

Environmental Impact of Geotubes and Geotextiles used in Breakwaters and Small Breakwaters Construction (Case Study: Rigoo Public Breakwater in South of Qeshm island - Iran)

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ABSTRACT

Coastal erosion has always been a serious problem in shorelines, which causes heavy damage to coastlines and public properties around the world. Rapid and uncontrolled coastal developments were started to prevent the exacerbation of erosion hazards. However in turn they have had a damaging impact on coastal ecosystems. The current study presents a comparative environmental impact assessment of two protective alternatives in coastal and shoreline structures, including traditional rubble system and a more novel one called geotube system. A case study of two breakwater structures in Bushehr and Qeshm in the south of Iran was performed and beneficial aspects of geotube system were identified.

1. Introduction

Coastal regions are subjected to an erosion process from actions of adjacent water body. This erosion can be caused by waves, littoral currents and tides. This process has led to extensive damage to coastlines around the world. To address such undesirable effects, shoreline development and evolution of coastal areas are growing with the rate of thousands of kilometers every year. High growth in renovation and development also gives emphasize to the importance of coastal constructions. On the other hand, the quality and ecological functioning of coastal environment are under a constant threat by the unplanned coastal development itself. This is because economic objective of such developments often runs counter to coastal environmental considerations. As a result, both short-term and long-term undesirable impacts on environmental resources have been considered in such regions [1]. One of the most harmful consequences of coastal projects seems to be carbon dioxide (CO₂) emissions during the construction operations. Remedial actions should be made to these projects and also under-design new ones to reduce and avoid future environmental impacts. These include impact mitigation, the development of alternate solutions, and modification of the original project [2; 3].

In recent years, because of the shortage of natural rock, traditional forms of river and coastal structures have become very expensive to construct and maintain. Therefore, the materials used in hydraulic and coastal structures are changing from the traditional rubble and concrete systems to cheaper materials and systems. One of these alternatives employs geotextile tube technology in the construction of shore protection structures, such as breakwaters and breakwaters (See Fig. 1). Recently, geotextile tube technology has changed from being an alternative construction technique and, in fact, has advanced to become the most effective solution of choice. Geotubes are long woven polypropylene tubes which are mainly used as core elements for dams and breakwaters, as groines and as longshore protection [4]. In the past decade, the high cost of traditional rubble mound (RM) coastal structures, due to the shortage of natural rock, has allowed geotube technology to change from being an alternative construction technique to an option worthy of serious consideration [5; 6]. Besides the well-known economic advantages of geotube systems, a geotube breakwater would have positive environmental impacts; both transport to an offshore disposal site and the dredge disposal volume would be reduced. It would also reduce excavating and rock transport to the site [7].

