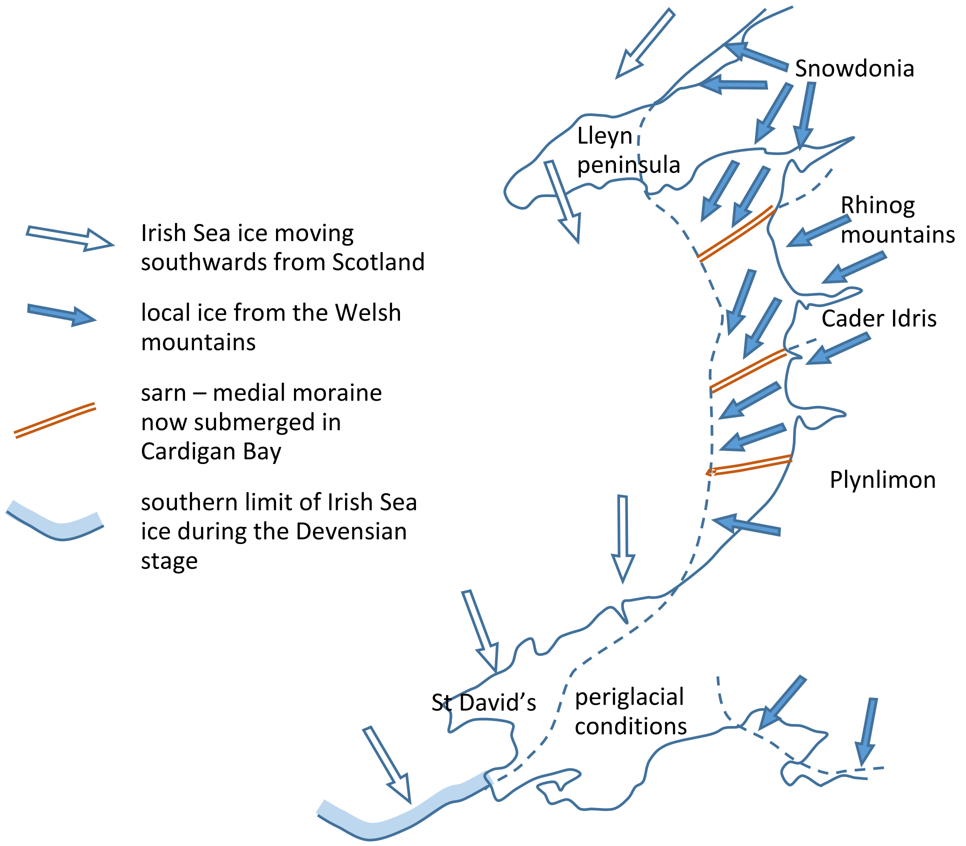


Figure 1:

Ice flows during the Devensian maximum glaciation of Wales.

A series of moraine ridges were deposited at the edges of major glaciers. These can now be seen along the Welsh coast at low tide, forming shingle bars known as 'sarns'.

After a warmer interglacial period when ice sheets receded, the final event of the Ice Age known as the Devensian valley readvance saw glaciers extending outwards from major valleys such as the Mawddach. On reaching the sea coast, the glacier decoupled from the valley floor. Rock debris carried beneath and within the ice could then be deposited as moraine (fig.2).

A marine survey by Larcombe and Jago (1994) has identified a large glacial moraine deposit off-shore from the Mawddach estuary (fig.3). Further sand and gravel was washed out from the receding ice sheets, with finer material deposited in the shallow waters of Cardigan Bay to form a coastal plain.

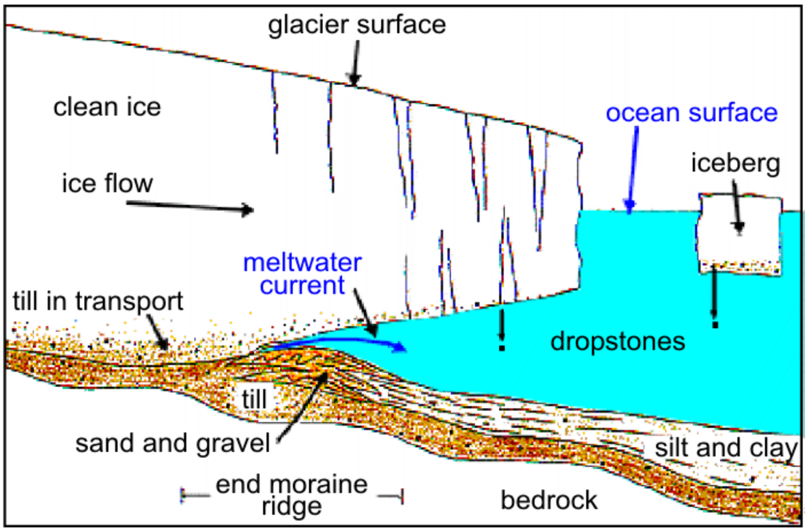


Figure 2:

Deposition of glacial sediments at the termination of a glacier flowing from land to sea.

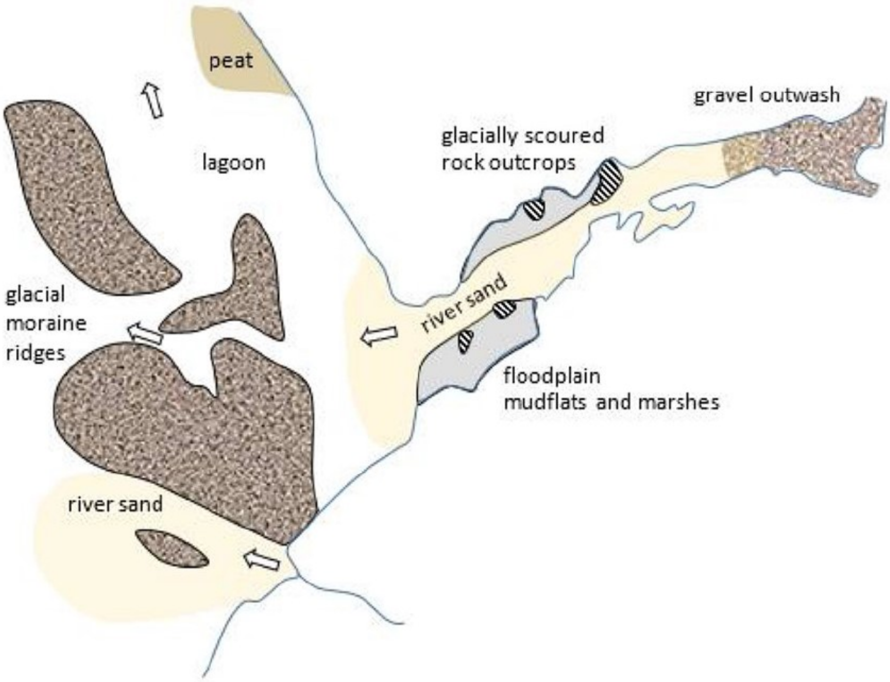


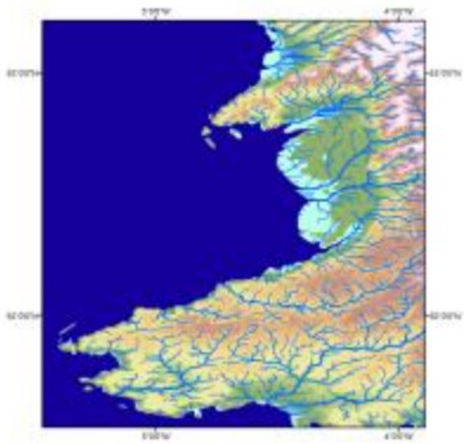
Figure 3:

Sedimentation around the Mawddach estuary in the late Devensian stage of ice retreat, 12,000 years before the present (after Larcombe & Jago, 1994).

Over the past 12,000 years, marine erosion and sea level rise have gradually reduced the extent of the coastal plain to create the present coastline (fig.4).

