The Role of Georisk Management in Marine Renewable Energy Projects

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***Abstract*— There are ambitious goals around the world to install 748 GW by 2050 through the development of marine renewable energy generation in Offshore Wind, Tidal Stream, and Tidal Range projects. A key development arising out of the latest round of offshore wind farm developments in UK coastal waters is the significant potential benefit of a reduction in ground investigation costs to project developers in managing risks associated with seabed and sub-seabed conditions. Optimisation of a geological Ground Model is a key part of this process. The role of Georisk Management in marine renewable energy projects is ultimately to understand, reduce where possible, and quantify the risks associated with the dynamic geological and marine systems at and around proposed infrastructure projects, and ultimately to mitigate those risks. This has been discussed through consideration of three strategic approaches, namely, (a) the use of best practice guidelines; (b) determination of the geohistory of a site; and (c), by gaining an understanding of the potential physical impacts of the environment on a renewable energy project. Consequently, we are recommending that for near-shore offshore renewable energy projects consideration is given to the broader panoply of processes, both terrestrial and marine, including impacts of changing climate.**

***Keywords*— Georisk; marine renewable energy; offshore wind; tidal range energy; 3D Ground Models.**

I. INTRODUCTION

There are ambitious goals around the world for substantial development of marine renewable energy generation through Offshore Wind, Tidal Stream, and Tidal Range projects. Ocean energy deployment could reach 748 GW by 2050, create 160,000 direct jobs by 2030, with a market worth ~£40bn per annum by 2050 [1].

The Offshore Renewable Energy sector around UK coastal waters has been through three rounds of development. The latest projects are now using lessons learned from earlier ones with reduction in energy generation prices being a principal goal. It is critical that, to achieve optimised developments with the lowest Levelized Cost of Energy (LCoE), the risks associated with the dynamic geological systems into which these schemes are being placed are assessed and mitigated as far as is economically and technically feasible.

A key development that has emerged is the significant potential benefit of a reduction in ground investigation costs to project developers in managing risks associated with seabed and sub-seabed conditions. Optimisation of a geological Ground Model (GM) is a key part of this process [2]. As each stage of an incremental Site Investigation (SI) is optimised based on the results of the last, cost reductions accumulate through the development period [3]. A similar approach is being adopted for the prospective development of a 2.5 GW tidal range project off the North Wales coast, UK.

The role of Georisk Management in marine renewable energy projects is ultimately to understand, reduce where possible, and quantify the risks associated with the dynamic geological and marine systems at and around proposed infrastructure projects, and ultimately to mitigate those risks. It is also to support funding, development, and operation of the asset. The location of a prospective marine renewable energy site relative to the nearest coast will influence the scope of what geohazards need to be considered. Offshore wind farms located beyond the horizon and out of sight from the coast are typically considered as open water systems, where the seabed and sub-seabed conditions influence foundation type and design, inter-array and export cable layout, and installation methods. Seabed sediment mobility may also be another major consideration [4]. In addition to daily and seasonal events, near-shore projects may also be affected by near-coastal processes as well as the possible effects of low-frequency, high-impact events. An example of the latter would be short-duration debris-charged flash floods emanating from rivers engorged by extreme rainfall/typhoon events inland. Tidal range schemes, in addition to issues relating to seabed and substrate conditions, can be significantly affected by sediment fluxes and water quality issues that are strongly influenced by estuarine or riverine flows into the tidal impoundment.

II. Role of Georisk Management

The role of Georisk Management is presented through three approaches:

a) Use of best practice guidelines
b) Geohistory of a site
c) Impacts of the environment on a project

A. Best Practice Guidelines

Examples from offshore wind farm (OWF) developments around UK coastal waters (*e.g.* [3], [5]) are given to describe the use of best practice guidelines that have been developed over the last decade for integrated geological and geophysical marine investigations in the development of 3D Ground Models, which are commonly required as part of Environmental Impact Assessments. This includes consideration of the engineering value of the interpolation and extrapolation of geological and geotechnical data points informed by the integrated interpretation of multiple measurement methods.

Two examples of the use of best practice guidelines are presented where an integrated approach in marine Site Investigations (SI) has been successful in minimising the risks associated with developing Offshore Wind Farms.

