Geo-Resilience 2023 Conference, Cardiff, Wales
D.G. Toll & M.G. Winter (Eds)
British Geotechnical Association, London. 2024
https://doi.org/10.53243/Geo-Resilience-2023-4-2

High Tensile Stainless Steel-Wire Cell with the Inclusions of Stones as Sustainable Approach to Protect the Coast against Natural Hazards and to Mitigate the CO_2 – Footprint

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Abstract

Rising sea levels and climate change is a product of greenhouse gases and CO_2 emissions, primarily due to human activities. The detrimental effects of this has inflicted consequences for many coastlines around the world in the form of erosion and risks of floods. The occurrence of so makes Coastal Erosion Management (CEM) quintessential, to protect local communities and livelihoods. However, protecting the coast by utilizing coastal defences and preventing erosion is not always adequate and taking a sustainable approach in finding a fit solution with minimum carbon footprint is necessary. The purpose of this study is to portray how the high tensile steel-wire cell solution is a more sustainable approach in comparison to rock armour and concrete revetments by making carbon foot print assessments and evaluations through a case study in Beesands UK. Based on the findings, it was found that the high tensile steel-wire cell had around 20%-30% less CO_2 emissions than rock armour, and that concrete revetment had around two times more emissions than rock armour, showing promising grounds for the steel-wire cell as a sustainable solution. Moreover, besides the favourable aspect of sustainability of the high tensile stainless steel-wire cell, Digital Elevation Model (DEM) and RTK GPS data from the University of Plymouth exhibits that not only the coastal solution stopped the erosion in a dynamic wave environment, the data also conveyed that the solution was stable, did not shift and maintained its structural integrity. Results confirm that the steel-wire cell solution is an effective implementation of an erosional geo-hazard measure.

Keywords: carbon footprint, natural hazards, stee-wire cells

1. Introduction

Coastal erosion is one of the biggest geological concerns in the UK, with the Southern and Eastern coasts of England being some of the most susceptible areas to coastal erosion. Several influential factors have contributed to the accelerated rates of flooding and coastal erosions, including Rising sea levels, Climate change, and increased urbanisation of coastal regions. Hence, placing a large burden on many coastal communities (Poulton, et al., 2006). According to national statistics, 17% of the UK coastline is suffering from coastal erosions, with England and Wales being disproportionally affected. In these regions, nearly a third of the coastlines are retreating at an alarming rate of more than 10 cm per year. Consequently, 45.6% of the English coastline requires some form of artificial protection including Seawalls, Groynes, or other coastal defences (Russell et al., 2018). Moreover, The Environment Agency estimated approximately 700 properties in England could be at risk of collapsing in the next 20 years, and without appropriate coastal protection, this figure could rise to 5,000 properties (Masselink et al., 2018). Consequently, residential owners are set to suffer significantly, as compensation for their losses is typically limited or non-existent. Thus, the careful analysis and planning of these coastlines are very important (Poulton et al., 2006).

The efforts in reducing greenhouse gases and having zero carbon initiatives have internationally grown substantially (Paris Agreement, recent COP26 in Glasgow). The aim of this article is to showcase existing shore protection solutions such as rock armour and concrete revetment and to present a more sustainable coastal solution like the steel-wire cell with the inclusion of stones. To estimate the potential CO2 footprint reduction the steel-wire cell has over other existing solutions, a qualitative comparison in CO2 footprint is taken (based on the literature, data, and a case study in England, Beesands beach). Furthermore, data undertaken by the University of Plymouth will be evaluated to convey how the steel-wire cell provides a successful solution against erosion which is a growing geo-hazard problem.