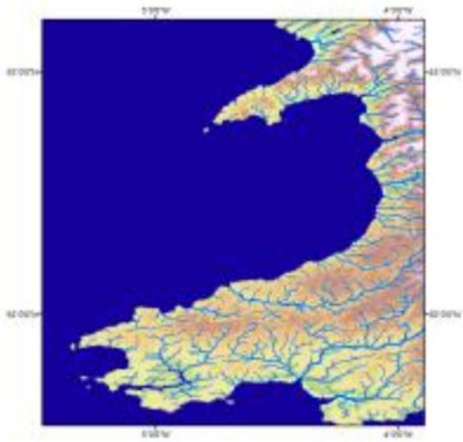
A relic of the former coastal plain can be seen at very low tides in Borth, where remnants of a former forest are exposed (fig.5)

(a) 12,000 years before the present.



(b) 10,000 years before the present.

(c) 8,000 years before the present.



(d) 6,000 years before the present.

Figure 4: Reconstructed coastal positions at different times since the final glaciation in Wales. Pale blue colour indicates the likely tidal range (Kavanagh & Bates, 2019).

Figure 5:

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

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 (fig.6).

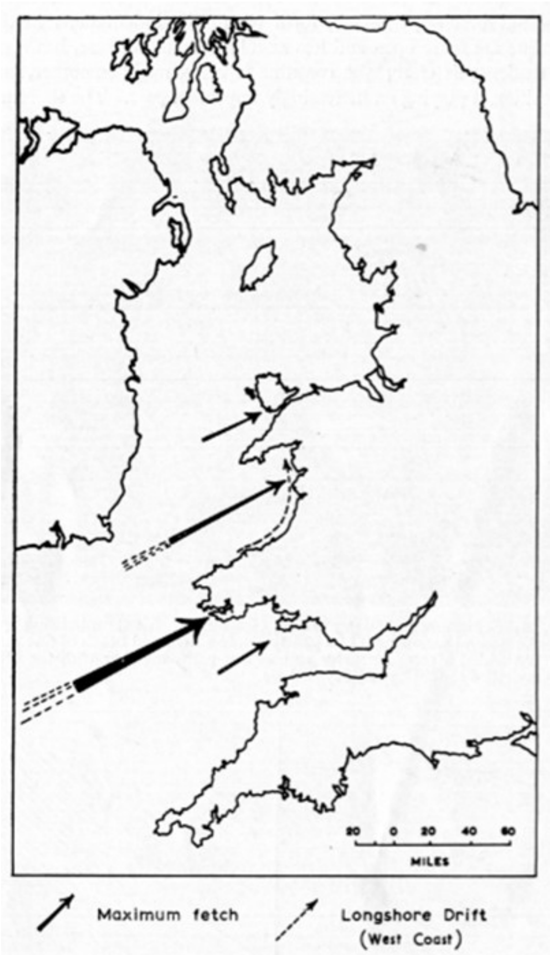


Figure 6:

Directions of maximum wave fetch around the Welsh coast, and the creation of long-shore drift.

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.7). 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.

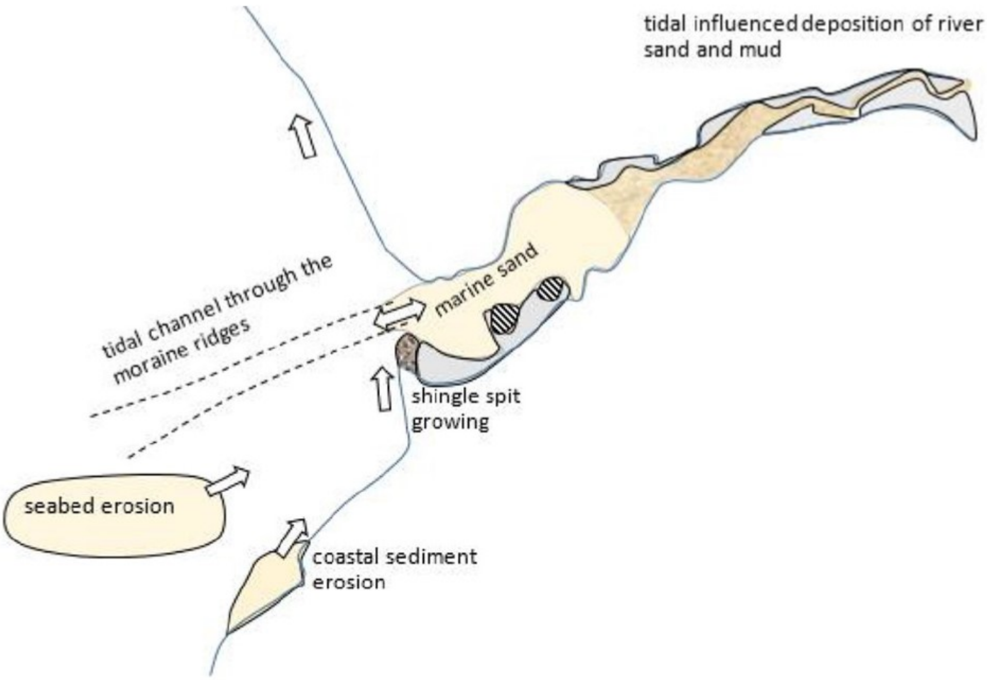


Figure 7:

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

Glacial material for the construction and replenishment of the Ro Wen shingle storm beach has come from two sources:

The first is rock material picked up by storm waves from shallow off-shore moraine deposits. This is similar to the coarse pebbles making up the sarns which extend into Cardigan Bay and are exposed at very low tides (fig.8). Originally deposited by glaciers, this material has now been reworked and sorted by waves and currents.

Figure 8:

Sarn Badrig moraine, exposed off the coast of Harlech during very low tides.

A second source of pebbles is from the erosion of soft boulder clay cliffs, which extend southwards from Fairbourne along the coast between Llwyngwril (fig.9) and Tonfannau.

Figure 9:

Glacial deposits in the cliffs at Llwyngwril.

The Ro Wen spit now extends for some 3km from Friog cliff, past Fairbourne village, to the mouth of the Mawddach estuary at Barmouth.

Fig.10 shows the Ro Wen spit as it approaches the mouth of the Mawddach estuary. At this point, the shingle bank is covered by sand dunes, produced as dry sand is blown inland from the foreshore at low tide by the prevailing south-westerly winds.

Figure 10: Sand dunes produced by windblown sand from the foreshore deposited above the shingle storm beach towards the northern end of the Ro Wen spit.

The foreshore at this point is predominantly sand, but a bank of coarse pebbles and larger rocks can be seen in the middle distance next to the water. Studies by Larcombe and Jago (1994) identified this deposit as a remnant of the glacial moraine deposited at the mouth of the Mawddach valley (fig. 11).

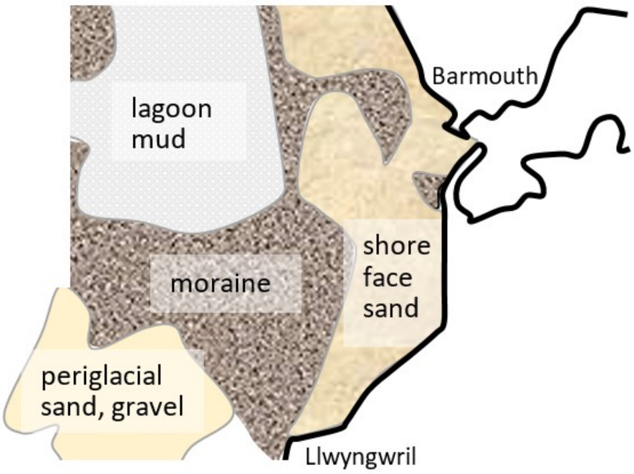


Figure 11:

Distribution of glacial deposits at the mouth of the Mawddach estuary.

It appears that the Ro Wen spit developed northwards from Friog cliff until the moraine remnant was reached. Further development of the spit has occurred at an angle caused by the movement of shingle into the estuary mouth during rising flood tides (fig.12).

Figure 12: Intertidal deposits at the mouth of the Mawddach estuary. Remnants of the Mawddach moraine are indicated by dotted outlines.

3. Stability of the Ro Wen spit

To help in assessing the stability of the Ro Wen shingle storm beach, we can examine historical records.

With the coming of the railways in Victorian times, holidays at the coast became increasingly possible and 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. To facilitate construction work, he set up a network of horse drawn tramways. One of these ran along the coast and was adapted to carry passengers as a visitor attraction (fig.13).
A similar line remains in use at the present day as the Fairbourne narrow gauge railway.

Figure 13:

Photograph from 1900, showing the horse drawn tramway built initially by Solomon Andrews during construction work at Fairbourne.