The first example is that of the Rhiannon OWF zone in the Irish Sea [5]. The Irish Sea Zone of which the Rhiannon OWF represented about a third of the development zone, was located between the islands of Anglesey, North Wales, and the Isle of Man within the Irish Sea. A systematic workflow (**imagis**TM) was applied to the processing and interpretation of single-channel seismic data and to the incorporation of geotechnical test results from intrusive investigations. This led to a more standardised approach to managing the results from the SI for the development of a 3D geological Ground Model (GM). In the GM developed for the OWF, seismo-acoustic facies analysis of reprocessed archive single-channel seismic data was integrated iteratively with a detailed review of geotechnical samples using gINT software to produce a mutually-consistent and robust interpretation. An exemplar seismic section is shown in Fig. 1 with the geotechnical results from one borehole demonstrating the cross-correlation between data types. These integrated data demonstrated that the originally-held view of the geological structure as being a simple vertical layer-cake sequence of sands and glacial clays over till on top of bedrock was incorrect. Instead, the survey demonstrated the presence of over-consolidated glacial structures (e.g. ribbon moraines and drumlin-like features) with normally-consolidated fluvio-glacial and lacustrine sands infilling the areas between the moraine ridges, with considerable lateral as well as vertical variability. Furthermore, some of the over-consolidated glacial deposits outcrop at seabed and protrude through forming local topographic highs. This had implications for seabed cable installation methods where a highly-tailored design would have had to be developed in order to deal with the spatial variability of both the normally- and over-consolidated sediments, had the area been developed.

The resulting initial GM was used to target second stage ground investigations that in turn informed the development of a second-stage GM with decreased uncertainty. The GMs are suitable for use in the interpretation of soil profiles and foundation designs in which uncertainties can be quantified and understood.

This approach has been successful in minimising the risks associated with complex sub-seabed geology and geohazards. It has proven to be particularly effective when applied to archive seismic survey data that may otherwise have been entirely written off by the offshore wind farm developer. Consequently, the 3D GMs derived from the integrated interpretation of geotechnical and geophysical datasets are quantifiably more robust and with lower uncertainty and reduced risk than those derived using conventional approaches. This also resulted in very significant prospective cost savings to the offshore wind farm developers.

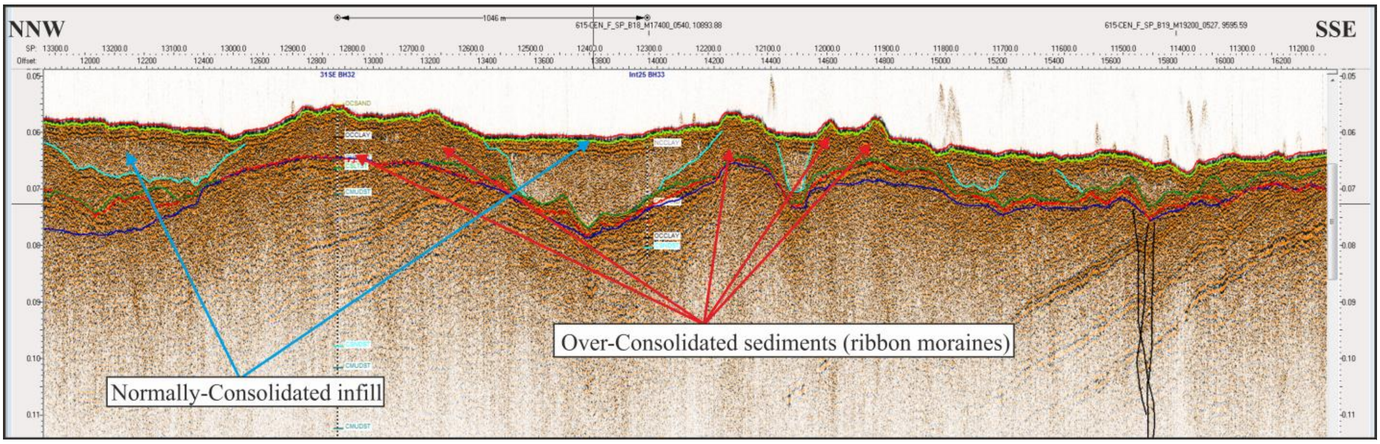

Fig. 1 Extract from a seismic line showing the tops of ribbon moraines forming topographic highs in the seabed, separated by areas of Normally-Consolidated sediments sitting on top of a veneer of Over-Consolidated sediments over the bedrock (Undiferentiated Carboniferous) depicted by the dark blue line