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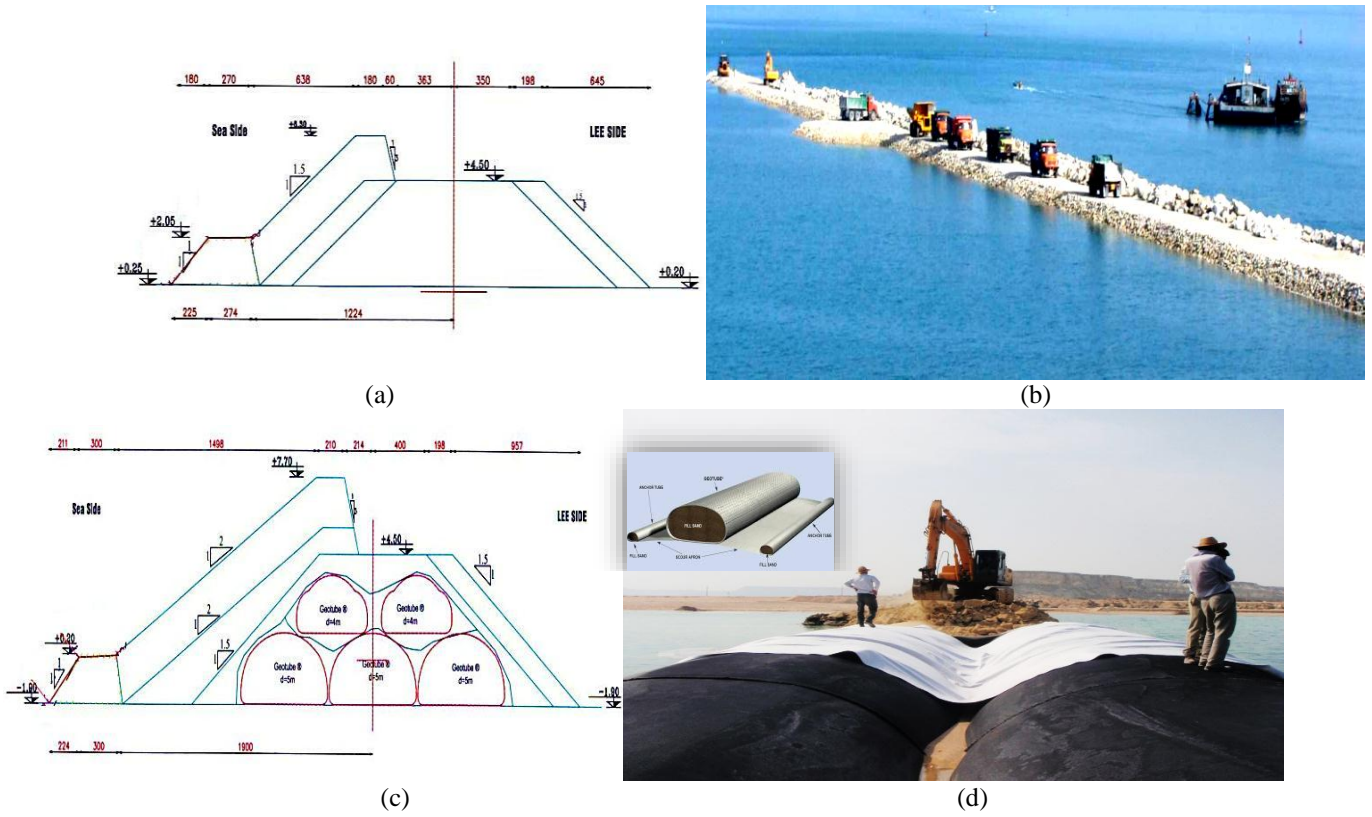


Fig. 1) Traditional System (a and b) versus Geotube System (c and d) for Breakwater and Small Breakwater Construction

The subject of geotube applications in civil and environmental engineering has received marked attentions in the literature. In 1980, Koerner and Welsh [8], and afterwards, Pilarczyk [9;10] provide an overview of the many primarily erosion control applications using the various types of containers. Sprague [11] presented the basic design concepts for geotextile tubes filled with dredged material. The geotextile sheets are permeable, yet soil-tight, so that any excess water drains from the geotextile tube. This causes the tube height to decrease, so that the tube may have to be pumped more than once in order to achieve the desired height [12]. Heibaum [13] also presented various case histories of geosynthetic containers applied as armour, ballast, filter, storage, core for hydraulic structures, flood protection, scour repair and protection, and improvement of earth dam. The technical considerations of geotubes for coastal structures was presented by Spelt [14], Gibeaut et al.

[15], Zhu et al. [16], Koffler et al. [17] and Yiming et al. [18]. Sheehan et al. [19] demonstrated the potential economic advantages of geotube technology when compared to traditional rubble mound coastal structures constructed from quarried material (QM). Recently, geotubes have been applied as core element for a breakwater named Rigoo. The case study described in this paper aims to demonstrate the potential environmental merits of geotube technology when compared to traditional RM coastal structures constructed from excavated material (QM). To the best of author's knowledge, only few studies have been conducted into the environmental impact assessment of using geotube system in breakwater construction. For the comparison purpose, details from a traditional breakwater in Bushehr have also been taken into account. Both structures are assessed for the CO₂ emissions from the excavating, transport and construction processes.



Fig. 2) a) Location of Rigoo Harbor and b) Aerial view of the study breakwater

Application of Geotube in Port of Rigoo

Rigoo harbor is located in the south of Iran (see Fig. 2) within 15 Km west of Qeshm in the Hormozgan province. A 325-meter-long breakwater was constructed for safe loading and offloading of the shipsand to protect shorelines against erosion, and to withstand heavy wave impact at high tides.