A map of 1902 (fig.14) shows the Ro Wen spit with a similar outline to the present day, except for a substantial accumulation of shingle which has subsequently occurred at the northern end of the spit.

Figure 14:

Map of 1902, showing the shape of the Ro Wen shingle spit closely resembles its shape at the present day.

One of the works undertaken by Solomon Andrews was to excavate the crest of the shingle storm beach and emplace a concrete defence wall (fig.15).

Figure 15:

Photograph about 1913 showing the sea wall constructed by Solomon Andrews to protect the newly established seaside resort of Fairbourne.

This wall, now covered by a tarmac path, has had a side wall added to raise its height (fig.16). This reduces any overtopping by storm waves, and has led to further accumulation of shingle on the top of the storm beach.

Figure 16:

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

Extensive surveying of the shore face profiles of the Ro Wen spit has been carried out by Professor M. Phillips and colleagues at University of Wales Trinity St David's. Data is available for the period 1991 – 2013. It was found that the shore face profile in front of Fairbourne village remained remarkably stable over this period (fig.17).

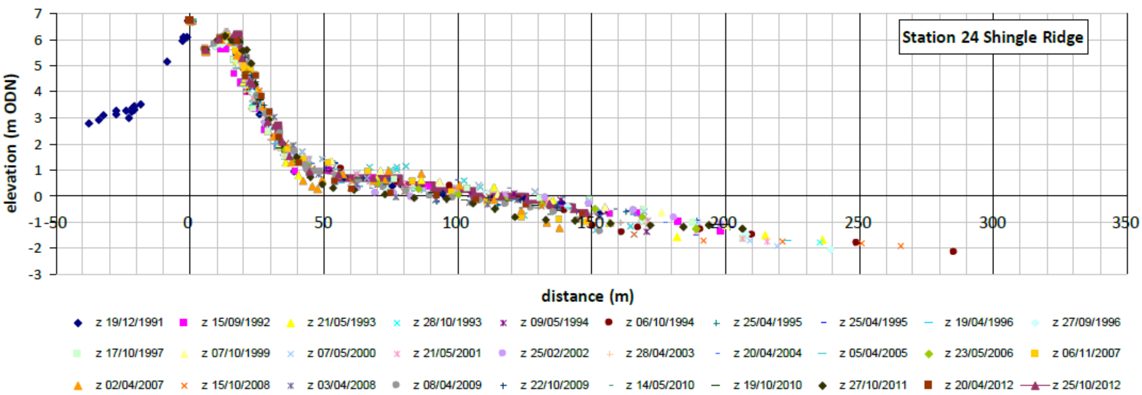


Figure 17: Monitoring of the storm beach profile in front of Fairbourne village over the period 1991 – 2012 (Phillips et al., 2017).

Work by Phillips et al. (2017) shows some variation in sediment volumes along the Ro Wen spit during the recording period. Whilst the profile in front of Fairbourne village is stable, the spit is slowly losing shingle at the southern end near Friog cliff, and gaining a similar amount of shingle at the northern end opposite Barmouth (fig.18).

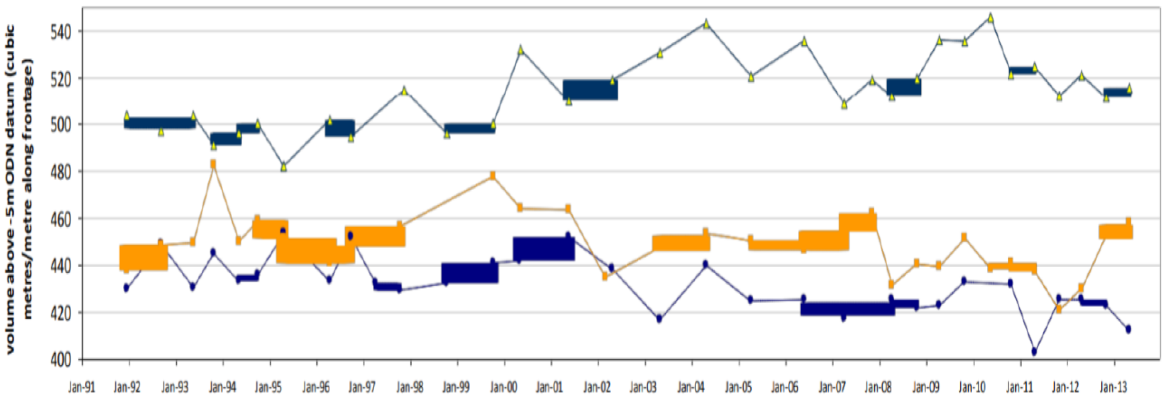


Figure 18: Volume of storm beach shingle over the period 1991-2013 (Phillips et al., 2017). The storm beach is seen to be losing shingle at Friog corner (blue), stable at Fairbourne village (yellow) and slightly gaining shingle at the northern end of the spit (green).

Towards the northern end of the Ro Wen spit, there is evidence of substantial shingle accumulation over the period since the Second World War. Anti-tank defences have been buried by shingle to a depth of up to a metre (fig.19).

Figure 19:

The storm beach between Fairbourne golf course and the end of the Ro Wen spit. Notice how World War 2 concrete anti-tank defences have been almost buried by deposition of shingle in the intervening period.

Similar concrete defences at Fairbourne village appear much as constructed, indicating stability of the shingle spit profile over the past half-century (fig.20).

Figure 20:

The storm beach in front of Fairbourne village.

World War 2 concrete anti-tank defences remain at their original height relative to the shingle, indicating stability of the storm beach at this location over the intervening period.

An area of concern in recent years has been the section of storm beach immediately adjacent to Friog cliff. Loss of shingle was recorded by Phillips (2017), and this is confirmed by comparison of air photographs (fig.21).

2009

2021

Figure 21: Comparison of the extent of storm beach deposits at Friog corner (Google Earth).

Erosion continued until failure of the sea defences occurred at Friog corner during a storm (fig.22). Wave action removed the small remaining amount of shingle from in front of the Solomon Andrews sea wall, which then fractured and allowed inflow of water. The Friog mobile home park was flooded to a shallow depth, along with neighbouring agricultural land, although Fairbourne village was unaffected.

Figure 22: Failure of the eroded section of the Ro Wen shingle spit at Friog corner during a storm, causing localised flooding.

Repairs to the sea wall were carried out by Gwynedd County Council and Natural Resources Wales, including the emplacement of sheet steel piles to prevent water inflow, and the addition of large boulders to dissipate wave energy (see title page illustration). This work has been effective in preventing the inflow of water during subsequent storms, and no further flooding has occurred at Friog.

4. Coastal processes

The principal process which has created the Ro Wen spit is long-shore drift. This is the result of the oblique approach of waves, which is at approximately 10^{o} to the line of the shingle spit for much of its length (fig.23). Breaking waves carry sediment up the beach in the direction of wave travel. Gravity return flow of the sea water then moves sediment back down the beach along a path at a right angle to the shoreline. Over a period of time, bulk transport of beach material occurs in a northerly direction.

Figure 23:

Fairbourne. Long shore drift movement of beach sediment due to the oblique approach of waves to the shore.

The shingle storm beach of Ro Wen has developed above the level of normal spring high tide (fig.24). Below this level is a sand beach which is exposed at low tide (fig.25).

Figure 24:

Ro Wen shingle spit at calm water high tide. Notice that the tide just reaches the junction between the sandy foreshore and the base of the shingle storm beach.

Figure 25:

Ro Wen spit at low tide. A berm runs parallel to the shore, separated from the beach by a trough.

To understand the formation and continued evolution of the Ro Wen spit, it is necessary to consider the mechanism by which storm waves approach and break on the shore. During a storm, the bulk of sea water at depth is stable, but waves develop by rotational movement of water near the surface. Energy is transferred to the waves from wind blowing over the sea surface. This energy maintains the rotational motion of the upper layers of sea water, with the extent of the rotation reducing with depth (fig.26). As waves approach the shore, the lowest layer of rotating water makes contact with the shelving beach, and its motion is slowed. As the base of the rotating water is progressively slowed and reduced in depth, the disturbance feeds back to the surface waves which become increasingly asymmetric. A point is reached when the waves become unstable, overturn and 'break'.