The second example is that of the East Anglia ONE (EAONE) offshore wind farm in the southern North Sea. The development of the EAONE GM [3] allowed the developer to acquire sufficient information, in earlier stages, for optimising the Site Investigation strategy and allowed a robust foundation Front-End Engineering Design stage as well as progressing a number of feasibility studies. This included the development of a specific pre-drilling information product using **imagis**™ workflows ('Expected Conditions Sheets') that displayed all the relevant data from an initial GM in a simple format that provided an onboard geotechnical engineer sufficient information to manage the intrusive testing. This enabled the engineer to select appropriate depth ranges for sampling and ensure that the intrusive testing was not stopped too short of a key interface (thereby leaving it unsampled) or extended unnecessarily too far (redundant information and avoidable costs). In addition to making the actual intrusive SI technically more effective and with optimised costs, this approach provided the project team with time to deliberate on and refine the OWF layout (foundations and cables). It also informed the different work packages in a timely manner for the various project teams to proceed with the desk studies, tenders, and detailed designs required before starting construction and installation.

The following points highlight the main benefits of the GM solution for EAONE:

- Optimisation of planned SIs and the soil modelling for foundation design and foundation/cable installation, as well as support on turbine and foundation installation;
- The different approach to SI and design needed to optimise windfarm developments, particularly for UK Round 3 projects that encompass wide areas, with a consequent need for optimisation of SI approaches;
- The importance of this approach in case of the requirement for micro-site/micro-route work and for establishment of confidence levels on ground conditions;
- The importance of the use of Expected Conditions Sheets for optimising the SI as it progressed as well as for improving foundation design.

With the iterative approach described here, the total SI cost was spread out over a number of field campaigns during the GM development period, limiting upfront expenses as well as allowing the optimisation of the SI approach by means of a strategy based on confidence levels [6]. This approach was estimated to reduce the overall SI costs by about 10-15% and increased the level of confidence on the soil properties across the site when compared with the more traditional soil modelling strategies. Additionally, as each stage of the GM development was optimised based on the results of the last, cost reductions accumulated throughout the development period.

The approach used for the EA ONE OWF GM development resulted in an extremely cost-effective process and a consequent reduction of total costs: an ultimate goal of any OWF development. A visualisation of the final GM for the EAONE OWF is shown in Fig. 2.

B. Geohistory of a site

The second approach is to consider past geological conditions and undertake paleo-landscape reconstructions, which can lead to a better understanding of the physical environment and processes that have resulted in the geological record identified at marine renewable energy sites. For any offshore renewable energy development, the current site conditions are the culmination of the site's previous geohistory over previous millennia, if not longer. By gaining a better understanding of how a landscape, now submerged, has evolved, better insights can be achieved to the earth system processes that have been and that may still be active at that location. Most marine renewable energy projects are located where current water depths are typically less than 45

