Special Topic

Shore Protection against Erosion: Carbon Footprint of an innovative Steel Wire Mesh Cell Solution compared with other Solutions

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Geobrugg developed an innovative solution of steel mesh cells in high-tensile stainless steel for coastal protection. This article estimates the carbon footprint compared with rock armour and concrete revetments for a case study in Devon, United Kingdom.

Geotechnics • Hydraulic engineering • Shore protection • Mesh • Carbon footprint • Innovation • United Kingdom

1 Introduction

Many shorelines in Europe are subject to erosion. For example, of Great Britain's around 17,600 km of overall shoreline, at least 3,000 km are estimated to face erosion issues. Approximately 2,300 km of Great Britain's shorelines are artificially protected [1]. For many other European countries with long shorelines, such as Norway, Greece, Italy, Croatia and Denmark (including Greenland) [2], wave erosion and artificial protection against it is and remains a major issue for local communities, politicians, researchers and planners.

Rising sea levels and the expected increase in extreme weather events such as storms may lead to an increasing demand for coastal management and artificial protection structures in the coming years. In accordance with international efforts to limit and reduce greenhouse gases (Paris Agreement, recent COP26 in Glasgow), the demand of low carbon footprint solutions for shore protection is expected to rise. Sound and sustainable shore management methods include spatial planning, but also new types of engineered solutions with a low carbon footprint.

This paper shows existing solutions for shore protection such as rock armour and concrete revetments and introduces a new type of specially engineered solution called Tecco Cell [3], which is an array of steel mesh cells filled with locally sourced blocks, stones and pebbles. Using a qualitative comparison of carbon footprints based on literature, data and a case study in England, this paper aims to assess the potential reduction in carbon footprint of the innovative steel mesh cell solution compared to existing solutions for a project appraisal stage. It also lists areas of interests for further studies such as recommendations for a better quantitative understanding of carbon footprints for specially engineered shore protection solutions.

1 Rock armour
Source: Jonathan Wilkins, www.geograph.co.uk

2 Precast-concrete elements
Source: Coastalwiki, www.coastalwiki.org

3 Steel-mesh cells filled with blocks, stones and pebbles
Source: Geobruggg AG, www.geobrugg.com

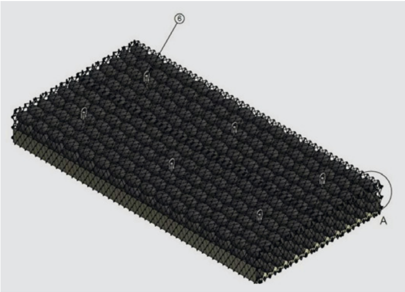
4 Curved concrete seawall
Source: Engineering Civil, https://engineeringcivil.org

Fig. 1: Different types of shore protection

2 Existing Shore-Protection Systems

Existing systems for shore protections (**Fig. 1**) include, but are not limited to:

1. **Rock armour:** this system consists mainly of large boulders installed on a relatively low gradient on the shore to dissipate energy and protect the shore from wave erosion (scour)
2. **Precast-concrete elements:** as for rock armour, this type of revetment is often used on shallow slopes to protect the shore from wave erosion (scour).
3. **Gabions:** these come in different sizes, are mostly rectangular shaped and are filled with locally sourced blocks, stones and pebbles.
4. **Concrete or sheet pile seawalls:** this type of wall, which is mostly vertically installed, acts as a barrier on the shore, is sometimes back-anchored, and varies in dimension and style.



Principal drawing of Tecco Cell mobile mattress
Source: Geobruggg AG, www.geobrugg.com

Tecco Cell installed as shore protection
Source: Landmarc, https://landmarc.co.uk/

Fig. 2: Tecco Cell principal drawing and installed as shore protection

All the above solutions are proven engineered solutions for coastal protection. Depending on site-specific conditions, the comparison of advantages and disadvantages of different engineered options will lead to the choice of the most appropriate solution. In the case of shore protection, main factors to consider are:

- Cost of material and transport
- Cost of installation
- Overall service life
- Resistance to scour
- Maintenance costs
- Dismantling/recycling

Carbon footprint assessments have become an important tool for decision makers from the beginning of this century. For example, the Environment Agency for England and Wales (EA) now requests a carbon lifecycle assessment for any newly funded shore protection structure. Many other countries with long shorelines have already adopted similar regulations or will probably establish them soon, considering the aim of the industrialized world to significantly cut back on carbon emissions.