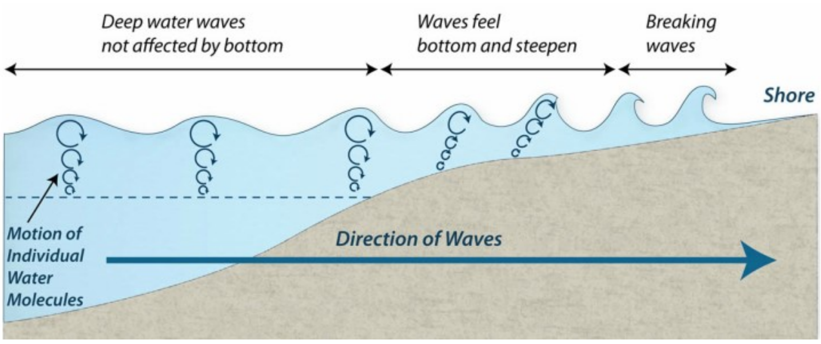


Figure 26:

Mechanism by which waves ground and break on reaching a shelving beach.

Sediment can be picked up from the sea bed and transported by approaching waves. The maximum grain size which can be picked up depends on the amount of rotational energy stored below the waves, and the depth to which the rotating cells of water are able to reach. During moderately windy conditions the sea water may be able to pick up and transport inshore sand, whilst during the most powerful storms it may be able to pick up both sand and coarser pebbles from deeper sea bed deposits.

As storm waves break on the shore, the transported load of sand and pebbles will be thrown up the beach (fig.27). After breaking, the gravity return flow of sea water is able to carry sand back down the beach, but the heavier shingle is left behind. Over a period of time, a large shingle storm beach can be constructed.

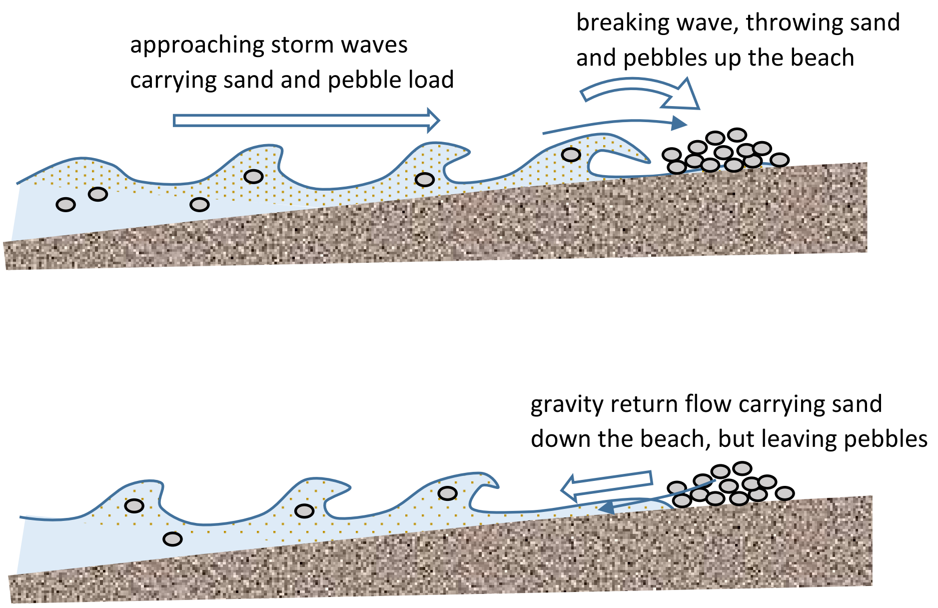


Figure 27:

Formation of a shingle storm beach by wave action during a storm.

The Ro Wen storm beach near Friog is shown in fig.28, looking from the edge of the sandy foreshore at the level of a calm high water spring tide. The shingle embankment extends to a height of 5.5m above the sand beach. This height is not by chance, but represents very closely the maximum height reached by breaking storm waves along this shore. The storm beach is a dynamic structure in equilibrium with marine processes. There is every indication that the height of the storm beach will adjust naturally to slow sea level rise over a number of decades, maintaining a height equal to maximum storm wave height. This will occur through storm waves throwing shingle onto the top of the existing structure if sea level rises and makes this possible.

Figure 28:

Shingle storm beach near Friog, looking upwards from the sandy foreshore marking the level of calm water high spring tide.

It is known that the Ro Wen storm beach has been very stable for thousands of years since its formation at the end of the Ice Age, and that its profile has changed little in the past century. This is due to the ability of the shingle spit to adapt naturally to changing sea conditions. However, it is apparent that marine erosion in recent years has affected a short section of the spit adjacent to the mobile home park at Friog corner. Possible causes of this erosion will now be considered.

Waves may break on a shore in different ways (fig.29):

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

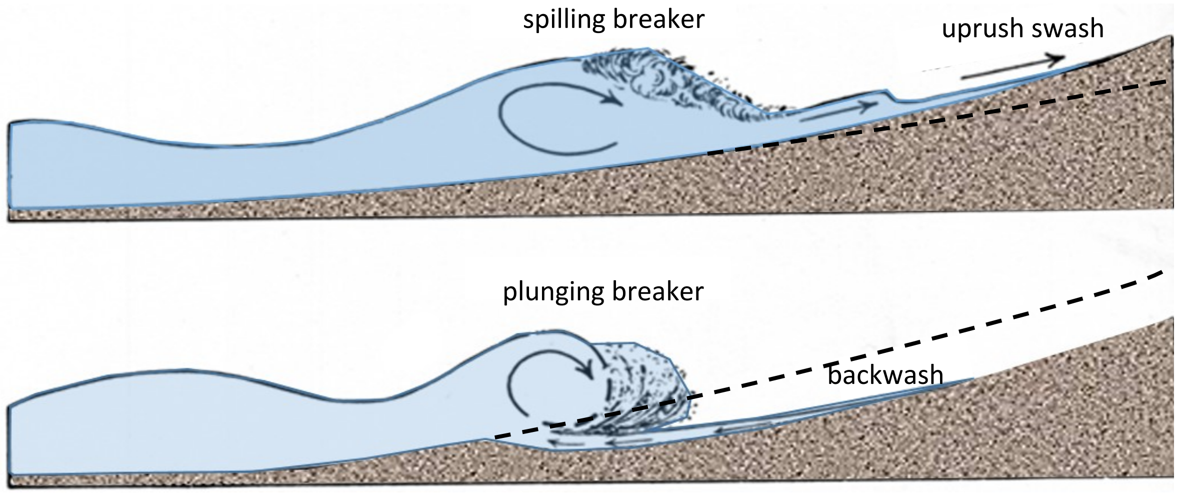


Figure 29a: (above) Constructive spilling breaker. **b**: (below) Erosional plunging breaker.

The immediate cause of recent erosion at Friog corner was due to the angle of the storm beach face at this point, which was steeper than along the majority of the spit (fig.30). This favoured a plunging type of breaker, which caused further erosion until the concrete sea wall was exposed.

Figure 30:

Shingle storm beach at Friog corner. This photograph was taken shortly before the sea wall failed during a storm.

Fracture of the concrete sea wall probably occurred because the wall was inadequately supported on the landward side against wave impact. Shingle had been removed at this point to create a flat area of ground for a group of huts (fig.31). This was probably done during the Second World War, to provide accommodation for troops manning the coastal defences.