Geotube Versus Traditional RM Structures

In this research, a parametric study was conducted to compare the traditional rubble mound breakwater and the geotube structures. Regarding the geotube technology, minimum impact on the environment, beneficial use for dredged material (DM), cost effectiveness, no special required equipment, custom site specific fabrication, and also low maintenance are valuable aspects of application of this system [20; 21]. Although both systems have some similarities, usage of excavated material, transport and placement operations and usage of geotextiles are found to be the main controlling parameters [19].

Economic Considerations

From the results of a subsequent economic analysis, it is concluded that, for projects which require relatively high amount of quarried material, using geotubes filled with dredged material lead to significant cost savings (See Fig. 3). In this figure the vertical axis is normalized by total cost of traditional system.

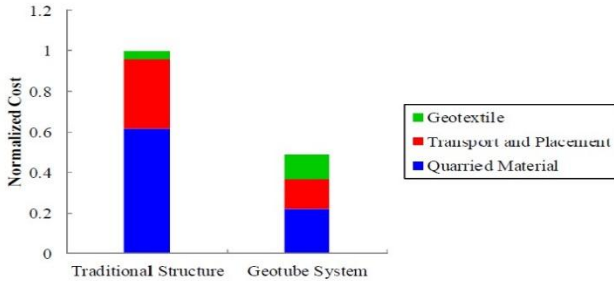


Fig. 3) A comparison of total cost between traditional structure and geotube system

Sensitivity analyses were undertaken and showed that the size of structure is the most significant economic factor and the distance from the quarry site is the second most important one. In general, it can be concluded that as the quantity of excavated material required increases, greater cost saving can be achieved by using a geotube structure with dredged material substituting for excavated material. Moreover, the selection of the largest feasible geotube is an important parameter for cost optimization.

Environmental Considerations

Public opinion of new coastal development is often very strong. People that will benefit from greater levels of protection may be in favor of coastal defense schemes, such as breakwaters and breakwaters, while others may be concerned for the potential damage to

the environment and visual impact on the coast. In this regards, traditional RM and geotube systems are different in some environmental aspects which more attention should be paid to them[22].

Table 1 presents the QM required for both traditional and geotube system, and the approximate CO2 emissions produced from the extraction of this QM. Overall, the geotube system has some environmental advantages over the traditional method of construction as following:

- Reduces excavated material;
- Reduces transport of excavated material and fuel consumption;
- Reduces overall CO2 emissions in transport and placement operations;
- Waste material is used as a resource in a beneficial manner;
- Minimizes disposal at sea for dredged material;
- Decreases negative impacts on habitats and extraneous spices;
- Reduces the disturbance of biota due to repair and maintenance during the lifetime of structure.

As far as protective breakwaters are concerned, the construction should be designed site specific, and a great deal of analysis has to be done in order to assess their possible environmental impact.

Table 1: CO2 emissions produced from quarrying of the required material in breakwater construction

CO ₂ emissions from extraction of QM (ton)	200	100
Quarried material required (ton)	150'000	41'200
Quarried material required (m ³)	20'000	12'300
Dredged material required (m ³)	-	25'100
Total volume of materials (m ³)	20'000	20'000
	Traditional system	Geotube system

Environmental Analysis

Validated data from case study were collected and used to evaluate required parameters, e.g. the CO2 emissions produced, by both types of coastal structures. CO2 emissions analyzed here are generated by the recovery, transport and placement of quarried material, as well as the dredging, pumping and filling of the geotubes and disposal of dredged material at sea. Data from the aggregate industry indicates that CO2 produced from quarrying involves between 4.0 and 5.0 kg CO2 per ton of material produced [23]. Environmental analysis on a large scale project highlights the major parameters in CO2 production (Fig. 4). The CO2 produced by a traditional breakwater construction (820 ton) is nearly three times the quantity produced by a geotube breakwater construction (275 ton). The recovery of QM is the main source of CO2 production accounting for nearly 70% of both the traditional and geotube breakwater's total. The CO2 produced from the transport of the QM

