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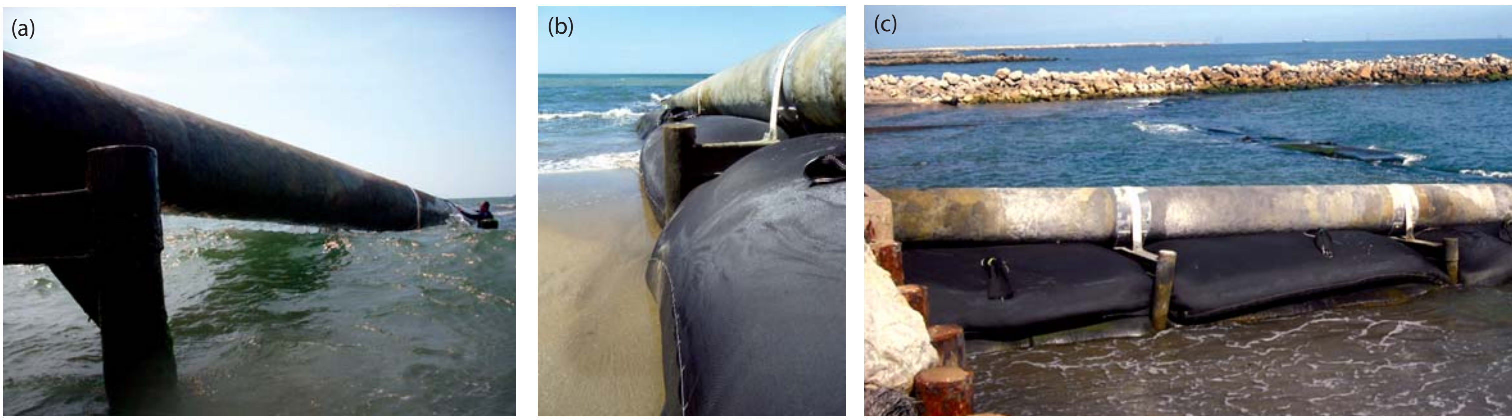
Geotextile tubes filled with sand work as foundations and support beds for oil pipes at the Dos Bocas facilities for Petroleos Mexicanos. **Below:** (a)—At some locations, gaps between the sea floor and pipe were more than 2m. (b) & (c)—The geotextile tube foundations were designed to fill the gaps for each pipe. See also Figure 3, page 31.

Photos courtesy of Marco Sánchez and the authors



PEMEX marine facilities in Tabasco, Mexico

Geotextile tubes are integral components for oil-pipe foundations, erosion control

By Alfonso Solís, Amy Tang, and Zoe Lin

ABSTRACT

In this project, geotextile tube technology is adopted as part of an integral solution for beach erosion problems at the Dos Bocas marine facilities for Petroleos Mexicanos (PEMEX).

The solutions designed consisted of:

- geotextile tubes (GT) filled with sand working as beds for oil conduction pipes that were previously in risk of collapsing due to sand foundations lost within the surf zone **(see photos, left)**.
- installation of a submerged breakwater using GT along 1.9km of coastline.
- installation of 62,000m^3 of beach nourishment for coastline stabilization.

This article describes elements of the design criteria and installation process, field survey data before and after beach profiles comparison and graphical material is presented, and analysis corroborating natural beach recovery after breakwater installation. Post-construction evidence is also given, leading to the conclusion that this project has worked as expected, ensuring long-term oil conduction and storage facility integrity.