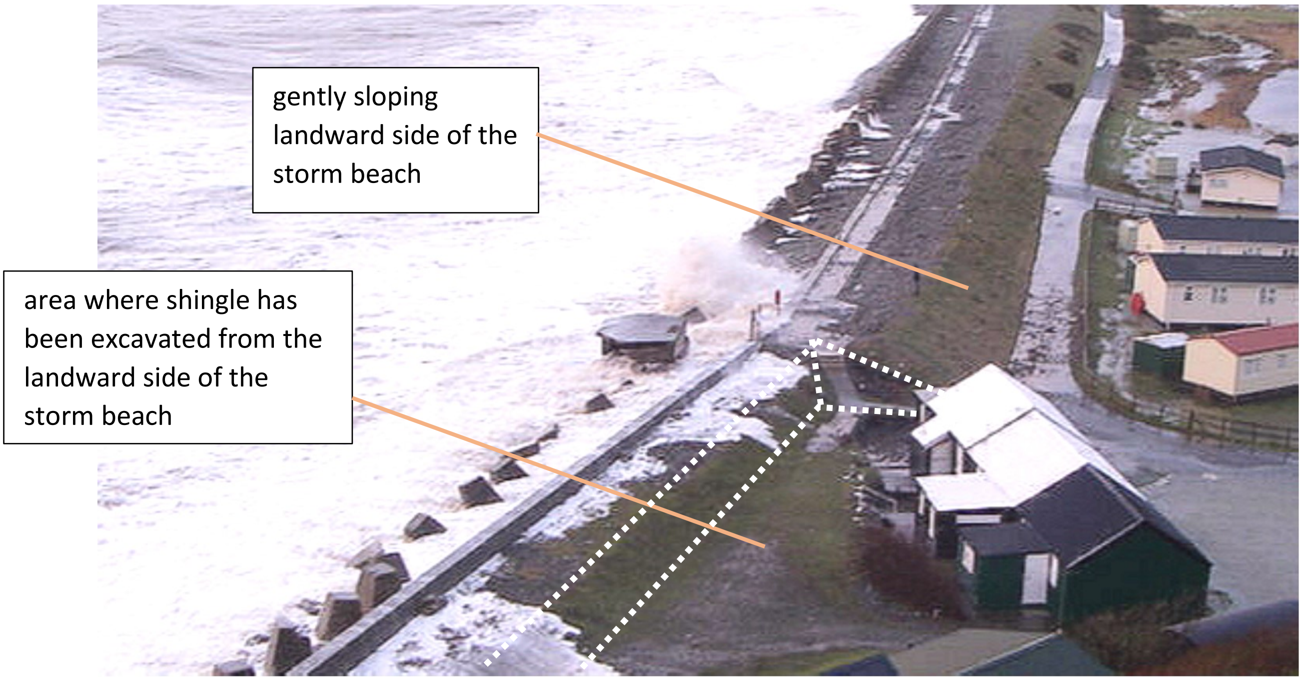


Figure 31: Friog corner under storm conditions, before reconstruction of the sea wall.

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.32). It was found that the pebble size at Friog corner was very substantially larger than at other locations.

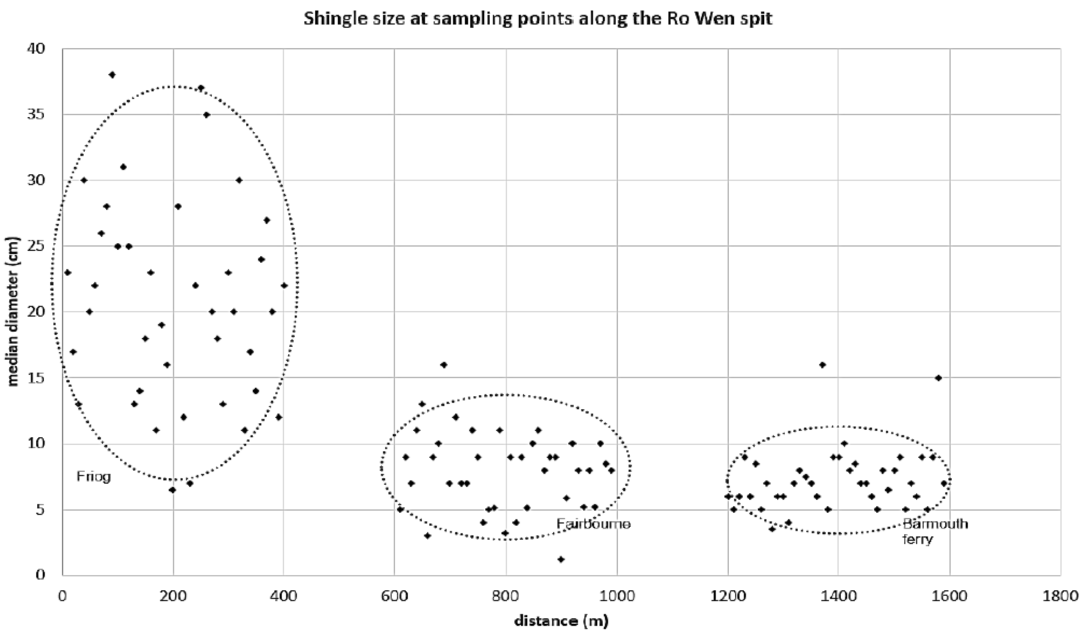


Figure 32: Sizes of random samples of storm beach pebbles at points along the Ro Wen spit.

A mechanism for the coastal erosion at Friog can now be suggested:

- Waves are refracted into the bay at Friog corner, approaching parallel to the shore. The water mass experiences a rapid change in direction northwards (fig.33). This creates a powerful current along the shore which carries smaller shingle towards Fairbourne, leaving only the larger and heavier material in situe.

Figure 33: Approach of waves at Friog corner, and redirection of the water mass along the spit.

- The removal of smaller shingle caused a steepening of the remaining storm beach at Friog corner. This favoured the plunging type of breaking waves, leading to further storm beach erosion. Eventually, the sea wall was exposed, and this fractured during a storm due to lack of structural support.

It is possible that changes to the shallow sea bed topography have occurred off-shore from Friog and Llwyngwril, perhaps due to erosion of the remaining glacial moraine. This has led to a change in the wave approach direction at Friog corner, initiating the erosional sequence.

5. Protection of the Ro Wen shingle spit

From evidence presented above, it can be said with confidence that the Ro Wen shingle spit from Fairbourne village to the estuary mouth is stable and is at no risk of being breached under storm conditions during the coming century. The damaged sea wall at Friog corner has been effectively repaired and reinforced, and there is currently no foreseeable danger of another failure occurring.

The Ro Wen spit has been observed during and after a series of severe storms over the period from 2020 to 2022 (fig.34). There has been no damage or erosion at any point due to storm waves, and no significant wave overtopping occurred. At no time was there any flooding in Fairbourne village or at the Friog mobile home park.

Figure 34: The Fairbourne coastline during Storm Clara, February 2020.

In view of the previous sea wall failure at Friog corner, and the evident coastal erosion which has taken place at this point, it is strongly recommended that action is taken to eliminate any risk of future failure of the sea defences at this point.

A first step would be to prevent the direct impact of storm waves on the repaired sea wall, and to reduce the scouring action of storm waves as they are deflected towards Fairbourne. This can be done by the construction of a reef along the shore (fig.35). This might consist of boulders, concrete blocks, or other materials which would be stable against wave impact.

Figure 35: Proposed artificial reef to deflect storm waves at Friog corner.

The reef should be emplaced at an angle to the shore line, with the intention of causing storm waves to break and then deflect the water mass northwards along the shore.

A sheltered section of beach will be created behind the reef. It is recommended that shingle is brought from the northern end of the Ro Wen spit (fig.36) and deposited in this area, where wave action will carry it onto the shore and build up a new storm beach against and above the rock armour of the repaired sea wall. It is likely that any shingle removed from the end of the spit will be replaced naturally by longshore drift.

Figure 36: Northern end of the Ro Wen shingle spit. It appears that the large hooked end has been built up by shingle accumulation over the past century. Long shore drift carries sand and shingle along the spit to this point. Tidal currents can transport sand into and then out of the Mawddach estuary, allowing it to continue on a northwards passage to Barmouth beach. However, the tidal currents are not sufficiently powerful to transport shingle, which accumulates around the end of the spit.

Urgent attention should be given to restoring the landward profile of the storm beach at Friog corner, to provide mechanical support to the sea wall when impacted by storm waves. It is recommended that the huts at this point are relocated further from the sea wall (fig.37), and the landward slope built up with rock material. Slate waste, available locally, would be suitable for this purpose as it contains a large amount of clay which would prevent any infiltration of sea water beneath the sea wall during high storm tides.

If these precautionary works are carried out, there should be negligible risk of a failure of the sea wall occurring within the next century.

Figure 37a: Current position of huts at Friog corner. The excavation to produce level ground can be seen behind the huts.

Figure 37b: Suggested relocation of the huts further from the sea wall, with restoration of a substantial embankment to provide support for the concrete wall.

6. Evaluation of flood models presented in the 'Fairbourne Preliminary Coastal Adaption Masterplan'

A series of flood models have been presented in the publication 'Fairbourne Preliminary Coastal Adaptation Masterplan' (Fairbourne Moving Forward Partnership, 2019a). Computer models appear to be the principal evidence presented to justify abandoning and demolishing Fairbourne village. It is therefore important to assess the accuracy of the models.