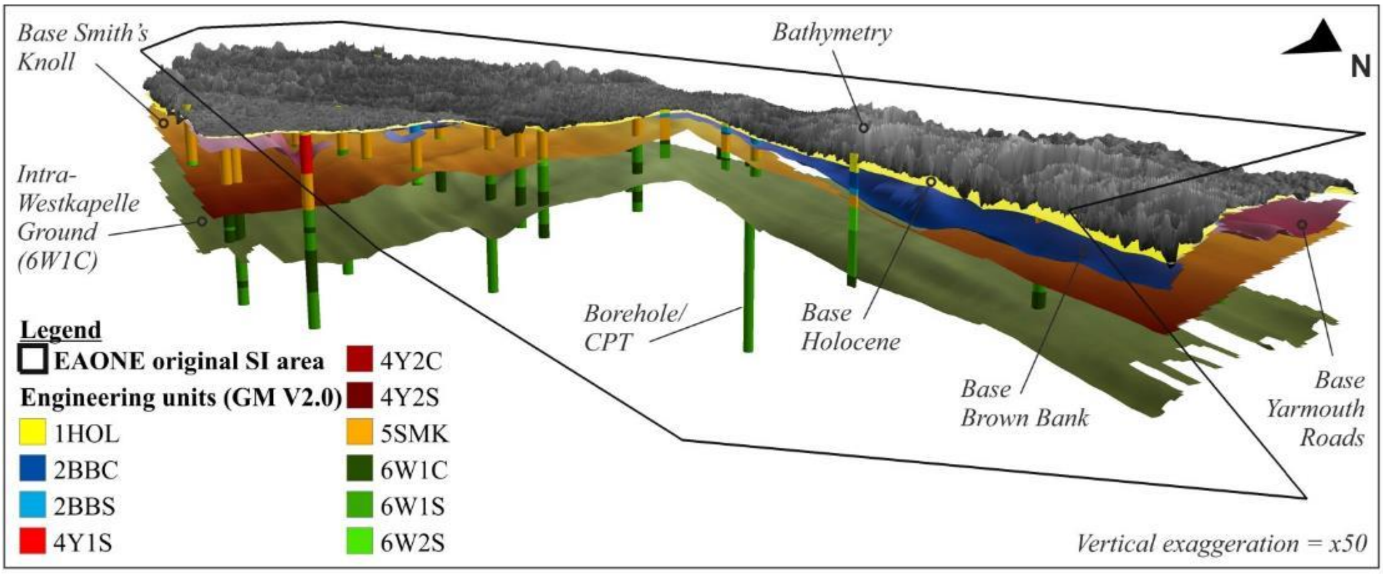

Fig. 2 3D cut-away view of the EAONE GM V2.0

m. At some point since the last global Ice Age, sea levels were significantly lower than this, with the then terrestrial landscape subject to aerial processes coupled over time with the consequences of marine transgression through to ambient conditions. It is also necessary to consider the implications of neo-tectonic changes over comparable timescales. We need to understand the tectonic setting and how it affects current processes, such as seismicity and fault activation. However, one limitation often affecting offshore renewable energy projects is that, commonly, consideration is often only given to the conditions within a project's development footprint. Yet recent history demonstrates that far-field influences can still be felt at a site-specific level, as will be discussed below.

Around 27,000 years ago to the British-Irish Ice Sheet (BIIS) comprised several co-joined ice flow centres, one straddling the island of Ireland, one located predominantly over Scotland and northern England, and another, smaller, ice dome over northern and central Wales, each flowing radially outwards. At that time global sea level was over 120 m below that of today [7]. Over the following 8,000 years the BIIS continued to shrink but sea level remained at about the same level. As the ice sheet edge retreated, new terrestrial landscape emerged and was exposed to fluvio-glacial and para-glacial processes. By 18,000 years before present (BP) the Welsh Ice Dome had become separated from the remnants of the larger part of the BIIS. In north Wales, the waning Welsh Ice Sheet continued to flow north-eastwards into Liverpool Bay and north-westwards around what is now the island of Anglesey. One ice sheet retreat scenario [8] suggests that the northern part of the Welsh Ice Sheet, whilst still linked to the rest of the BIIS, formed an ice dam that impounded a large pro-glacial lake. In contemporary geographical terms, this would have filled the south-eastern Liverpool Bay area. When this ice dam collapsed, it might have released the lake water westwards around the northern side of Anglesey. However, caution as to the interpretation of the presence of ice dammed pro-glacial lakes has been recommended [9] due to the overall lack of direct evidence. It is conjectured that the glacial landforms of drumlins and ribbon moraines (e.g. Fig.1) might have formed at this time. Fluvio-glacial sediments were deposited over much the former palaeo-glacial landscape. It was probably during the period from 18 ka BP to 9 ka BP that sea level rose dramatically with a marine transgression working progressively north-eastwards through what is now the southern Irish Sea between Ireland and Wales, and then subsequently around what is now the North Wales coast. The sea level reached to within a couple of metres of what it is today around 7 ka BP [6]. It is necessary to consider how the complex palaeo-glacial and palaeo-fluvio-glacial deposits affect the design of structures to be placed in and on the seabed, such as a tidal lagoon or an offshore wind farm off the current north Wales coast [4-5, 10].

If consideration is made of the situation within the Taiwan Strait, the physiography is represented by two depressions whose axes are parallel to that of the long axis through Taiwan [11]. The north-eastern depression, Kuayin Depression, is 60+ m deep, and deepens towards the northeast. The western depression, Wuchu Depression, is 60-70 m deep, and drains southwards into the Penghu Channel and thence into the Penghu Canyon to the south of Taiwan. The two depressions are separated by the Yunchang Rise [11], which is also referred to as the Changyun Ridge [12].