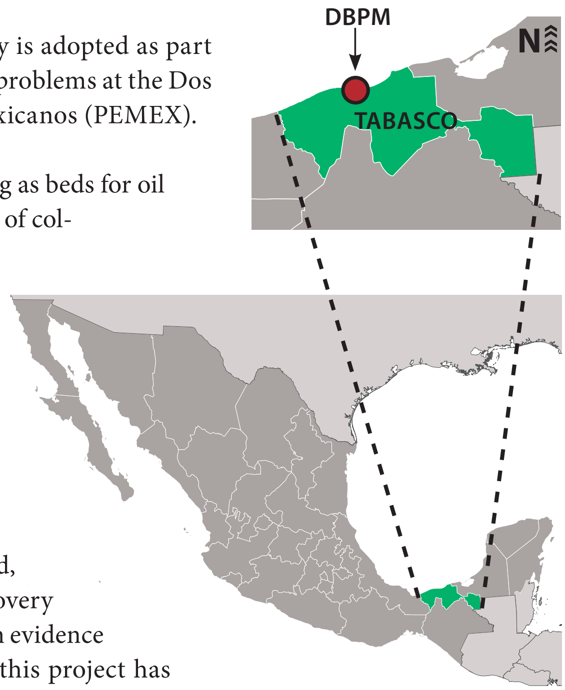


FIGURE 1 Project site location

Introduction

The Dos Bocas PEMEX marine facilities, located at Paraíso, Tabasco, Mexico **(Figure 1)**, had sustained progressive beach erosion, which was compromising oil conduction and storage infrastructure integrity.

Beach protection hard structures (groins and stone revetments), built two decades ago, had been seriously damaged by wave action, losing 30% of their original length and 40% of their height, failing to ensure beach-site stability.

A major issue was the loss of sand foundation for the marine conduction pipes within the surf zone, leading to potential risk of pipe failure and catastrophic economic and environmental consequences.

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Marco Sánchez, an engineer with ML Ingeniería and a member of *Geosynthetics* magazine's Editorial Advisory Committee, also contributed to this article.

Project description

Figure 2 depicts the coastal area where this project was developed. The area is divided into seven sections, each one delimited by the existing groins.

In section 4, three pipes conduct oil from inland to marine facilities where it is shipped for distribution. Within section 7, four 36-in.-diameter pipes conduct oil to inland facilities for storage.

The primary objective was to recover and restore the pipe foundations, and, further, to ensure shoreline stabilization to protect inland storage facilities.

FIGURE 2 Aerial view: Project coastal area

Solution design

After analyzing several beach protection options, PEMEX decided to adopt a solution that involved the use of woven propylene geotextile tubes (GT).

GT were selected as an environmentally responsible solution and for their flexibility to adapt to a dynamic maritime media. The possibility of quick modification of structures, according to morphological response, and comparatively lower costs for initial installation and maintenance were also considerations. For this project, installation logistics and equipment required only slurry pumps and small boats.

Pipe support elements

Preliminary study results showed that 5 of the 7 oil conduction pipes had lost their foundations due to beach erosion. The most critical cases were detected along pipes 6 and 7 where, at some points, gaps between the sea bottom and pipe were at 2.5m—see **Photo (a)**, page 28.

After analysis of field data, it was decided to use 7.8m-circumference (1.25m height) GT as pipe support elements. Two types of sections, depicted in **Figure 3 (a and b)**, were designed, taking into account gap height from sea floor to pipe. Finally, according to these criteria, for each particular case the proper arrangement was defined to fill the existing gaps.

Submerged breakwater

The submerged breakwater was designed to achieve two main objectives: to reduce the incident wave energy on the beach by controlling the wave-breaking process, thus promoting natural sand accumulation shoreward of the structure; and to perform as a confining element for beach nourishment.

Under this premise, the primary requirement for an efficient submerged tube cross-section design was to define the crest high, in relation to the still water level (SWL), for all tide ranges since "this would govern the wave breaking mechanism that controls wave energy reduction” (Alvarez et al., 2006).

The breakwater cross section design **(Figure 4)** was built with a 7.8m-circumference principal GT seamed to a 2.5m-long scour apron and to a smaller GT that works as an anchor tube (1.4m-circumference). Given the principal GT’s proposed dimensions that, when filled with sand to its 90% capacity, would reach a 1-1.25m height (Leshchinsky et al., 2006). Based on this criterion, the submerged breakwater was placed at a 1-1.25m depth, ensuring structure crest would coincide with mean low water level (LWL).

Beach nourishment

The beach fill profile was designed to reach 0.10m above the high water level (HWL). As depicted in **Figure 5**, material would be retained by the breakwater, widening the beach by 30-40m after wave action profile stabilization.

An important issue for beach nourishment success is that the material artificially placed has the same, or larger, grain size and density as the natural beach material (USACE, 2004). This was ensured by dredging material from offshore submarine banks 400m offshore that were previously monitored and authorized by federal environmental authorities.

Installation process

Preliminary work before GT installation consisted of removing from the sea floor anything that could be a threat to GT integrity (stone, steel, debris, etc.).

