

## **WORKS PERFORMED AS MITIGATION MEASURES AFTER HEAVY RAINFALLS**

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### **ABSTRACT**

*This study addresses the mitigation measures taken in response to the record-breaking rains that affected the city of São Sebastião, located along the Serra do Mar in the state of São Paulo, Brazil, a highly inhabited region. The OSBAT oil pipeline, stretching 120 km, traverses the slopes of the region and is vital for supplying two state refineries. The rainfall recorded in February 2023 reached exceptional volumes, resulting in geotechnical events such as erosion, landslides, debris flows and mudflows at various points along the coast and in urban areas, tragically claiming lives. Although no leaks or damages occurred directly to the pipeline, 52 geohazard occurrences with varying levels of severity were identified. Detailed inspections were conducted using helicopter flights, drones, satellite imagery, and on-foot inspections along the entire affected pipeline section. This study presents the emergency measures taken to mitigate the risks faced by the pipeline right-of-way. The mitigation works at the five most critical points allowed for the safe resumption of operations, albeit with restrictions. The ongoing works aim to enhance safety at all 52 identified points. This study emphasizes the importance of effective emergency actions to ensure the operational safety of facilities in areas affected by geotechnical events such as erosion, landslides, and debris flows.*

### **1 INTRODUCTION**

Transpetro is a wholly owned subsidiary of the Brazilian state-controlled oil company Petrobras, and our business is the storage and transport of oil and oil products for our parent company as well as for private companies. The São Paulo Right-of-Way Maintenance Crew oversees the maintenance of little less than 3000 km of pipelines running along some 1200 km of rights-of-way in the State of São Paulo. OSBAT is a right-of-way that stretches around 120 km from São Sebastião to Cubatão; its first 60 km cross the Serra do Mar (Ocean Ridge), a very mountainous region with many steep slopes along São Paulo's coastline. This is an area highly prone to geotechnical issues.

On February, 17<sup>th</sup> 2023, Transpetro's right-of-way maintenance crew issued a warning for heavy rainfall for the following two days along the São Paulo coastline. The warning

forecast precipitation of about 250 mm about to occur (at that rainfall level, the interruption of OSBAT pipeline was advised).

Instead, from February 18<sup>th</sup> 2023, a Saturday, at 21:00, to February 19<sup>th</sup> a Sunday, at 08:00, 681 mm fell over OSBAT, with intensity peaks totaling 400 mm in three hours on Saturday night.

Rainfall was particularly concentrated along OSBAT's Serra do Mar length, of about 60 km long, (the most critical stretch geotechnically), receiving up to 610 mm. Along with potential damage to the pipeline, yet the main road crossing the area was interrupted. Densely populated communities were affected. A total of 52 lives were lost, leading the mayor of São Sebastião to decree a Public Calamity, along with five other coastal cities. (1)

### **2 THE FIRST MEASURES**

Transpetro's immediate action was the creation of an Organizational Response Structure, besides the mobilization of geotechnical engineers, aerial inspections via helicopters and drones, and on-foot inspections. In-line inspection, reading of inclinometers and standpipes, and mobilization of mitigation works were also carried out.

Right from day one, inspection flights were made, using helicopters hired by Transpetro itself, as well as equipment borrowed from the Army and the Police. Those flights resulted in 28 points of geotechnical occurrences being identified, 12 of which had low-risk, five moderate-risk, six high-risk and five being critical high-risk. This represented the first screening of geohazards in the critical area.

#### **In-line Inspection**

Between February 26<sup>th</sup> and 27<sup>th</sup> in-line inspections were carried out, with a Geometric PIG and an inertial PIG run. No anomalies were found by the former, and no displacements were assessed by the latter.

#### **2.1 On-foot Inspection**

On-foot inspections were performed between February 23<sup>rd</sup> and March 03<sup>rd</sup> by the geotechnical engineering crew for the OSBAT length stretching from km 0+950 to km 42+000, comprising roughly the Serra do Mar mountainous region.