The physiography suggests that Taiwan and the east coast of China were connected by an isthmus identified by the -60 m bathymetry contour around 10 ka BP [7]. As sea level rose the land bridge was gradually inundated by a marine transgression; topographic highs above the -40 m bathymetry contour formed islands within the Taiwan Strait, but were themselves submerged by ~9 ka BP [7]. It is therefore to be expected that in areas shallower than 60 m below present sea level to have layers of marine Holocene sediments overlying former terrestrial deposits.

However, from the modern sedimentological and hydrodynamic viewpoints, it has been suggested [13] that the Taiwan Strait Shelf comprises a modern tidal deposition system. The Penghu Channel and Yuchang Rise (Changyun Ridge) are considered to be a tidal erosional-depositional system. Under the influence of the tidal currents, the Penghu Channel becomes a scour furrow due to the erosion by the strong tidal currents. In contrast, the Yuchang Rise (Changyun Ridge) results in a tidal sand sheet due to the accumulation of sands carried by the waning tidal currents. The sedimentary characteristics of this sand ridge have been described in more detail in [12]. Consequently, the present-day accumulation of sediments within the Taiwan Strait reflects the tectonic setting [11] as well as the results of the marine transgression over the last 10,000 years coupled with contemporary marine processes [12] with, as will be suggested below, influx of terrestrially-derived sediments delivered through the present-day river systems.

Furthermore, due to the tectonic setting of Taiwan, the area is seismically active, and earthquakes are known to affect areas off the western Taiwan coast that are designated for the development of offshore wind farms (Fig. 3), as evidenced by the Chi Chi earthquake (M=7.6) that occurred on 20th September 1999. In addition, it is known [14] that, historically, the southwest coast of Taiwan has experienced a catastrophic tsunami, most probably from a seismically-induced marine landslide. It is therefore essential that for any offshore renewable project to be developed along the western shore of Taiwan, the geo-history of the area and associated processes are taken into account with respect to anticipating how a site might develop into the near future.

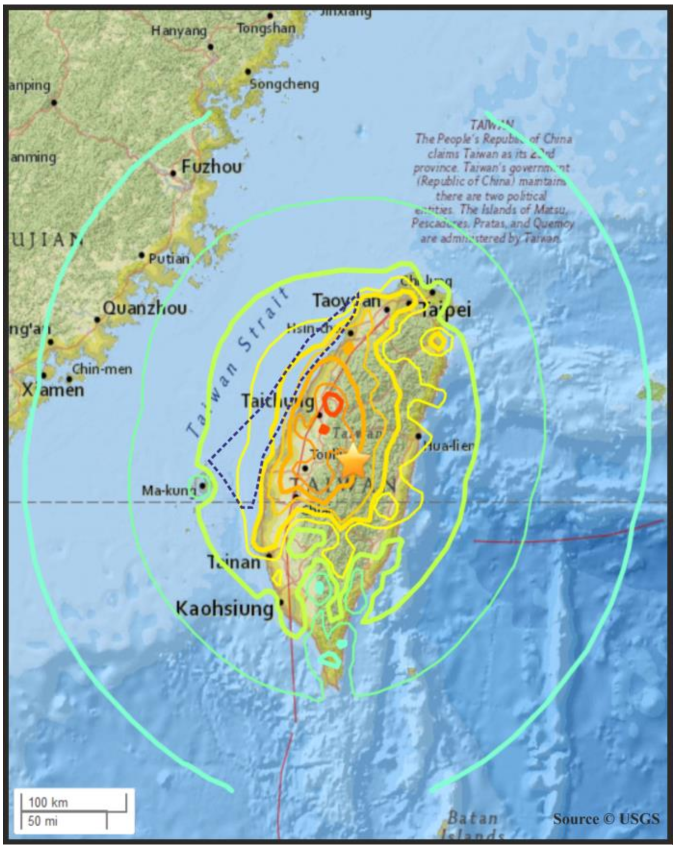

Fig. 3 Iso-intensity map for the Chi Chi earthquake M=7.6 (epicentre shown by the star), relative to the region in which offshore wind farms are being developed just offshore Taiwan (dark blue dashed outline). (Iso-intensity map courtesy of USGS.)

C. *Impact of environment on marine renewable energy projects*

An important aspect of marine renewable energy development projects is not only their impact on the environment, but the impact of the environment on them. The geological record may preserve evidence of relevant processes not otherwise recorded, but which can be identified using hydrographic, geological, and geophysical methods [14] as discussed above.