During the GT sand filling process, stresses in the encapsulating geosynthetic due to slurry pumping pressure was an issue because overpressure during filling of the tubes may cause geotextile failure (Leshchinsky, et al., 1996). This job was carried out with 4-in. discharge-diameter slurry pumps with volume discharge rates up to 40-50m^3/hr with 10–30% of solids.

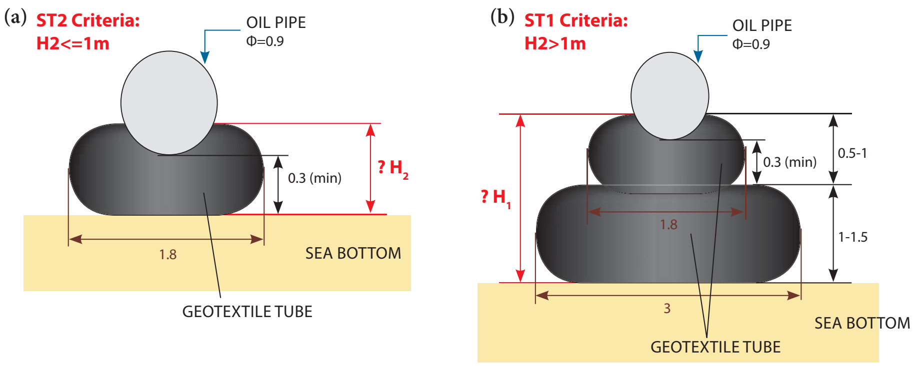

FIGURE 3 Designed sections: (a) gap <1m; (b) gap >1m

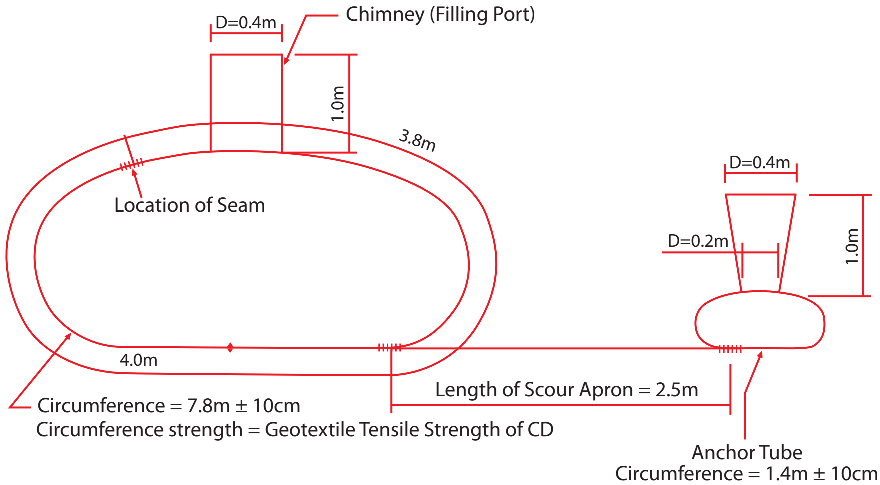

FIGURE 4 Breakwater cross section

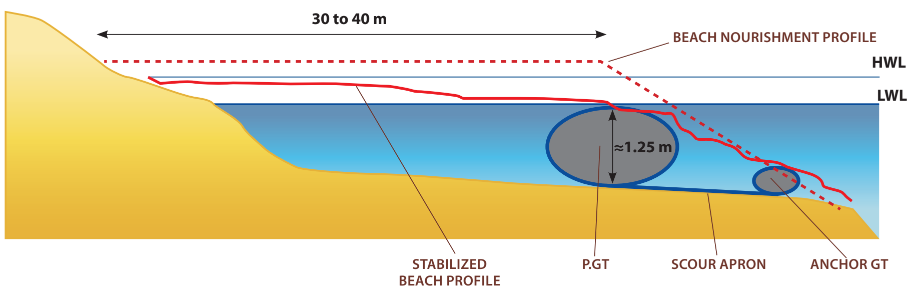

FIGURE 5 Beach nourishment designed profile

FIGURE 6 Filling GT tasks: (a) pipe support elements and (b) breakwater

FIGURE 7 Beach nourishment activities

FIGURE 8 Before-and-after comparison for pipe 3

FIGURE 9 Before-and-after comparison for pipes 6 and 7

Figure 6 shows slurry-pumping operations for both the GT support elements and breakwaters. Pumped material was obtained from submarine banks 50-70m offshore.