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Those inspections have as normative rule Petrobras standard N-2775, according to which risk is classified in six steps: LOW I, LOW II, MODERATE III, MODERATE IV, HIGH V and HIGH VI. The aim was to start field inspections of all relevant geohazards and cover all mountainous spots in the abovementioned length. Therefore, the inspections were done on foot by Geotechnical Engineers, to assess, register and classify all geohazards on the way.

As a result, 52 geohazards were assessed and classified as shown below (2):

LOW I	22
LOW II	12
MODERATE III	7
MODERATE IV	3
HIGH V	3
HIGH VI	5
TOTAL	52

As can be seen, there were five HIGH VI spots, which demanded the interruption of the pipeline operations. They are located at: km 36+150, km 37+000, km 37+500, km 41+100 and km 41+700.

### 3 THE CRITICAL POINTS

#### 3.1 The five high-risk critical points

Km 36+150:

Occurrence of high-dimension landslide on steep, high and densely vegetated natural slope. Great quantities of soil, rock and mud formed a mudflow (3).



Figure 1: km 36+150 right after the rainfall (4)



Figure 2: Aerial view showing large landslides. (3)

Km 37+000:

Massive spot affected by three large debris flows (4) on very steep natural slope, densely vegetated. Large amounts of soil and vegetation converged forming a downhill movement, reaching tens of meters down to the nearby highway. Many logs and rocks were in movement, others remain in the thalweg awaiting conditions to move again. Exposed rock can be seen at the top, showing the huge erosive power of the process. Channels were sculped along the flow path, leaving the exposed rock at the top. (3)

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Figure 3: km 37+000 - Three debris flows crossing the right-of-way and the road reaching the shore. (4)

### Km 37+500:

Large landslide upstream from the right-of-way and transversal to it, debris deposition over the right-of-way. Inertial PIG run showed no evidence of lateral movement, evidencing the movement was not deep. (4)

The landslide scar has considerable width, showing how large a soil and vegetation amount was involved in this event.

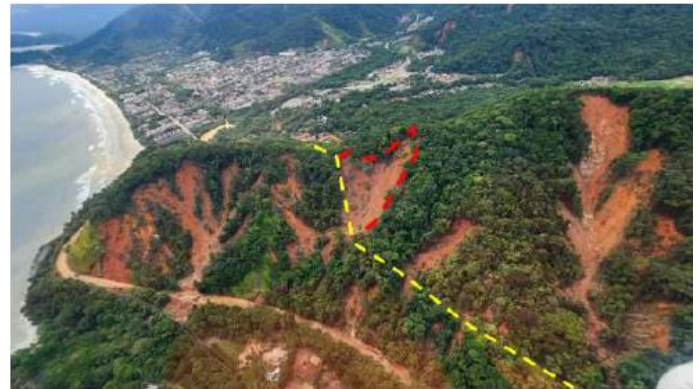


Figure 4: km 37+500: Large upstream landslide, yellow dotted line shows OSBAT

### Km 41+100:

Upstream lateral landslide, large volume of soil, rocks and trees moved downhill and deposited on the right-of-way. Huge mass amounts deposited on the right-of-way, potentially overloading the pipeline.

Soil, rock, and trees moved downhill, reaching the right-of-way and a house.



Figure 5: km 41+100 - Deposited mass on the right-of-way

### Km 41+700:

This spot was affected by two process types: huge landslide followed by mudflow and cut slope slide involving both soil and

rock. Additionally, downstream from the right-of-way, another landslide occurred.