For instance, near-shore wind farm developments along the western coast of Taiwan could be impacted by typhoon-derived terrestrial debris-charged flash floods that could reach the near-shore marine environment. On the 8th August 2009 during Typhoon Morakot, heavy rain led to the formation of 17 landslide dams, one of which initiated a landslide that dammed the Chi-Shan River. The landslide dam’s collapse after only one hour led to 398 deaths in Hsiaolin Village, and to a debris-charged flash flood that flowed downstream [15, 16]. Google Earth oblique images (Fig. 4) acquired on three different dates illustrate the physical situation at Hsiaolin Village: on 17th November 2001, when there is no obvious sign that a major landslide would be initiated at this location; on 29th January 2010, almost six months after the disaster – the edges of the landslide are depicted by the yellow long-dashed lines (Fig. 4); and on 4th March 2017, which shows how the area has altered subsequently. It is also evident on the image from 29th January 2010 that another, much smaller and less catastrophic, landslide (depicted by the brown short-dashed line) initiated a debris flow into the river (indicated by pale blue short-dashed lines in Fig. 4). Whether landslide dam outburst floods or debris flows drain into the rivers, these events can contribute not only a great deal of sediment at the time of the rain-induced events but also subsequently, during normal rainfall, contributing higher levels of suspended sediment into the river systems and ultimately out into the marine environment for significant time periods after the main event.

Similarly, typhoon rainfall can lead to rivers being dammed by large rapid influxes of sediment from tributaries that block the mouth of the main river. An example of this occurred during Typhoons Wutip and Sepat in August 2007 at the confluence of the Laonang River, southern [17]. Rather than form a dam that blocked all the flow of the main river, the sediment fan gradually decayed through erosion by the river. Also, the impoundment area infilled by sediment transported through subsequent river flow. Again, the rapid deposition of sediment into the river system led to higher levels of both suspended- and base-load sediment concentrations that would have decreased over time. However, the large exposure of fresh sediment in the alluvial fan at the confluence of the main river and its steep tributary provided an ongoing source of sediment that could be mobilised into the river system in any subsequent rainfall event.

What is also apparent in the case of Taiwan is the role of the high mountain topography along the spine of the island, such as the peak associated with Mount A-Li in the south-central part, and Mount Nio-Dray in the north of the island. The existence of the Central Mountain Range only minimally affects the storm tracks of approaching typhoons but plays a significant role in substantially increasing the total rainfall amounts over Taiwan [18]. This may lead to an increased likelihood of heavy rainfall-induced mountain processes within certain rivers in the west and south of the island. Where rivers drain westward towards Taiwan Strait and into the near-shore area, where offshore wind farms are being planned and developed, sediment fluxes associated with these rainfall events may have consequences for near-shore sedimentation and the availability of mobile sediment to tidal current influences. This could be a factor that needs greater attention with respect especially to inter-array cable installation and maintenance and similarly for export cable routes between the offshore wind farms and cable landfalls.