1.1 Site study

Start Bay embayment encompasses five interconnected gravel barrier beaches on the south coast of Devon undergoing erosion at a rate of 2 meters a year1. The four beaches include Hallsands, Beesands, Slapton Sands, Blackpool Sands, and Strete Gate2. The shoreline sediment is comprised mainly of rounded gravel (D50 = 2– 10 mm) derived from flint and quartz, with some locally sourced material in the form of mica-schist and slate resulting from cliff erosion (Ruiz de Alegria-Arzaburu and Masselink, 2010). The wave climate is directionally bi-modal undergoing swell waves from the south and wind waves from the east. According to Wiggins et al., (2017) the embayment is meso to macrotidal in which the neap and spring ranges 1.8 m and 4.3 m respectively. The extensive rate of erosion has caused the urgency of implementing a coastal defence solution in Beesands in order to protect the coast, from the risk of homes/infrastructure collapsing. However, due to the lack of space available because of mass erosion, the use of hard engineering structural solutions such as the steel-wire cell is obligatory. Additionally, the wave environment is detrimental thus, the use of soft engineering defence solutions (such as dune stabilization or beach nourishment) are not applicable.

2. Existing coastal defence measures present at Beesands

Beesands beach has several coastal protection systems in place including but not limited to: rock armour, precast concrete elements, steel-wire cells, and concrete seawalls. A large section of the beach is still protected by rock armour (CMAR, 2022). Rock armour due to many failure modes such as displacement, scouring, and overtopping is associated with high maintenance costs. Whilst it may dissipate low-energy waves it cannot withstand storms or very severe dynamic wave environments, and thus sustains damage. As in many occasions, due to some extreme winters and intensified wave conditions (“the beast from the east”) large wave heights and long peak wave periods in Beesands were experienced. However, the rock armour was incapable of withstanding the wave environment as there was overtopping, showing its low capacity and flood risk disadvantages. Displacement was also evidenced due to scouring and thus, the rock armour was dispersed in the sea on many occasions such as “storm Darcy” (CMAR, 2022). The displacement of the rock armour is a pivotal yet anticipated concern as not only does it show its ineffective competence but also its constant need of maintenance to arrange the dispersed rock armour to its original form. Causing it to be a costly measure for the council and increasing the carbon footprint of this coastal solution.

3. Steel-wire cell design and installation

The design of the steel-wire cells can be described as a steel array of mesh-filled stones, in interlocking cell compartments. With tensioning cables in the centre of each cell, to compact, ensure more structural integrity, and to stop the movement of stones within the cell. The steel utilized is of very high quality as it is high-tensile and stainless with a grade of 1.4462 (AISI 318). Insinuating that the wire mesh is corrosion resistant for the most intense and high salinity seawater conditions. The steel-wire cell in which Geobrugg manufactures goes through strict testing to the latest European standards and is entitled to wear the CE-marking.

To safeguard the coast the following installation steps are necessitated for a safe and successful structural intervention:

i. To prepare the terrain an excavator is utilized for earthworks
ii. Once a 45-degree slope angle and profile are achieved a layer of geosynthetic is laid on the slope
iii. Installing a base steel mesh array on the slope
iv. Assembling the baffles using the steel mesh and interlocking the base and baffles using a helicoil
v. Adding tension cables in the centre of each of the cell compartments
vi. Filling the cell array with locally sourced stones
vii. closing the top of the cell compartments using a steel mesh array and interlocking the top with the side baffle, using a helicoil
viii. Tensioning the cables by using a tensioning machine