The first two models (fig.38) indicate that Fairbourne village would have been flooded in 2018 during a storm with a magnitude occurring once in 50 years (T50), or once in 100 years (T100).

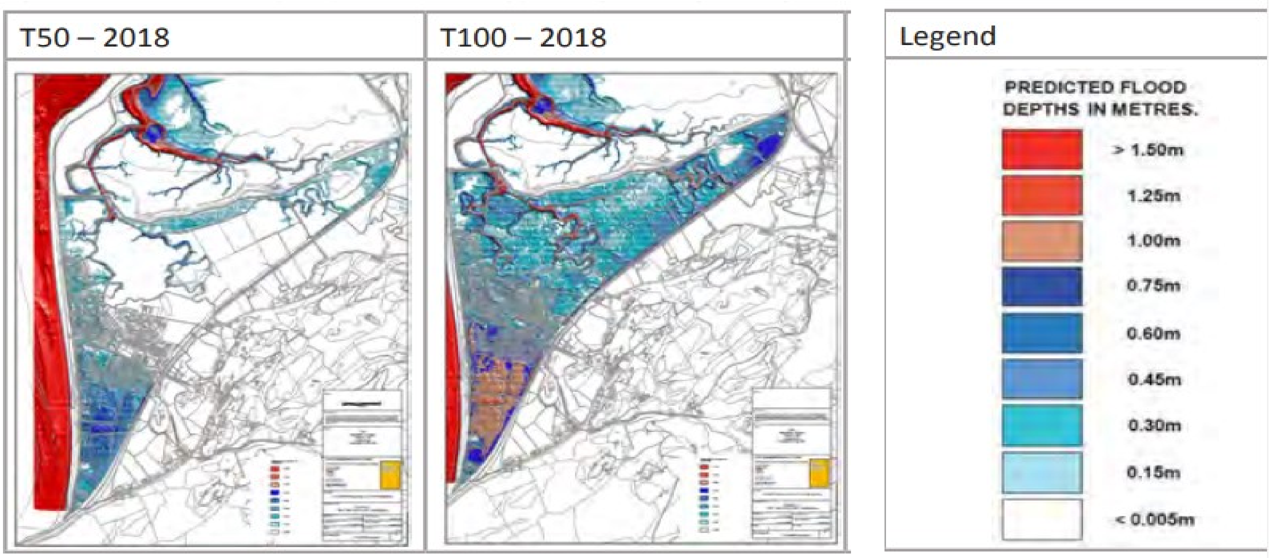


Figure 38: Computer models for flooding of Fairbourne in 2018 for storms of 50 year and 100 year frequency.

In both cases, the village is shown as flooded to a depth of around 0.45m, which is about knee deep. This is similar to flooding which occurred in Towyn, near Abergele (fig.39).

Figure 39:

Flooding at Towyn.

Major storms have actually occurred in North Wales during the period specified for the models. Storm Clara in February 2020 and Storm Eunice in February 2022 both caused extensive flooding and damage to property across North Wales. These storms were at the limit of storm magnitude possible for the Welsh coast, taking into account the geometrical configuration of the Irish Sea basin and the maximum wind force produced in the Atlantic. They therefore count as close to 100 year events. **However, no flooding at all occurred in Fairbourne during either storm, and no damage was done to any of the sea defences (fig.40). Both flood models are totally in error, and have clearly been based on invalid assumptions or data.**

Figure 40: Fairbourne beach and Friog sea defences a few hours after Storm Eunice, February 2022.

It is asserted that Fairbourne is at imminent risk of a catastrophic breach of the Ro Wen shingle spit during a storm, leading to immediate inundation of the village and danger to life (Fairbourne Moving Forward Partnership (2019b). This scenario is shown in the third computer model (fig.41).

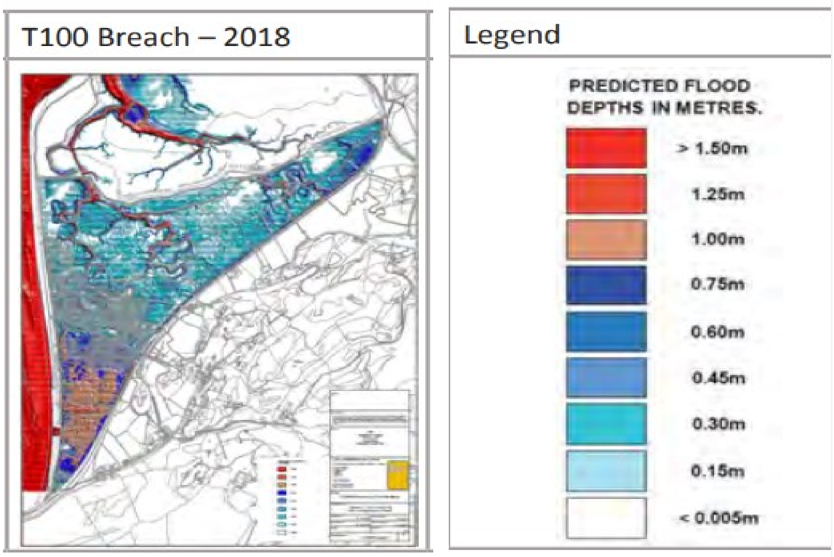


Figure 41:

Computer model for flooding of Fairbourne due to a breach of the Ro Wen shingle storm beach.

The breach which has been simulated appears to be a gap of around 50m, cut through the Ro Wen spit at a location just north of the Friog mobile home park. The model shows the breach extending down to a level close to the sandy beach in order to allow water to flood through the gap.

The sequence of photographs in fig.42 show the line of the simulated breach. Data collected by M. Phillips (fig.18) indicates that the storm beach in this location has a volume of approximately <u>400 cubic metres</u> of shingle per metre along the spit. Additionally, a concrete wall has been emplaced along the centre of the structure, approximately a metre in thickness and extending to a depth of about 3 metres.

Figure 42:

Sequence of images across the Ro Wen spit. The foreground represents the location of the simulated breach of the storm beach.

(a) beach and face of the storm beach.

(b) upper surface of the storm beach

(c) landward slope of the storm beach

A breach could conceivably occur by one of two mechanisms (fig.43):

- Erosion of the front face of the storm beach cuts back to reach the sea wall, which then fractures, allowing erosion to continue through the landward embankment.
- Erosion works downwards from the upper surface, washing shingle in both directions away from the sea wall, which finally fractures.

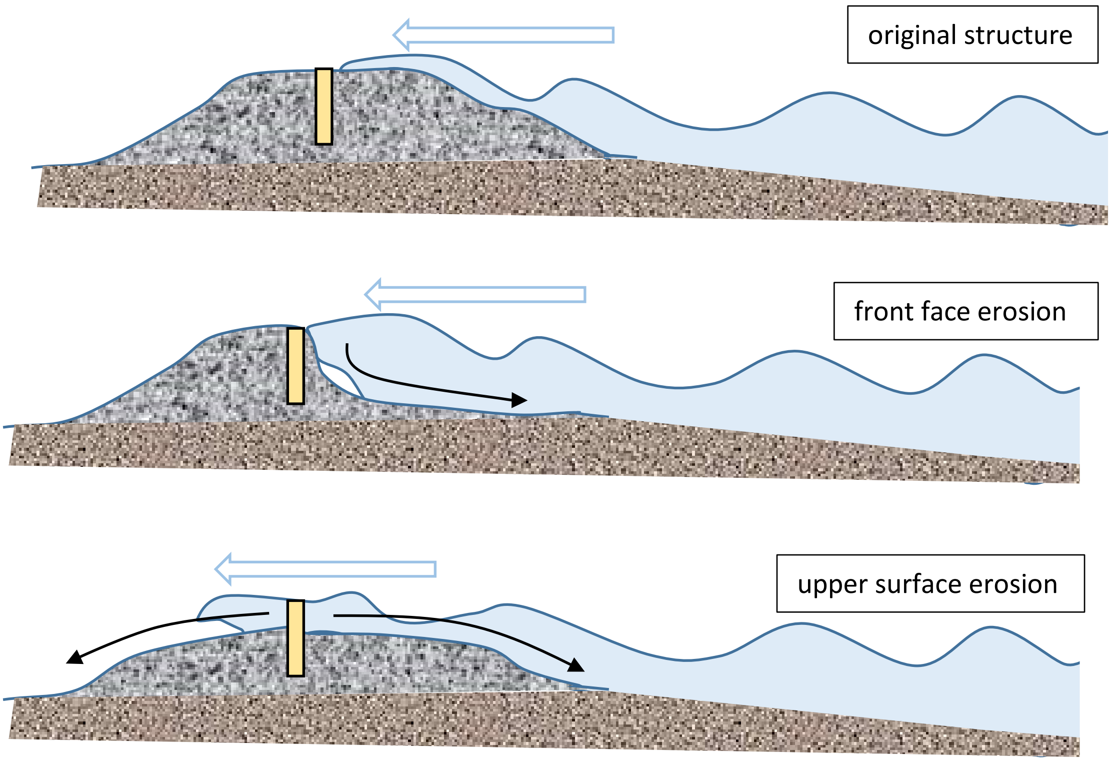


Figure 43: Conceivable mechanisms by which a breach of the shingle spit could occur.