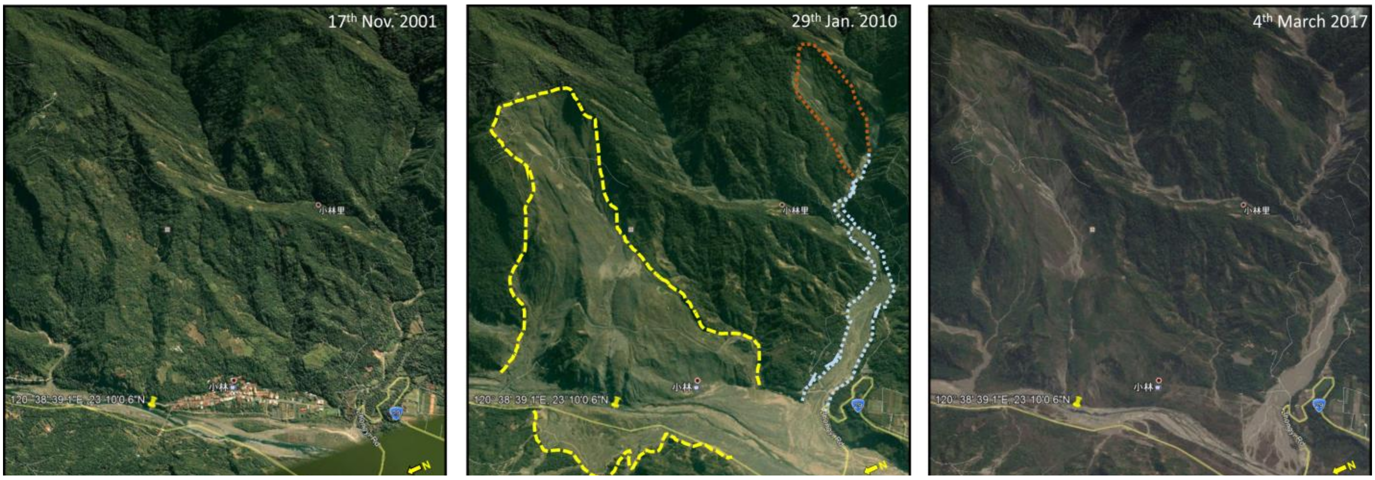

Fig. 4 Oblique Google Earth images for the area around Hsiaolin landslide, southern Taiwan, taken on three dates as indicated in each panel. The village of Hsiaolin, which can be seen in the left panel, was overwhelmed by the landslide on the 8th August 2009 during Typhoon Morakot. See text for details.

Around 90% of typhoons in the West North Pacific-East Asian (WNP-EA) region affect the island of Taiwan. It is located at the turning point of typhoons in the region. Two major typhoon paths occur in the WNP-EA region. One moves directly westwards to the south of Taiwan directly to the South China Sea; the other turns north just to the southeast of Taiwan towards Korea or Japan [19]. It was found that the average number of typhoons affecting Taiwan increased in 2000 from 3.3 typhoons per year (1970-1999) to 5.7 typhoons per year thereafter (2000-2006). Coupled with this observed increase in average number of typhoons per year from 2000, the typhoon track shifted abruptly with a northward trend. It was questioned [19] whether the change in the number of typhoons affecting Taiwan and the northwards shift in typhoon tracks is a function of a changing climate. If this is the case, then it is possible that Taiwan will experience more typhoons each year with all the attendant physical effects. This would imply that heavy rainfall events associated with typhoons will also occur more frequently and that, therefore, the possibility of more landslide-dam outburst floods will occur, with an increased sediment flux through the river systems. It is recommended, therefore, that those involved in the investigation of the near-shore areas off western Taiwan consider the likelihood of increased terrestrial sediment input into the near-shore marine environment.

In the case of a projected tidal lagoon off the North Wales coast, UK, while not affected by typhoons, two rivers, namely the Dulas, and the larger, Clwyd, drain the North Wales coastal hinterland and flow into the area that would become impounded by a tidal range lagoon scheme, if the project is built. The significance in this case, is not the issue of sudden sediment influxes *per se*, but by the way these rivers focus run-off from the largely agricultural land within their respective catchments. The two rivers are ecologically significant in terms of migratory fish populations (river trout and salmon) although the fishing is too small-scale to have commercial significance. What is perhaps less clear but no less important is the way in which these two rivers transport pathogens and particularly astro-viruses within the agricultural run-off. If the outflows from these two rivers were to collect within a tidal lagoon impoundment, water quality could be adversely affected. In an area recognised through the European Water Framework Directive for the quality of its bathing waters along the coast, water quality is not only ecologically but also economically important. Two factors need to be considered. One is how the agricultural run-off can be controlled to reduce the concentrations of pathogens. This includes how the environmental regulator, Natural Resources Wales, can facilitate this process. The other is how overall water quality within a tidal impoundment can be controlled and preferably improved. One suggestion for the latter is to deploy large banks of managed mussels that could be operated purely for their water filtration benefits rather than as farmed seafood. The Menai Strait, to the west of the suggested tidal impoundment, is famous for its edible mussels, and local mussel farmers are keen to develop their commercial interests to help with water quality within a local tidal impoundment, should the opportunity arise.