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also responsible for a significant proportion of the total emissions; 21% and over 18% for the traditional and geotube breakwater, respectively. These values propose that the volume of QM required and the transport distance are main parameters for CO₂ production. In addition to the emission savings from using DM there are also substantial emission savings to be achieved by minimizing the use of QM. Sensitivity analyses were also undertaken to assess the most critical parameters including:

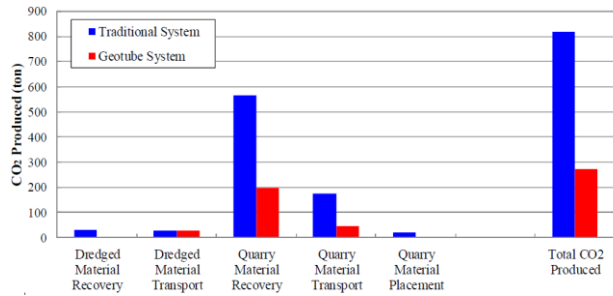


Fig. 4) CO₂ produced from the different parts of breakwater construction operations

- the size of the structure;
- the distance to the quarry;
- the distance to the disposal at sea site.

When analyzing each construction method for each of the above parameters all the other parameters remain constant. Trend-lines are fitted to the data points for each sensitivity analysis undertaken. For all the figures presented, y axis is the CO₂ produced and x axis is the parameter analyzed.

A sample result curve for the effect height of structure on the produced amount of CO₂ is presented in Fig. 5 which presents the transport emissions produced in constructing a breakwater for heights between 6 m and 9.5 m for both traditional and geotube system. A linear function relationship was used to reach an acceptable correlation for transport emissions to the height of the structure. For the under study traditional breakwater, an increase in height of the structure by 1 m will increase the CO₂ transport emissions by 69.12 ton. Introducing a 1 m increase in height for the geotube breakwater results in an increase of 10.67 ton of CO₂, that is approximately 85% less than the increase in the CO₂ emissions for the traditional breakwater. Although these equations indicate that in a certain height (and less), the traditional breakwater construction would produce less CO₂ than the geotube breakwater, in practical sizes, as it can be seen from the figure, the traditional breakwater produces greater CO₂ emissions.

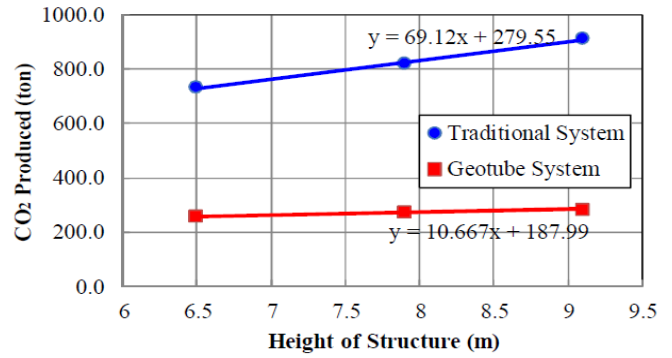


Fig. 5) CO₂ emissions based on a change in the size of constructed breakwater

Fig. 6 shows how a change in transport distance from the quarry affects the quantity of CO₂ produced from each construction system. The CO₂ produced by the traditional breakwater increases by 3.94 ton CO₂/km travelled. In comparison, the CO₂ produced by the geotube breakwater, which uses less QM in its core, increases by 0.593 ton CO₂/km travelled, approximately 84% less than the traditional breakwater. As it can be concluded from the equations, a geotube coastal structure always produces less CO₂ than a traditional one. Thus, since the distance from quarry is a significant in the construction of a traditional breakwater, geotube system could be considered as the best solution especially in areas away from the quarry.