3 Innovative Cell Mesh Solution

Gabions filled with stones and pebbles have been in use for several decades and are now a well-known solution.

Tecco Cell: installation in 2021
Source: Landmarc, https://landmarc.co.uk/

Finished installation of shore protection in 2021
Source: Landmarc, https://landmarc.co.uk/

Fig. 3: Tecco Cell installation and finished work at Beesands, Devon UK

Tecco Cell and Tecco Cell mobile mattresses extend the range of possible shore-protection schemes (**Fig. 2**) using a steel wire mesh in high-tensile stainless steel 1.4462 (AISI 318) [4]. The product is a specially designed array of steel-mesh cells. According to the manufacturer Geobrugg, this wire mesh (product name Tecco) possesses a European Assessment Document EAD [5] and the product is therefore entitled to carry the well-known CE-marking. The CE-marking confirms that the product is tested according to the latest European Standards, and that regular factory production control (FPC) is carried out.

The following main installation steps are necessary:

1. Preparation of the slope to be protected using an excavator
2. Installation of geosynthetics as required for separation and filtration
3. Deployment of the empty cell array, on the slope
4. Filling of the cell array with locally sourced blocks, stones and pebbles
5. Closure of the cell array with clips and ropes
6. Completion of installation with rock armour at the edges of the cells to prevent scour

The above steps will be considered for the carbon footprint evaluation in **chapter 6**.

4 Case Study – coastal Protection with Tecco Cell in Beesands, Devon UK

In 2016, an installation of Tecco Cell was realized at the beach of Beesands, Devon UK. According to the local contractor, the history behind the rehabilitation of eroded shore protections can be summarized as outlined below [7]:

"The whole beach front at Beesands is protected by various types of sea defences. The part of the beach that has most residential properties and businesses has been protected by concrete revetment/walls and very large rock armour (each rock heavier than 5 tonnes). The lower (or Northern) section of Beesands has the village green and around 15 properties behind it. This is the section the case study focuses on.

Severe storms early in 2014 caused the existing rock-armour sea defence to fail along an approximately 150 m stretch of the beach. As a first measure, a geotextile mattress with rock revetment was installed. That solution failed due to exposure of the geotextile to UV-light and after severe storms. The rock-armour revetement then collapsed.

The local authorities then published a tender to replace the damaged rock armour revetement including geotextiles and was also calling for innovative solutions for better type of shore protection.

In a joint venture between the contractor and the producer of Tecco Cell, a custom-made solution was designed for first an initial length of 20 metres. The project was completed in 2016 after being approved by of the Environment Agency".

After the successful installation of the 20 m stretch, in 2021 another 70 linear metres were secured using Tecco Cell (**Fig. 3**). After storm Darcy, the contractor in 2021 published a video [8] showing that this construction has performed well in the years since installation and showed no damage or corrosion as of November 2021. [9]

5 Estimated Carbon Footprint Comparison for Shore-Protection Solutions

5.1 Types of Shore Protection Solutions examined

Carbon-footprint studies are nowadays used to investigate account for possible damages to the environment. For this study, the carbon footprint of three different types of shore protection was compared:

- Tecco Cell
- Rock armour
- Concrete revetment

For the comparison, the author chose to work with the site of Beesands, since it is well documented and two of the three selected revetements had been installed at the site (see **chapter 4**). A stretch of 70 m length and 12 m width was compared, which is the actual size of the project carried out in 2021.

5.2 Tools and Data

The following tools and databases were used to estimate the carbon footprint:

- Shipping and construction documents provided by the contractor and the producer of Tecco Cell
- Personal communication by the contractor of the Beesands Project
- Various literature values of carbon footprint for the extraction of material, for example [15]
- An online carbon-emission calculator for transport [14]
- The latest carbon-modelling tool of the British Environment Agency EA [11]
- 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 [10]

5.3 Type of Assessment

The Environment Agency for England and Wales (EA) distinguishes between primarily two kinds of assessment:

- **For an early product appraisal stage:** Carbon modelling using databases of existing projects as estimates. This is mainly used to identify possible alternatives in an early project stage.
- **For a project undergoing official approval by the EA:** Carbon calculation of the whole product cycle (whole-life carbon assessment).

