CHAPTER 240

EMERGENCY SITUATION IN THE SHORELINE REACH OF AN OFFSHORE OILFIELD PIPELINE AND REMEDIAL MEASURES

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Abstract

This paper describes the critical situation experienced in the northeast coast of Brazil by an oil and a gas pipeline, in their shoreline reach,due to the growth of a spit, and the remedial measures adopted, which avoided an environmental and economical disaster.

Introduction

For the exploitation of the offshore gas and oil fields of "Agulha" and "Ubarana", in the coast of Rio Grande do Norte State in Brazil (Fig. 1), PETROBRÁS, the Brazilian Petroleum Company, has installed a group of six steel pipelines linking the offshore to the mainland facilities.

The region is a flat sand beach, with a mean slope 1/1360 between 0 and -10m depth contour,in a coast with an E-W alignment (Fig. 2) and subjected to the action of waves coming from the NE quadrant and winds blowing from N to SE. The currents outside the breaker zone, with velocities up to 0,5m/s, have a westward resultant and are also influenced by the tide which is semi-diurnal and has amplitudes ranging from 1.0 to 3.1m (INPH 1981) (Moreira et al. 1987). In consequence, there is a westwards littoral drift which promotes the growth of spits in the region (Fig. 3).

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Figure 1. Situation Map

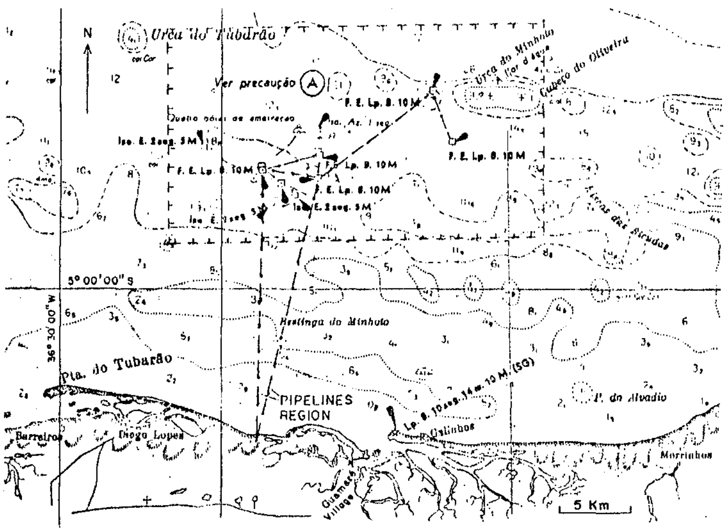

Figure 2. Key Map (Guamaré Coast)

Figure 3. Galinhos Spit

The bottom is active with respect to sediment movement down to depths of 12 to 13m, as observed comparing sucessive bathymetric surveys made in the pipelines region, which also revealed the existence of sand banks (Fig. 4).

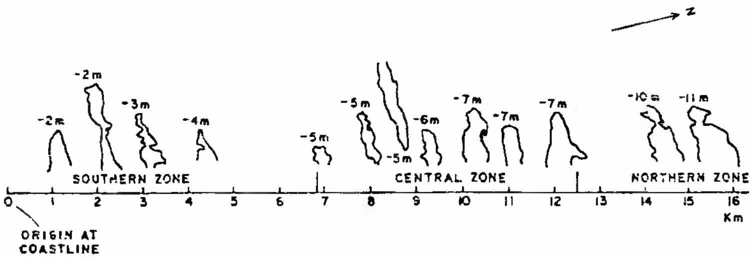

Figure 4. Sand Banks in the Coastal Region of Guamaré

When the pipelines where buried, the shoreline reach presented no problems. Nevertheless, there existed eastwards a spit, almost parallel to the shoreline, originating in a nearshore island situated in front of Guamaré village. With the growth of this spit (Fig. 5), which defines, between it and the mainland, a double-entrance estuary, the pipelines region, in the shoreline, was submitted to a tidal current that eroded severely the sea bottom under the two western pipelines, due to a narrowing of the tidal channel right in their placement, leaving in suspension an extension of about 40m of both lines (Fig. 6, 7, 8 and 9). One of them is a gas and the other an oil pipeline, both with an outside diameter of 0,66m and lined with a concrete coating, 7.6cm thick.