Figure 6: km 41+700: Multiple occurrences

## 4 Technical solutions for mitigation

### 4.1 Mobilization

Mobilization of emergency mitigation works, constituted by the removal of soil deposited over the pipes, provisional drainage, protection of the pipes against eventual new landslides with steel plates and provisional protection of slopes with plastic sheets on the critical geotechnical events, which prevented OSBAT 24” operation, classified as High-Risk VI by the N-2775 Petrobras norm. (5)

### 4.2 Emergency mitigation works on critical High-Risk events

For each of the five critical High-Risk VI spots (km 36+150, 37+000, 37+500, 41+100 and 41+700), there were field inspections by external consultants, i.e., a CENPES (Petrobras Research Center) geotechnical engineer and an IPT (Instituto de Pesquisas Tecnológicas) geologist. In consensus, emergency measures to be taken on each spot were defined for mitigation of risks and for increase of safety so as to allow the return to safe operation of the OSBAT 24” pipeline.

After these measures, all of the five spots formerly classified as High-Risk VI have been reclassified as High-Risk V, which means, they no longer prevent the operation of the pipeline, although caution is still necessary.

### 4.3 The mitigation measures, spot by spot

#### Km 36+150

Visual reconnaissance of the right-of-way, cleaning of the area by means of removal of soil and trees, pipe localization field survey, installation of steel plates, re-sloping of upstream debris, installation of provisional drainage system to divert water which would otherwise open new paths.

#### Km 37+000

Visual reconnaissance of the right-of-way, cleaning of the area by means of removal of soil and trees, pipe localization field survey, installation of steel plates, installation of furrows at the main landslide event, installation of provisional drainage system to divert waters which would otherwise open new paths, and ground levelling with the nearby roadway.

#### Km 37+500

Visual reconnaissance of the right-of-way, cleaning of the area by means of removal of soil and trees, pipe localization field survey, installation of provisional drainage system to divert water.

#### Km 41+100

Visual reconnaissance of the right-of-way, cleaning of the area by means of removal of soil and trees, pipe localization field survey, installation of steel plates, installation of furrows at the main landslide point to divert water.

#### Km 41+700

Visual reconnaissance of the right-of-way, cleaning of the area by means of removal of soil and trees, pipe localization field survey, installation of steel plates, installation of furrows at the main landslide center, installation of provisional drainage system, removal of loose rocks, provisional covering of downstream slope with plastic sheets.

### 4.4 Contractual Aspects

The emergency works demanded at least 40 different companies. On that occasion, there was no single company which could face the entire demand. All resources and equipment necessary to minimize losses, human and environmental as well as corporative, were disputed between commercial companies and public authorities.

Internal and external consultants recommended immediate and continuous geotechnical measures and works. Given the possibility of new rainfalls, even in smaller volume than on February 19<sup>th</sup>, 2023, there could possibly arise new catastrophic events of pipe breakage and loss of contention.

Transpetro then needed to perform a great number of works simultaneously, in a volume never seen before in the company.

Logistics for assessment of necessary mitigation measures were extremely difficult, demanding helicopter flights and

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drones to reach places of difficult access, sometimes isolated by the obstructed roadways. Commercial helicopters were in short supply, so Transpetro had to utilize the Army and Police machines.

New risky spots were found out as works progressed, which made planning of resources for the work fronts a challenging task. It demanded constant rearrangement of planning of necessary resources.

The fulfillment of planned tasks was directly dependent on the weather, since the summer rains persisted, hampering the safe progress of the works.

Simultaneous geotechnical events were so numerous that they demanded exceptional volumes of resources, tools, and equipment. This meant a logistical challenge which affected the construction market, demanding displacement of resources from other regions in Southeastern Brazil.

As can be expected, this surge in demand meant a very high price surge as well.

For the emergency works to fulfill the Brazilian Law, a judicial analysis was performed, allowing fast enough contracting as demanded by the emergency.

### 5 Performance of mitigation on pipe safety

For each of the five critical points, a field assessment survey was carried out by TRANSPETRO's geotechnical staff, as well as outside consultants. In consensus, mitigation measures were planned to increase pipe safety to allow its return to operation. These mitigation measures were concluded on March 8<sup>th</sup> 2023 (6).