[1] https://www.bbc.co.uk/news/uk-england-devon-18779584

[2] https://www.coastandcountry.co.uk/blog/start-bay-guide

4. Effectiveness of the steel-wire cell solution in Beesands, Devon UK

In 2016 the steel-wire cell solution was installed because there had been detrimental erosion causing the coast to recede. Because the rock armour had failed to serve its purpose of stopping erosion and dissipating the energy of the waves. As mentioned above, Beesands has different coastal defences at different parts, places in which inhabit more residents, houses and businesses are commonly safeguarded by seawalls and are reinforced with rock armour units. On the contrary, the Northern section of Beesands which has the village green is a less congested area with only 15 properties behind it, which is the section this report concentrates on. And hence why the steel-wire cell has been deployed in that part of Beesands. The deployment of the steel-wire cell solution has been successful in solving the geohazard concerns. The effectiveness of the steel-wire cell solution in preventing and stopping erosion and whilst at the same time, its ability to dissipate the dynamic energy of the wave, can be linked to the structural arrangement of the solution. The structure is monolithic with the inclusion of strong tension cables between each cell compartment which when tensioned do not allow any movement in the stones within the cells. Enforcing the structure, providing stability and structural integrity making it robust for the most critical conditions. The solution is also adaptable because it rises and drops with the elevation of the sea level. These beneficial aspects minimise the wave run-up and wave reflection for the most dynamic wave environments. Additionally, the solution is extremely discrete and integrates well with the coast allowing safe access for visitors.

5. Results and evaluation of the Digital Elevation Model (DEM) data

The outcome of utilizing the high tensile stainless steel-wire cell solution facilitates promising grounds for many coastlines and specifically for Beesands. To support the effectiveness and successful implementation of this solution, the main surveying method used for the project is the digital elevation model (DEMs) generated through photogrammetry techniques from aerial imagery, captured using an Unmanned Aerial Vehicle (UAV/Drone). The technique requires aerial image collection across the extent of the site. With 80% overlap between the images they can be aligned and rectified onto a local coordinate system providing a representation of the surface elevation of the area. In order to compare the change between surveys the UAV measurement accuracy needs to be considered and accounted for in this analysis. Thus, a Geomorphic Change Detection (GCD) tool was adopted in which gave a new DEM output model of the difference (DoD) between two UAV survey surfaces. Showing the geomorphic change that can be considered real (with 95%) and not a result of measurement error. This survey technique was undertaken by making surveys at different intervals of time denoted as S2, S3 and S4. In which survey S2 was taken immediately after post construction, S3 was taken in the summertime and S4 was taken in the winter.

From the collection of data and the GCD analysis in which allows the overlay of the DoD surface onto the site, it is able to examine any change in elevation within the thresholds applied. Between S2 and S3 (summer 2021) it can be witnessed that there is widespread accretion observed across the intertidal beach with evidence of a significant 'berm' feature present (~1 to 1.5 m accretion; Figure 1). There is no evidence of any change to the new defence apart from some small accretion at the base where it is likely some final re-profiling of the beach was undertaken after S2. Between S3 and S4 (winter 2021/2022) we see the opposite trend with widespread lowering of the berm that was evident in Figure 1 with 1 to 1.3 m of material removed (Figure 2) due to sediment redistribution. Again, we see no evidence of changes in high tensile stainless steel-wire cell defence itself. This conveys that There is no clear indication of significant changes in the beach material adjacent to the defence (CMAR, 2022).

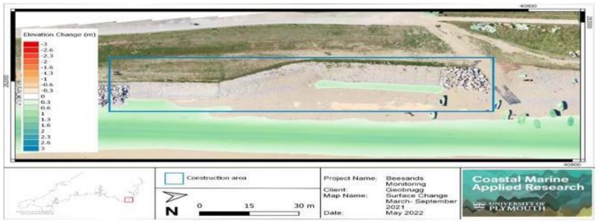


Figure 1: Aerial image from Survey 3 overlaid with the DoD elevation changes observed between Survey 2 and Survey 3 (summer 2021) (CMAR, 2022).

[3] https://ghgprotocol.org/life-cycle-databases

[4] https://www.carboncare.org/co2-emissions-rechner.html

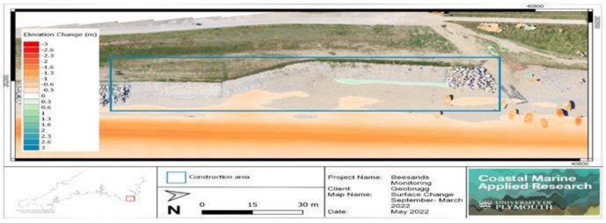


Figure 2: Aerial image from Survey 4 overlaid with the DoD elevation changes observed between Survey 3 and Survey 4 (winter 2021/2022) (CMAR, 2022).