Whilst intended to provide essential criteria for financial investment in the terrestrial hydropower sector, The World Bank [20] has recently published guidelines on Disaster Risk Management and especially Integrated Geohazard Assessment. Over $3 billion in losses to hydropower assets have occurred within the Himalayan Region alone in just four years. These have occurred due to earthquakes, cloudbursts, landslide dam outburst floods, to name but four causes, and in some cases a combination of processes in cascading multi-processes. It is important to broaden consideration of natural disasters from being single-issue events (i.e. an earthquake, a landslide, a cloudburst flood, etc.) to how a combination of processes can cascade the magnitude and complexity of a catastrophic event. An example would be a cloudburst triggering landslides that dam rivers, and the landslide dams then burst releasing torrents of flood water and sediment downstream. A temporary impoundment of a river in spate can very quickly retain a couple of million cubic metres of water and sediment, which, when its dam bursts, can release the water and debris at rates measured in thousands of cubic metres per second as a short-duration but catastrophic flash flood, such as happened in north-central Nepal in 2016. This resulted in tens of millions of dollars of damage to hydropower installations downstream and loss of power generation (and hence revenue) for years afterwards. Therefore, it is hardly surprising that one of the key global funders of major hydropower projects has developed methods by which georisks can be assessed prior to the release of major capital to a project developer. There is no reason why the strategies being espoused by such guidelines cannot be extended to augment georisk assessments for near-shore renewable energy projects. It is for these reasons that we are recommending that for near-shore offshore renewable energy projects, be they off the coast of North Wales or off the western coast of Taiwan, consideration is given to the broader panoply of processes, terrestrial and marine, in conjunction with the impacts of a changing climate. On offshore wind farm project may have a project life span of 25-35 years; a coastal tidal lagoon project could have a project life measured in excess of 120 years, during which time the cumulative effects of climate change may well become more pronounced and the consequences more severe. It is thus imperative that geo-risks are considered more holistically.

IV. Conclusions

There are ambitious goals around the world for substantial development of marine renewable energy generation through Offshore Wind, Tidal Stream, and Tidal Range projects. Ocean energy deployment could reach 748 GW by 2050, create 160,000 direct jobs by 2030, with a market worth ~£40bn per annum by 2050.

The role of Georisk Management in marine renewable energy projects is ultimately to understand, reduce where possible, and quantify the risks associated with the dynamic geological and marine systems at and around proposed infrastructure projects, and ultimately to mitigate those risks. This has been discussed through consideration of three strategic approaches, namely, (a) the use of best practice guidelines; (b) determination of the geohistory of a site; and (c), by gaining an understanding of the potential physical impacts of the environment on a renewable energy project.

Two examples of the use of best practice guidelines have been presented, with one for an offshore wind farm in the Irish Sea, and the other for one in the southern North Sea. A systematic workflow (**imagis**^{TM}) was applied to the processing and interpretation of seismic data and to the incorporation of geotechnical test results from intrusive investigations. This led to a more standardised approach to managing the results from the Site Investigation for the development of a 3D geological Ground Model. This approach was estimated to reduce the overall Site Investigation costs significantly and increased the level of confidence on the soil properties across the site when compared with the more traditional soil modelling strategies. Additionally, as each stage of the Ground Model development was optimised based on the results of the last, cost reductions accumulated throughout the development period.

The second approach presented is the consideration of past geological conditions (a site's geo-history), which can lead to a better understanding of the physical environment and processes that have resulted in the geological record identified at marine renewable energy sites. For any offshore renewable energy development, the current site conditions are the culmination of the site's previous geohistory over previous millennia, if not longer. By gaining a better understanding of how a landscape, now submerged, has evolved, coupled with appreciating ambient physical processes, better insights can be gained as to the earth system processes that have been and that may still be active at that location, and which may impact any prospective offshore renewable energy project.

An important aspect of marine renewable energy development projects is not only their impact on the environment, but the impact of the environment on them. For near-shore renewable energy projects it is increasingly important not only to consider the marine environment and associated processes but also the possible impacts of processes derived from nearby terrestrial environments, such as meteorological events (e.g. cloudbursts, typhoon rainstorms). These can trigger geological processes (e.g. debris flows, landslides) that can dam rivers impounding large volumes of water and sediment that are released when the dams break. Examples have been given of the possible impacts of typhoons on land system processes and how these may influence ambient conditions for near-shore offshore wind farm development. Similarly, for a case of a planned coastal tidal energy lagoon, influences of terrestrially-derived agricultural pathogens on offshore water quality can be both physically and economically significant and need to be managed.

It is for these reasons that we are recommending that, for near-shore offshore renewable energy projects, consideration is given to the broader panoply of processes, both terrestrial and marine, in conjunction with impacts of a changing climate.

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