Figure 5. Spit at the Pipelines Region
Date: 03/16/88 Hour: 15:30 W.L.= +3.1m (H.W.)

Figure 6. Undermined Pipelines
Date: 03/02/88 Hour: 10:24 W.L.= +0.7m

Figure 7. Gas Pipeline
Date: 03/02/88 Hour: 09:08 W.L.= +0.9m (ebb tide)

Figure 8. Gas Pipeline
Date: 03/02/88 Hour: 09:10 W.L.= +0.9m (ebb tide)

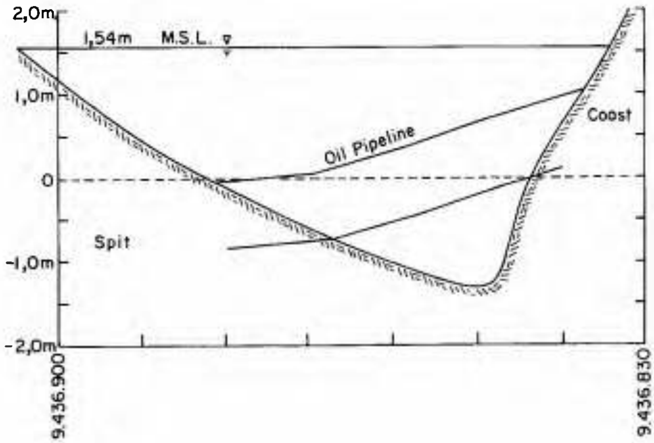

Figure 9. Channel Cross Section at Oil Pipeline Placement. Date: March 1988

Statement of the Problem

The influence of the strong crossing tidal currents, with measured values of 2.5 knots (1.3m/s), could produce rupture of the pipelines through a vortex shedding, prompt to happen for conditions nearly those the pipelines were subjected, as pointed out in a simulation study (Carvalho 1988):

a) the oil pipeline was in a situation dangerously close to resonance conditions because: for a free length of the order of 50m its natural frequency of vibration would coincide with the vortex frequency caused by a current of 2.8knots (1.4m/s) flowing in its surroundings. Indeed, the extremities of the suspended portion of the oil pipeline had already presented deep fissures in the concrete lining:

b) the gas pipeline, lighter than the oil pipeline and with a higher natural frequency would be in resonance for a free length of 70m and then it was in a situation of lesser risk than the oil pipeline.

The real free length of both pipelines were greater than the measured ones, as the pipelines would find effective support, only some metres inside the margins of the channel.

Remedial Measures

In order to cope with this situation, three alternatives were considered as remedial measures (Bandeira 1988) (Santos 1988):

I - burying the two pipelines deeper underneath the eroded bed;

II - holding the suspended portion of the pipelines by means of piles until, due to the westwards displacement of the spit extremity, the channel sections in the pipelines region might be naturally shoaled;

III - closing the tidal channel entrance by construction of two sand dikes, the first (E dike) as near as possible the region where the tidal waves, entering the channel at both entrances meet each other, and the second (W dike) in the western entrance, where the pipelines cross the shoreline.

Considerations about the Remedial Measures

The first remedial measure considered was abandoned due to the risks of rupture of the pipelines, during the process of burying, as they were already dangerously stressed and submitted to the action of strong crossing tidal currents.

The second one could avoid the imminent vortex shedding by diminishing the free length of the pipelines, but still the pipelines would be submitted to the strong crossing tidal currents until the channel sections in the pipelines region might be naturally shoaled.But this natural shoaling could not be assured and then, another intervention could be required.

Solution Adopted and Further Reaction of the Coastline

Having in mind the possible drawbacks of the first two considered remedial measures, PETROBRAS has decided to implement the third one, which seemed the most convenient and proved to be successful.

For the construction of the sand dikes, PETROBRAS made use of two bulldozers which piled sand in the two sides of the dike sections, and plastic bags filled with sand. Shortly before the low water of a neap tide, the plastic bags where placed in the deepest part of the channel section and, after that, the bulldozers, simulta-neously from both sides, pushed the piled sand over the section, completing the closure.

The E dike (Fig. 10 and 11) was built on March 22, 1988 and the W dike (Fig. 12) three days after.There was a strong sediment deposition westwards of the western dike as expected (Fig. 12, 13 and 14) and on March, 1989, a rupture in the spit portion be-tween the two dikes occurred during an equinoctial tide and is presently being monitored.