6. Results and evaluation of the RTK GPS data

To support the DEM data, it is also essential to analyse the movements of the steel wire cell defence by measuring the movement of the ground anchor positions immediately after post construction (S2) and after the winter season (S4). The sole purpose of this survey test was to measure the horizontal and vertical shifts of the solution. The terrestrial measurement method was calculated based on the movements of the ground anchor bolts used to pin the mesh in place (Figure 3a). The data (Figure 3b) encompasses the distribution of point measurement with the delta values for the horizontal and vertical parameters (dX, dY, and dZ). The majority of values fall well within the ±0.03 m accuracy of the RTK GPS for (dX, dY, and dZ) however the most significant movement in the dx direction at 0.05 m and -0.062 for the dy direction can be witnessed. This portrays that there has been little movement of the structure over the survey period. In which indicates There is no obvious movement or shift in the steel-wire cell solution.

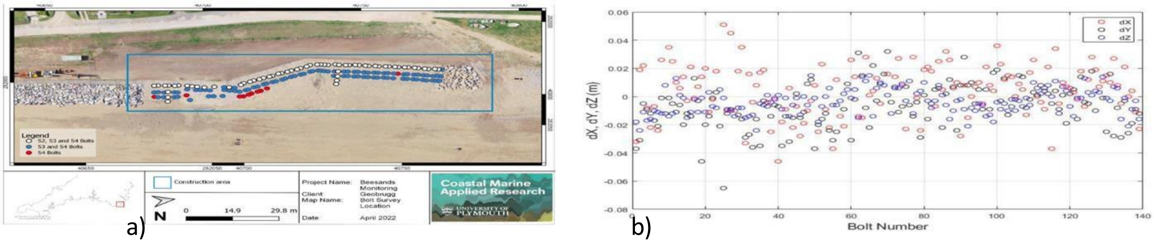


Figure 3: (a) Site Map indicating the location and sample frequency for the ground anchor bolts used on the defence with the RTK GPS, (b) Comparison of the defence bolt positions between S2 and S4 (CMAR, 2022).

7. Comparative estimation of CO2 footprint for engineered coastal defences

Carbon footprints are a leading indicator of environmental damage. One of the aims of this study was to assess the carbon footprint of three types of offshore defences including steel-wire cells, rock armour, and concrete revetment. The study was located in Beesands, with a stretch of 70m in length and 12m in width.

7.1 The methodology used for carbon footprint calculations

The following measures were used to estimate carbon footprint:

- Shipping and construction documents provided by the contractor and the producer of the steel-wire cells
- Personal communication by the contractor of the Beesands Project
- Various literature values of CO2 footprint for the extraction of material[3]
- An online carbon emission calculator for transport[4]
- The latest carbon modelling tool of the British Environment Agency EA (Denk M, 2022)
- A paper by a specialized consultant for shore protection in the UK comparing the carbon footprint of two types of coastal constructions (concrete caissons and rubble mound breakwater) to compare and verify the data (Broekens et al., 2010)

7.2 CO_2 footprint processes

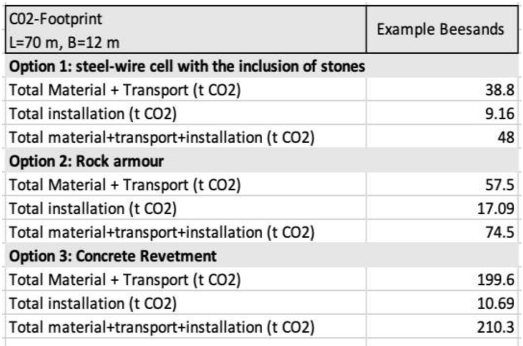
The process of using shore protection systems is crucial when taking into account and assessing subsequent CO2 footprint impact, from structures like breakwaters/dams. The individual contributors of total carbon emissions should be identified to get an accurate understanding of the shore protection system. The main relevant stages can be summarised with the following stages: material production, transport, construction/installation, and disposal. With respect to this case study, only the primary three stages were selected to use as a comparison between the aforementioned shore protection systems: material, transport, and construction/installation (Denk M, 2022).