Since Tecco Cell can be regarded as a viable alternative to existing protection solutions, the following carbon footprint comparison is carried out at the product appraisal stage.

In the calculations, the author chose to use the data obtained from literature and existing online carbon calculators. A cradle-to-gate (for materials) and well-to-wheel (for transport) approach was adopted. For this, some adaptations of the values had to be made by hand.

The calculations were also compared with values from the latest EA carbon modeling tool [11]. Moreover, the values were also compared with an estimation of a local EA expert on carbon footprint for verification [13].

5.4 Process

Assessment the carbon footprint of a shore protection system such as breakwaters and dams requires identifying the individual contributors to the total carbon emissions of the construction materials, transport to the site, construction activities, operation and maintenance, and disposal at the end of the constructions' design life [13]. In short, the following stages are generally considered:

- Material production
- Transport
- Construction/installation
- Operation/maintenance
- Disposal

For this case study, only the first three stages (material, transport, construction/installation) were compared, mainly for the following reasons:

- The first three stages account in most of the cases for the greatest part of the overall carbon footprint and would give a good first idea on a project appraisal stage, where options are evaluated.
- For operation and disposal, it is much harder to find robust data to compare. However, these stages will need to be accounted for in a whole life carbon assessment and are recommended to be included when seeking for approval from authorities for a specific project.
- For operation and disposal, a qualitative assessment will be given in **chapter 7**.

6 Results of the Carbon Footprint Assessment

The calculations for the carbon footprint assessment were made in an Excel-Sheet for the options outlined above (Tecco Cell/rock armour/concrete revetment). A summary of the results is shown in **Table 1**. The detailed calculations were carried out separately and can be provided on request.

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Table 1: Results of carbon footprint calculations for three options of shore protection for the Beesands case study (length = 70 m, width = 12 m)

Stage	Carbon footprint [t CO_2]		
	Option 1: Tecco Cell	Option 2: Rock armour	Option 3: Concrete revetment
Total material + transport	38.8	57.5	199.6
Total installation	9.16	17.09	10.69
Total material + transport + installation	**48.0**	**74.5**	**210.3**

7 Evaluation of Results

While the raw data of the calculations gives a good first impression of the different carbon footprints for the case study, the numbers need to be put into context for a sound appreciation. Therefore, some general statements regarding the quality of data, the sensitivity of values to changes, and whether the data can be generalized are given below.

7.1 Evaluation of Data used

- Generally speaking, data on carbon footprint values may vary greatly for one specific value and assumptions needed to be made by the person performing the study.
- Operational data for the case study (material weight, transport distances, type of machinery used and operating hours) were considered to be of good quality, because two of the above options (Tecco Cell and rock armour) where built at this site and reports and shipping documents are available.
- The data on carbon emissions for material extraction was sometimes hard to find and showed a wide range of values. This is often due to the fact that these values have not been assessed for the specific case (e.g. block extraction). For example, the material extraction cradle-to-gate for large blocks may vary greatly (by a factor of 10 or more) depending on whether the rock is extracted for that reason or is "left-over" material [10]. In this case, the author chose the same value as other authors had in their study [10], where the material was locally sourced as "left-overs".
- The author needed to update and estimate the values to obtain cradle-to-gate or well-to-wheel values for some of the positions. For example, the transport industry often gives "tank to wheel" values, which do not account for the extraction of the fuel itself and show a better result than in reality.
- The case study is representative, and its results may be compared for similar shore-types, wave impacts, gradients, use of materials, and transport distances. However, the results of this specific case study cannot yet be generalized. As further project use this novel kind of approach, more information on carbon footprint will be gained and values of this case study should be confirmed and adopted.