Once GT installation was finished, beach nourishment continued using a 12-in.-diameter suction dredge, with volume discharge rates up to $250m^3$/hr. Material was conducted to shore by a 10-in. flexible hose **(Figure 7)**.

The total fill volume required to reach the profile level designed along seven project sections was approximately $62,000m^3$.

Performance

Installation of pipe support elements concluded by the end of July 2009.

Figures 8 and **9** show before-and-after comparisons. In some cases, gaps had reached 2.5m. The photos also show the GT's flexibility and adaptation to marine media—key points for this project's success, giving complete support where required.

As for breakwater performance, **Figure 10** shows the wave-breaking concept due to GT presence, creating a wave energy reduction zone, with turbulence generated shoreward inducing sand accumulation.

During the breakwater installation process, beach evolution profile surveys were done for all sections, corroborating that the structure was performing as expected, promoting natural sand accumulation shoreward of the structure **(Figure 11)**.

Beach fill construction clearly enhanced project performance, providing additional stability to the shoreline and the support elements for the oil-conduction pipes. And as the breakwater continues to reduce longshore transport rates and minimizes end losses, it will ensure the lifespan of service for this facility **(Figure 12)**.

FIGURE 10 Breakwater performance

FIGURE 12 Final situation for section 7

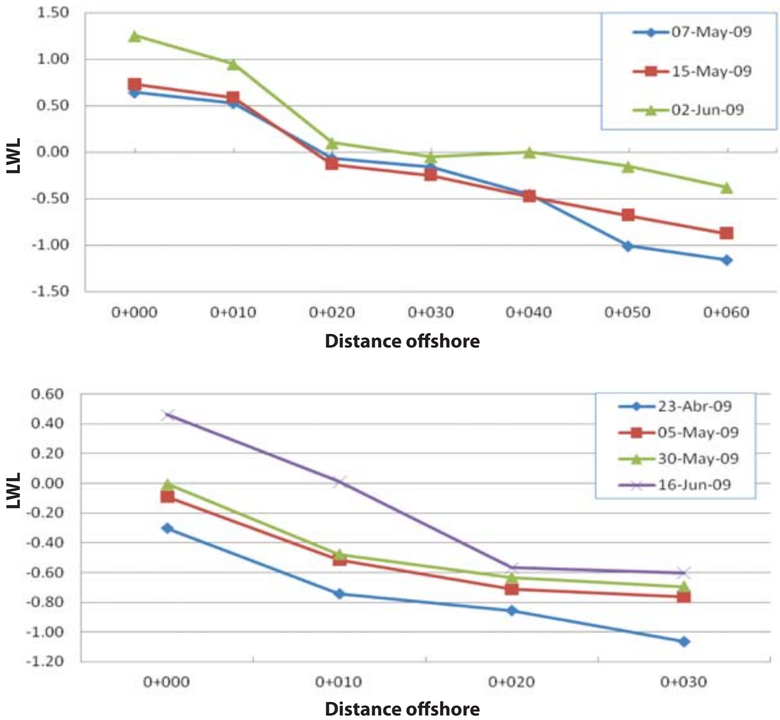

FIGURE 11 Beach profile evolution after breakwater installation: (a) Section 1, (b) Section 7

Conclusions

The following conclusions are highlighted for this project:

- Adopting an integral solution guarantees a long-term solution to this beach erosion problem.
- The versatility of the GT allows usage in an innovative application such as pipe support elements.
- As in other projects in Mexico (Alvarez et al., 2006; Alvarez and Espinoza, 2008; and Escalante and Solís, 2008), GT working as coastal protection structures have acted as effective and environmentally friendly alternatives for shore stabilization.
- Beach nourishment, in conjunction with shore protection structures, is a good alternative to increase the longevity of beach reconstruction projects.
- GT structure construction requires comparatively minimal logistics and equipment, while offering installation and maintenance cost benefits.

Regardless of the successes of this project and the proven potential of GT to be effective for shore protection, based on site observations during project construction, there are issues that require continued monitoring and research, including:

- GT durability against UV exposure.
- scour apron performance for assuring settlement control.
- strength of the seams and filling port sections of manufactured geotextile tubes.

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