The E dike was not constructed in the region where the tidal waves, entering the channel by both en-trance, meet each other (mangrove region in Figure 10)

Figure 10. East Dike and Mangrove Region
Date: 04/07/88 Hour: 08:25 W.L.= +2.2m

but, for environmental reasons and ease of construction it was situated at the narrowest section of the channel, near the mangrove region and west of it, as indicated in Figure 5, which was taken at the high water of a spring tide. In this way there was an increase in the tidal prism flowing through the eastern entrance.

Figure 11. East Dike (Closer View)
Date: 04/07/88 Hour: 14:23 W.L.= +0.8m

Figure 12. West Dike (13 Days After Closure)
Date: 04/07/88 Hour: 14:27 W.L.= +0.8m

Figure 13. West Dike (10 Months After Closure)
Date: 01/25/89 Hour: 13:50 W.L.= + 1.1m

Figure 14. West Dike (27.6 Months After Closure)
Date: 06/14/90 Hour: 14:00 W.L.= +0,6m

Then, when the rupture of the spit occurred (Fig. 15 and 16), PETROBRAS decided to open the E dike in order to re-establish the original tidal circulation in the mangrove area and in the eastern entrance (e.g. a decrease in the tidal prism flowing through this entrance). This action caused a correspondent increase in the tidal volume flowing through the new western entrance.

Figure 15. Disrupted Spit with the E Dike Opened
Date: 12/27/89 Hour: 9:55 W.L.= +0.7m

Figure 16. New Western Entrance
Date: 12/27/89 Hour: 10:00 W.L.= +0.7m

This new western entrance has now a greater tidal volume flowing through it than the original one (which is estimated in 425,000m³ relatively to the average tide amplitude), when the extremity of the spit was situated in the same region as the entrance. Now, there is a contribution of the tidal prism western of the mouth (in the channel between this mouth and the W dike) which is estimated in 326,000m³, giving a total tidal prism of the order of 751,000m³. This increased tidal volume flowing through the mouth added to the fact that now the flood flow branches E and W after crossing the mouth and the ebb flow coming from these two directions converges upon the entrance, may have an influence in the rate of advance of the mouth to W, compared to the velocity of migration of the spit when its extremity occupied the same region of the present mouth, from which there is no record.

Presently the mouth is situated about 1920m eastern of the section of the W dike, and its migration to W due to the unidirectional littoral drift is being monitored. In Figure 17, the contours of the two margins relatively to the MSL, are pictured for four surveys made in the interval February - May 1990. Geometrical calculations considering the portions of the shoreline contours limited by horizontal lines passing by A and B (E side) and C and D (W side), indicated an average rate of migration of the mouth to W:

V = 10.5m/month (E side)

and

V = 24.9m/month (W side)

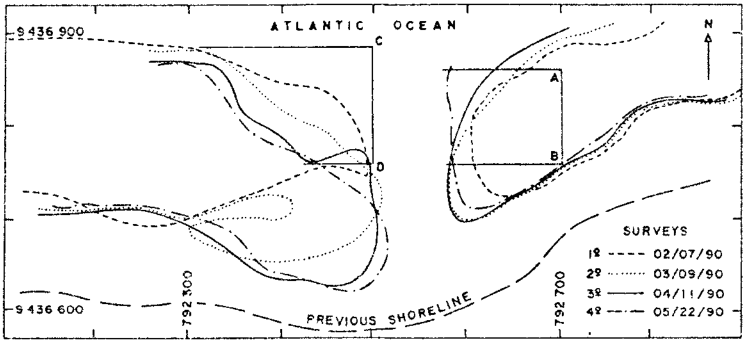

Figure 17. Surveys in the New Western Entrance

Conservatively assuming the rate of migration to W of the W side of the mouth as constant, in 1920/(24.9*12) = 6.4 years the problem could happen again, unless some preventive measures are taken, such as: to bury the pipelines deeper underneath the level of the eroded bed, before they are exposed to the strong crossing tidal currents again. In this way the spit can migrate freely, and it will not be necessary to construct dikes and alter the tidal circulation in the mangrove area.

The monitoring of the migration of the entrance will be continued at four months interval.

A great deal of information on the features of this unstable coast has been gained by the study of this emergency situation.

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