Neither of the mechanisms seems plausible:

Storm waves would only be of a sufficient height to affect the upper half of the storm beach face for one hour on either side of high tide. During this time, waves are most likely to break on the front face by a spilling mechanism due to the relatively gentle angle of the face, with no erosion occurring. Furthermore, much of the incident wave would be absorbed into the permeable structure of the shingle bank, where the water would drain downwards inside the shingle mass without causing any erosional effect (fig.44).

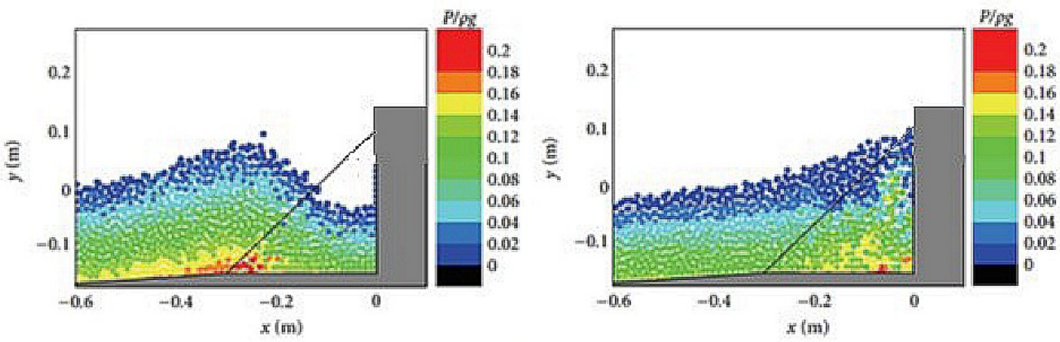


Figure 44: Model for the impact of storm waves on a permeable structure (Pu & Shao, 2012).

It is possible that some plunging breakers could cause erosion, but detailed measurements by M. Phillips have never identified more than 30 cubic metres/metre of erosion during any storm event, leaving 370 cubic metres/metre of shingle still in place. Furthermore, the lost shingle was normally replaced by constructive marine processes in the few weeks following a storm.

Storms waves would only be of sufficient height to overtop the crest of the shingle bank for an hour around high tide. The effect of waves washing over the top surface of the storm beach is to arrange the shingle into a closely packed structure, with smaller gravel filling the surface cavities (fig.45). This has the effect of armouring the surface, preventing subsequent waves from easily picking up material. Furthermore, any shingle carried back seawards down the front face of the storm beach would have the effect of reducing the slope angle of the face. This in turn would promote the breaking of waves by a non-erosive spilling mechanism.

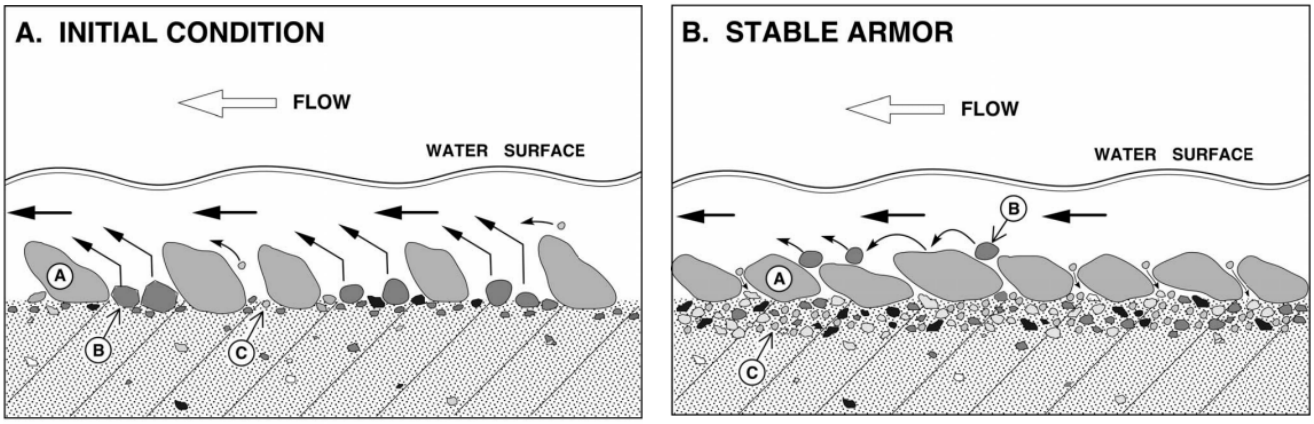


Figure 45: Mechanism by which the upper surface of the storm beach may become armoured against wave erosion (Hayes, Michel, & Betenbaugh, 2010).

We are left with the problem of how the concrete core wall could be fractured to allow ingress of water. In the case of upper surface erosion, there would simply not be sufficient time for this to occur before the tide fell and the flood risk receded. In the case of front face erosion, the large inland embankment behind the wall would provide mechanical support and prevent fracturing of the concrete due to wave impact.

We must conclude that there is no plausible mechanism for the breaching of such a massive structure as the Ro Wen spit during a storm event. Any small amount of erosion which might occur on the front face of the storm beach would present no risk to Fairbourne. This erosion would be repaired naturally by coastal processes, or could easily be repaired artificially by the replacement of the shingle.

The computer model for breaching of the shingle spit is based on invalid assumptions or data, and should be discounted as evidence of a flood risk to Fairbourne.

The remaining computer models (fig.46) make predictions of flooding which could occur in Fairbourne in the years 2054 and 2093 due to overtopping of the shingle storm beach or the Mawddach estuary embankment due to storm waves.

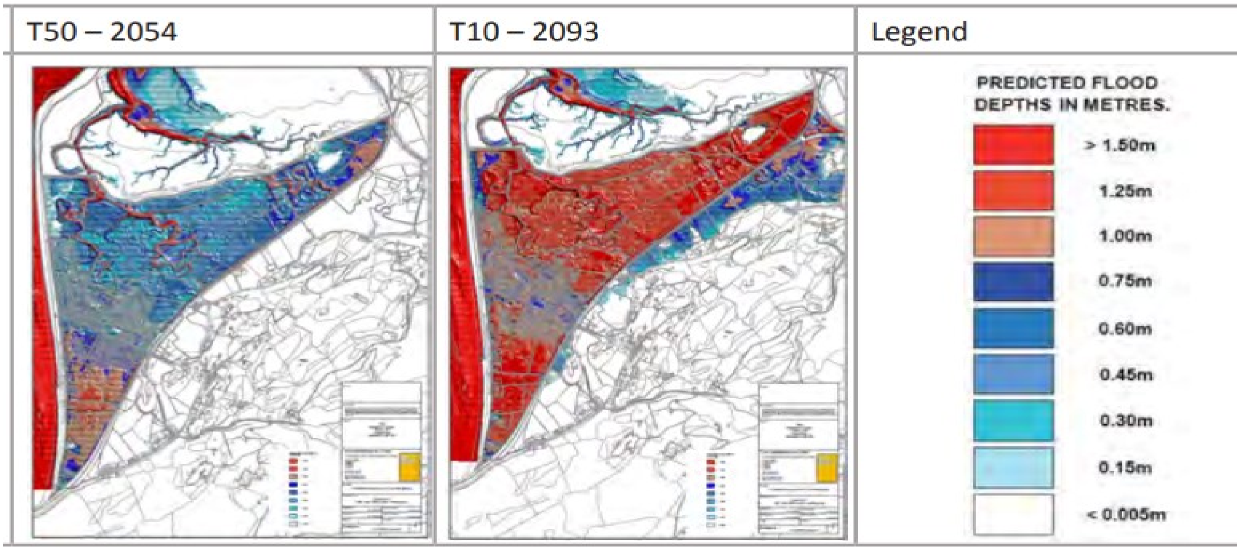


Figure 46: Predicted flooding of Fairbourne in the years 2054 and 2093.