The reasoning behind this can be encapsulated because of the impact that both operation and disposal have is difficult to quantify. After all, strong/reliable data is scarce. However, both stages would still need to be accounted for in the case of a whole-life carbon assessment and are recommended to be included when procuring approval from authorities, in specific projects. Additionally, the primary three stages account for a large majority of the overall CO2 footprint and would therefore give an informed estimation of a project's appraisal stage where in which options would be evaluated.

8. CO2 footprint results

The calculation to justify the CO2 footprint has been collated for the options outlined above (steel-wire cells with the inclusion of stones, rock armour, and revetment) and is summarised in Table 1.

Table 1: Results of CO2-footprint calculations for three different options of the case study (Denk, 2022).

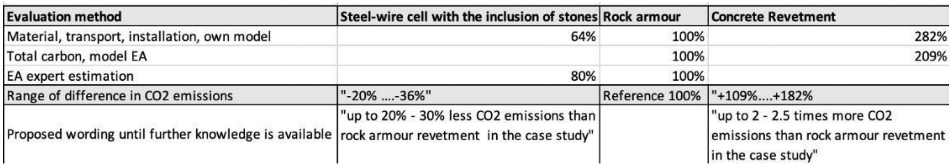


C02-Footprint L=70 m, B=12 m	Example Beesands
Option 1: steel-wire cell with the inclusion of stones	
Total Material + Transport (t CO2)	38.8
Total installation (t CO2)	9.16
Total material+transport+installation (t CO2)	48
Option 2: Rock armour	
Total Material + Transport (t CO2)	57.5
Total installation (t CO2)	17.09
Total material+transport+installation (t CO2)	74.5
Option 3: Concrete Revetment	
Total Material + Transport (t CO2)	199.6
Total installation (t CO2)	10.69
Total material+transport+installation (t CO2)	210.3

9. Comparative evaluation of CO2 data for the coastal defences

The information gained from the result in Table 1 was normalized and compared with values from the EA's total carbon model (for rock armour vs. concrete revetment) and an EA expert estimation (for steel-wire cells with the inclusion of rock vs. rock armour, educated estimate according to Denk M, (2022). Results are given in Table 2 below:

Table 2: Comparison of Normalized values of the CO_2 footprint based on the Beesands case study (Denk, 2022).



Evaluation method	Steel-wire cell with the inclusion of stones	Rock armour	Concrete Revetment
Material, transport, installation, own model	64%	100%	282%
Total carbon, model EA		100%	209%
EA expert estimation	80%	100%	
Range of difference in CO2 emissions	"-20% ....-36%"	Reference 100%	"+109%....+182%
Proposed wording until further knowledge is available	"up to 20% - 30% less CO2 emissions than rock armour revetment in the case study"		"up to 2 - 2.5 times more CO2 emissions than rock armour revetment in the case study"

The results of the case study show that the steel-wire cells with the inclusion of stones may lower CO2 footprint levels than that of rock armour and concrete revetments. This is because the steel-wire cells require significantly less quantity of stones and additionally the stones used are smaller in comparison than that of rock armour, this subsequently results in an overall lower amount of material extraction which can also be locally sourced. Moreover, the steel-wire cells and rock armour both do not use concrete, which when taking into account its cement, reinforcing steel, and the overall weight of using the concrete option would result in a much higher quantity of carbon footprint emissions if using the concrete revetments coastal protection solution (Denk M, 2022).