Table 2: Normalized values of the Beesands case study and comparison with other results

Type of shore protection		Tecco Cell	Rock armour	Concrete revetment
Carbon footprint [% of rock armour]	material + transport + installation, own model	64	100	282
	total carbon, Model EA	-	100	209
	EA Expert estimation	80	100	-
Range of difference in CO_2 emissions [% of rock armour]		–20 to –36	0	+109 to +182
Proposed wording until further knowledge available		"up to 20 - 30 % less CO_2 emissions than rock armour revetment in the case study"	reference for comparison	"up to 2 - 2.5 times more CO_2 emissions than rock armour revetment in the case study"

7.2 Comparative Evaluation of the Results

The information gained from the results 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 Tecco Cell vs. rock armour, educated estimate according to [16]). The results are given in **Table 2**.

The results of the case study show that Tecco Cell would result in a significantly smaller carbon footprint than rock armour and in a considerably smaller carbon footprint than a concrete revetment. The reasons for this result are mainly that:

- Tecco Cell would need significantly less and smaller-sized stones than rock armour. This results in a smaller amount of overall material extraction (which can be easily locally sourced).
- Tecco Cell and rock armour do not use concrete. The concrete's cement, reinforcing steel and the overall weight of this option are the key factor for the much higher carbon footprint of the concrete revetment solution.

Other findings of the case study are:

- According to the contractor, the blocks for rock armour are often difficult to source locally. For the Beesands case study, the blocks were able to be sourced locally, which seems to be an optimum and rather exceptional case. For other projects with rock armour, blocks needed to be shipped from overseas – Scandinavia or Belgium [9]. If this had been the case for Beesands, the Tecco-Cell option would have been even up to 30 – 40 % more CO_2-effective than the rock armour solution.
- For the Tecco Cell, the metal mesh needed to be shipped from overseas (Switzerland). The increase

in carbon footprint is compensated by the fact that filling was conducted using locally sourced small stones and pebbles.

For the maintenance and dismantling/recycling stages, which have not been considered in the calculations, a qualitative appreciation can be made:

- Generally speaking, the two stages maintenance and dismantling are estimated to account for less than 35 % of the overall carbon footprint, for all 3 options. Yet, depending on site specific conditions, these stages cannot be neglected for an overall carbon footprint model and sound estimates of these values need to be found in future studies.
- According to the manufacturer, the metal mesh used for the cell array may be recycled after use. A value for recycling of stainless-steel wire mesh still needs to be established for further studies.
- According to installers, the rock-armour solution in Beesands needed to be repaired each year after heavy storms, and Tecco Cell proved to be maintenance-free in the first five years of service life [9]. This information would further increase the carbon footprint of the rock-armour solution. While Tecco Cell is showing promising results after 5 years in use regarding maintenance, long-term experience regarding service life and maintenance still needs to be gained.

7.3 Assessment of the Results and Recommendations for their Use

The case study gives a good impression of the saving in CO_2 using Tecco Cell in this specific project for the stages of material extraction, transport and installation and enables the evaluation of options at a project-appraisal stage.

Please note that the results of the case study cannot be generalized. Other sites and conditions have to be evaluated separately. It is recommended to carry out a separate carbon footprint assessment for each future coast protection project using Tecco Cell or other protection solutions.

Until further knowledge is available, the author proposes a wording as given in Table 2 to communicate the results of this paper.

8 Recommendations for Future Studies

For further carbon footprint comparisons for Tecco Cell compared to standard solutions it would be interesting to study whether:

- For other projects, the values of carbon footprints remain in the same range as for the case study Beesands.
- For project parameters that differ significantly from the case study Beesands (e.g. steeper slopes), the carbon footprint of Tecco Cell including installation remains favourable when compared to standard solutions.
- CO_2 emission values for maintenance and dismantling/recycling of Tecco Cell can be established and confirmed.

9 Conclusions

The results of the carbon footprint assessment of a case study with Tecco Cell show that this novel kind of high-tensile stainless steel solution can help in reducing carbon impact for shore protection. It also shows that the technology is less dependent on large blocks being transported to the construction sites over very long distances and can use locally sourced material. The steel mesh for the cell array itself needed to be transported from abroad, but the overall savings in CO_2 emissions compared to standard solutions is significant, considering the parameters of the case study. The results of the case study may be adapted to similar kind of projects, but not be generalized for any type of project. Thus, it is strongly recommended – or, depending on the country, even required by law – to carry out similar carbon footprint assessments for future projects of a similar type.