To assess the validity of these models, it is necessary to consider the assumptions on which they are based.

- It appears that a sea level rise of 1 metre compared to the present day has been assumed for the year 2093. This is at the upper limit of possible sea level rise, but it is perhaps sensible to plan for a worst case scenario.
- Of more serious concern is an assumption that no further flood defences will be provided for Fairbourne village after the present day. It is therefore hardly surprising that flood risk will increase if there is a rise in sea level and no actions are taken to protect the village.

It is considered that these computer models represent a totally unrealistic scenario. There would be enormous and justified criticism of Gwynedd County Council and Natural Resources Wales if Fairbourne was denied funding for flood defences for political reasons, whilst other similar communities received protection.

A realistic and affordable flood protection scheme for Fairbourne village has been proposed (Hall, 2021; Hall, 2022). Key aspects of the proposal are:

- A new flood protection boundary would be created for the village by constructing a flood embankment across farmland to connect the existing estuary and railway embankments (shown as D in fig.47). This would eliminate any risk of surface water entering the village from farmland to the east, shown as flooded to a depth of 1.5 metres in the 2093 computer model above.
- The height of the estuary flood defence embankment would be raised by 1 metre to prevent overtopping under storm surge conditions and sea level rise. There is no current urgency as the estuary embankment is providing adequate protection at the present day (fig.48). This work could be carried out over the period between 2040 and 2060. The embankment lies at the head of a wide area of salt marsh which effectively dissipates wave energy, so it would be safe to raise the embankment level by the simple addition of slate waste or clay and sand materials. If the proposed new embankment has been constructed to the east of Fairbourne, only the short section of estuary embankment north of the village would need to be raised (shown as C in fig.47).

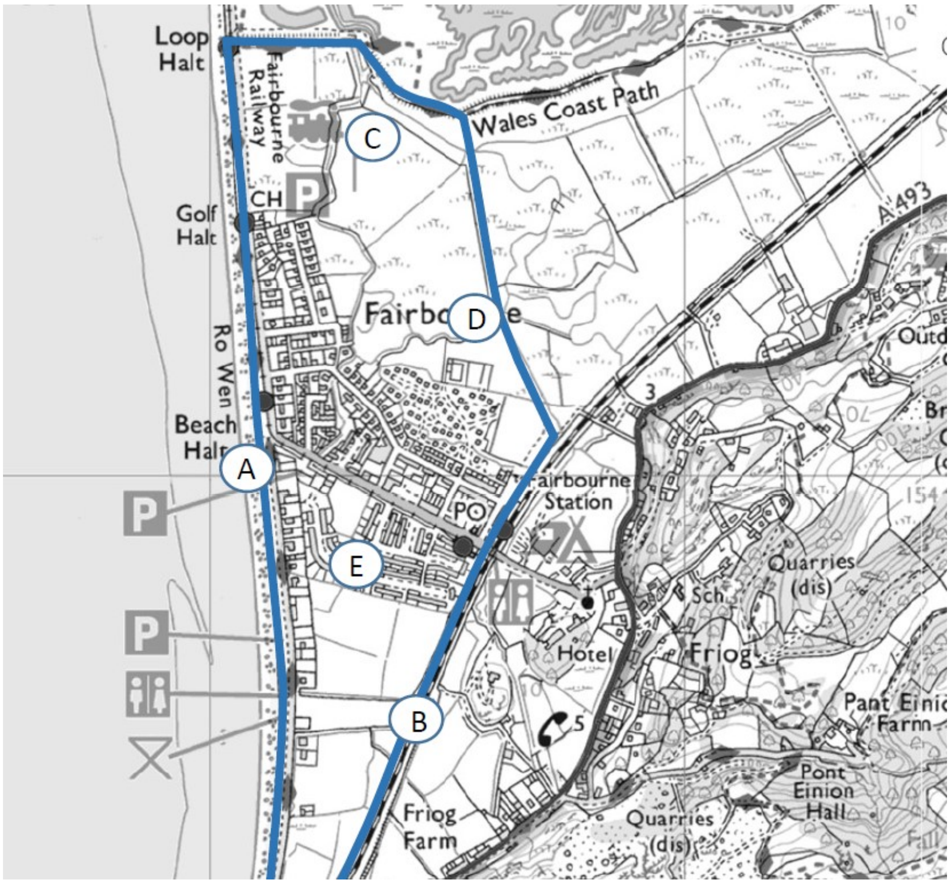


Figure 47:

Proposed flood protection boundary for Fairbourne, created by the construction of a flood embankment to the east of the village (shown as D).

Figure 48:

Estuary flood protection embankment north of Fairbourne (shown as C in fig.47 above).

- The Ro Wen shingle storm beach forms the seaward boundary of the Fairbourne flood protection area. It has been shown that the majority of the shingle spit is stable and at no risk of failure during a worst case storm at the present day. The only area of concern is a small section of the shingle spit at Friog corner, where coastal erosion is taking place. Recent repair and strengthening of the sea defences at this point have been very effective, and there is currently no risk of failure. Recommendations have been made above for precautionary works which would eliminate the risk of any future failure of the sea defences at Friog.

Consideration should be given to the effects of sea level rise on the Ro Wen shingle spit. The change in sea level of 1 metre is probably an over-estimate, and the change will take place very gradually over many decades. This will provide plenty of time for the storm beach height to adjust naturally to the prevailing wave heights. Shingle will be thrown onto the flat top of the storm beach whenever extreme waves make this possible, gradually raising its height (fig.49).

Figure 49: Upper surface of the storm beach, showing the accumulation of shingle thrown up by storm waves.

Modelling by Hall (2022) has been shown that wave overtopping along the length of the Ro Wen spit in front of Fairbourne village is negligible. Water washing onto the top of the storm beach generally dissipates into the porous surface of the shingle bank. Any water flowing over the embankment can be directed into the system of drainage ditches around the village and will flow back to the estuary.

If the proposed flood protection scheme for Fairbourne or some equivalent scheme is implemented, the computer flood models for the years 2054 and 2093 included in the Fairbourne Preliminary Coastal Adaptation Masterplan will be based on false assumptions and will be invalid.

References

Fairbourne Moving Forward Partnership (2019a). Fairbourne Preliminary Coastal Adaptation Masterplan. Gwynedd County Council.

Fairbourne Moving Forward Partnership (2019b) Fairbourne: A Framework for the Future. Gwynedd County Council.

Hall, G. (2021). Protection of Fairbourne village from flooding. www.grahamhall.org/fairbourne.html

Hall, G. (2022). Investigating the protection of Fairbourne village from flooding. www.grahamhall.org/fairbourne.html

Hayes, M. O., Michel, J., & Betenbaugh, D. V. (2010). The intermittently exposed, coarse-grained gravel beaches of Prince William Sound, Alaska: comparison with open-ocean gravel beaches. Journal of Coastal Research, 26(1), 4-30.

Kavanagh, K. E., & Bates, M. R. (2019). Semantics of the Sea-stories and science along the Celtic seaboard. Internet Archaeology, 53.

Larcombe, P., & Jago, C. F. (1994). The late Devensian and Holocene evolution of Barmouth Bay, Wales. *Sedimentary geology*, *89*(3-4), 163-180.

Orford, J. D. (1977). A proposed mechanism for storm beach sedimentation. *Earth Surface Processes*, *2*(4), 381-400.

Phillips, M., Thomas, T., Morgan, A. (2017) Flood and Coastal Erosion Risk Management: Fairbourne Going Forward coastal processes, beach profiles and aerial photographs assessment of change. University of Wales Trinity Saint Davids.

Pu, J. H., & Shao, S. (2012). Smoothed particle hydrodynamics simulation of wave overtopping characteristics for different coastal structures. *The Scientific World Journal*, *2012*.