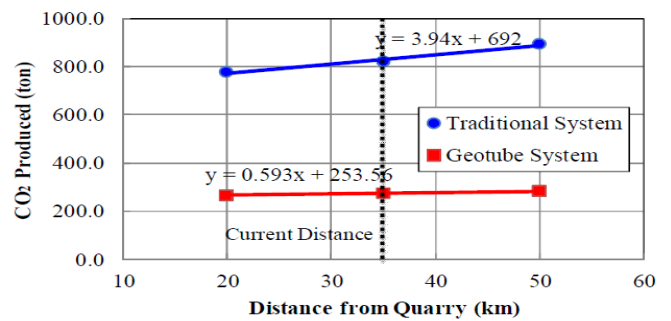


Fig. 6) CO₂ emissions based on a change in the distance from quarry

The effect of the distance to the disposal site on the CO₂ emissions of the breakwater construction is presented in Fig. 7. The traditional breakwater will produce an extra 8.22 ton CO₂/km travelled to the disposal site. For all sail distances, a geotube system produces less CO₂ than a traditional system. These results demonstrate how the CO₂ produced from DM disposal differs significantly with varying sail distance. Thus, the emissions reduction and subsequent environmental benefits associated with the use of geotubes may be attractive for locations considering the installation of a coastal structure where there is a substantial sail distance to the DM disposal site.

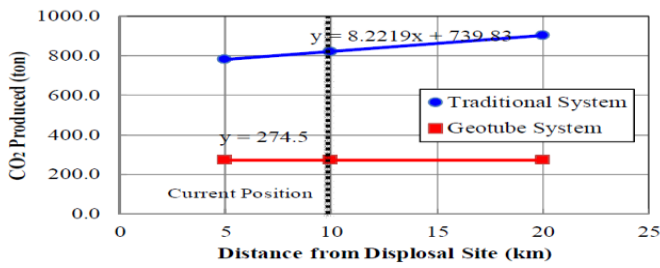


Fig. 7) CO2 emissions based on a change in the distance from disposal site

Discussion

Sensitivity analyses were performed to comprise the environmental feasibility of the use of geotubes and traditional system of breakwater construction. A summary of the results of the analysis is presented in Table 2. This table shows the influence of major parameters analyzed for both construction methods to highlight the areas most eligible for implementation of potential alternatives or mitigating measures. It is worth mentioning that an increase 20% from the current status of each parameter was considered as the adjustment factor.

As identified in Table 2, the size (height) of structure was the most significant environmental parameter in traditional system. A 20% increase in height of structure rise the quantity of CO2 emission for up to 115.3 ton and 14.6 ton in traditional and geotube system, respectively. As identified in Fig. 6, the recovery of QM is responsible for a substantial portion of CO2 emissions.

The distance from the quarry and the sail distance to the DM disposal site were found to be the parameter of second and third highest importance, respectively. A 20% change in the distance to the quarry causing CO2 emissions to change for about 37.98 ton CO2 (traditional) and 3.96 ton CO2 (geotube). These differences rise as the size of structure increases. Regarding the sail distance to the DM disposal site, a 20% change causing CO2 emissions to change by 19.99 ton

for a traditional breakwater, while, based on the site properties, the quantity of CO2 emissions from a geotube breakwater might not been affected by this change. This is especially relevant for dredging sites with large sail distances (to a disposal site) that are considering the construction of a coastal structure.

It can be concluded that a geotube breakwater produces over 85% less CO2 than a traditional breakwater. These values highlight the fact that as far as the geotube system is concerned, the greater the size of the structure, the greater the savings in CO2 emission.

Table 2: Summary results for the environmental sensitivity analysis

Dike structure	Parameter	Current status	Variation (20%)	Change emissions (ton CO ₂)
Traditional system	Size of structure	7.9	9.48	115.307
	Distance to the quarry	35	42	37.98
	Distance to the disposal site	10	12	18.993
Geotube system	Size of structure	7.9	9.48	14.613
	Distance to the quarry	35	42	3.966
	Distance to the disposal site	10	12	0

Conclusion

An environmental assessment is conducted to identify the beneficial consequences of using geotube systems in breakwater construction. Highlighting and prioritizing the critical parameters may allow management measures to be implemented subsequently that improve the environmental impact of the overall project. Thus, the emissions reduction and subsequent environmental benefits associated with the use of geotubes may be attractive for locations considering the installation of a coastal structure where there is a substantial sail distance to the dredged material disposal site. Results showed that the size of structure, the distance from the quarry and the sail distance to the DM disposal site are the key parameters which have the most environmental influence and the first one is found to be the parameter of highest importance. Geotube system produces over 85% less CO2 in comparison with traditional rock structure. Thus, not only using geotube system is a more economical method than traditional method of breakwater construction, but also it offers a better environmental alternative to traditional breakwater system.

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