Other relevant findings in the case study portray that when liaising with the contractor it was discussed that the blocks used for concrete armour are mostly difficult to source locally, in instances like this, the blocks need to be shipped in from overseas countries like Scandinavia or Belgium. In the Beesands case study, the blocks were able to be sourced locally but this seems to be more of an exception and not a common occurrence. But if the blocks would have to have been shipped to Beesands which is the case in most instances of rock armour protection, using the steel-wire cells would have been 30% - 40% more CO2 effective than the rock armour solution. regarding the steel-wire cells, the metal mesh needs to be imported from overseas such as Switzerland, although the rise in CO2 footprint from this would be compensated by the fact that the filling would be done using locally sourced smaller-sized pebbles and stones (Denk M, 2022).

For the stages of Maintenance and Dismantling/Recycling, which as discussed earlier would not be considered in the calculations but a qualitative appreciation can be made:

- In general, the process of maintenance and dismantling can be estimated to account for less than 35% of the total CO2 footprint in all 3 coastal defence solutions. Although depending on site-specific conditions these processes cannot be neglected for an overall carbon footprint model and estimations of these values need to be found in future studies.
- As informed by the manufacturer, the metal mesh used for the cell array can be in due course recycled after its use or product end of life. Thus, a recycling value of the mesh still needs to be established in future studies.
- As informed by the installers of the rock armour solution in Beesands, the rock armour needs to be repaired every year due to the impact of heavy storms on the structure, in comparison the steel-wire cells showed that it was maintenance-free in the first 5 years of its service life. This would conclude that the rock armour would incur additional CO2 footprint rates because of its regular maintenance requirements. This is in stark contrast to the steel-wire cells which is now showing promising results after 5 years in use in terms of sole maintenance. However, long-term studies still need to be done to have a more in-depth understanding of its maintenance and service life needs, for more accuracy (Denk M, 2022).

10. Recommendation for future studies

For a broader understanding and for more enhanced and accurate results it is crucial to do a CO2 footprint comparison of the steel-wire cells to other coastline protection systems by studying the following:

- To determine if the results of the CO2 footprint are similar or at least in the same range as the case study in Beesands
- finding whether projects with different parameters to the Beesands case study, have favourable CO2 footprint (including installation) for the steel-wire cells defence in comparison to other coastal defences (e.g. rock armour)

11. Conclusion

From the findings of this study, the CO2 footprint for the steel-wire cell defence solution in comparison to the rock armour and concrete revetments may help reduce the carbon impact, based on the Beesands case study. Even though the stainless-steel mesh array is transported from abroad the steel-wire cell defence has significantly less CO2 emissions than compared to rock armour and concrete revetment, in consideration of the parameters of this study. This is because the steel-wire cells do not necessitate large blocks of rock armour to be transported over a long distance to construction sites and can instead use locally sourced available material. Moreover, the solution requires no maintenance after five years unlike the concrete revetment defence and the ineffective rock armour solution which needs to be maintained every year because of the storms. This contributes to continuous maintenance and concerns over growing annual carbon footprints due to the consequences of global warming and more frequent and severe storms for rock armour defences. The results also prove that the steel-wire cell is an effective measure for an erosional geo-hazard measure and showcases its robust ability to dissipate dynamic wave energy. As data from the University of Plymouth exhibits that the majority of displacement values fall well within the ±0.03 m accuracy of the RTK GPS. And so, we can be confident that there has been little movement of the structure over the survey period. Meaning that the structure was stable and dissipated the energy of the waves without shifting or failing and stopped the erosion. The data of this study are highly related to the Beesands project and whilst the results may be adopted to similar kind of project with similar resemblances, it cannot be generalised for all types of projects. Therefore, for more accurate results it is important to carry out similar CO2 footprint assessments for a wide range of different projects.

Acknowledgements

I would like to express my profound gratitude to Peter Mccourt for being extremely helpful throughout my working life and being a very supportive mentor for me. Peter’s extensive experience has taught me many things and has enhanced my technical abilities as a civil engineer.

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