Through these measures, all five critical points could be reclassified from HIGH VI to HIGH V, which means caution is still to be taken, but they no longer stop the OSBAT pipe from operating.

#### Geotechnical instrument reading

Instrumentation reports from March 2023 show no anomalies, in general. An exception was the inclinometer at km 12+950, which displaced circa 30 mm. On-foot inspection on this spot showed no signs of movement which could harm the pipeline, so it was classified as MODERATE IV.

Therefore, no anomaly that could prevent the pipe from operating was realized by instrumentation.

#### 5.1 Measures taken for returning OSBAT back to operation

On March, 10<sup>th</sup>, 2023, a comprehensive meeting summarized and reported [3] the following measures considered

as necessary and sufficient for the return to operation of the OSBAT pipeline:

- A report from the inertial and geometrical PIG runs showing no anomalies found,
- A MFL PIG run scheduled for the following day,
- A tightness test carried out the day before, showing no anomalies,
- A geotechnical report issued on March 9<sup>th</sup> stating that the mitigation measures on the critical spots had been carried out, other risk spots were not critical to the pipeline operations,
- A geotechnical instrumentation report was issued stating that, despite one anomalous reading, (12+950), field surveys showed no evidence of instability. Further surveillance was recommended,
- A geotechnical consultant report, after field visits, both on-foot and airborne, states that OSBAT's right-of-way behaved well to the adverse events, recommending the continuity of the preventive works, and of the cleaning and drainage of spots,
- A geological consultant, after two overflights and an on-foot field survey, understands that the pipeline is able to return to operation, stressing necessity to continue the geotechnical risk management,
- A report on emergency works on the five critical spots stated the conclusion of these works, which have been evaluated by the consultants,
- An Operational Risk Analysis (ARO, in Portuguese acronym) was prepared for the pipeline return to operation,
- A technical instruction for the continuing of the works was made and reported to the field crew,
- A Permanent Committee was created.
- Given all the measures described above, the Meeting understood that the OSBAT pipeline was able to return to operation.

### 6 THE PHASE 3 WORKS

Soon after the rains, remediation works began. At first, in what was called Phase 1, the areas were cleaned of debris and trees; second phase consisted of the short-term construction of drainage structures, mainly small-dimensional channels. Phase 3 consisted of more robust works, designed to prepare the sites for the next summer rains. They included retaining structures as well as more robust drainage, as described above.

Among the 18 high/moderate-risk spots, nine have been considered as the most critical about the necessity of further field works after the mitigation field measures. These works involved special retention structures necessary to assure the long-term stability of the slopes. Five of those nine spots were judged as urgent enough as to justify an emergency bidding, for the other

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four, a normal bidding course was followed. A list of those spots is shown in Table 1, including the risk degree after the mitigations. In general, the works comprised retention structures such as soil nailing, some complementary drainage structures not made in the earlier phases and revegetation measures such as vegetation-improving sheets. The construction designs are still being made, so that results are still not available.

Emergency bid		Normal bid	
37+400	High V	24+800	High V
37+500	High V	31+500	Mod IV
36+150	High V	37+300	High V
41+700	High V	37+000	High V
30+850	High V		

Table 1: List of phase 3 spots

## 7 RESULTS AND DISCUSSION

At the time of writing, in August, the pipeline is operating normally, and no further geotechnical event has occurred. This shows that the emergency measures taken were correct. The phase 3 works, intended to be permanent, will not be tested until next Summer. Should other severe rains such as in this year occur, the pipeline should be protected.

## 8 CONCLUSIONS

Severe rainfall occurred last February on São Paulo's Serra do Mar, causing several landslides and debris flows and forcing Transpetro to halt the OSBAT pipeline. Immediate actions took place, including the execution of mitigation works, which allowed the pipeline to go back in operation within a short time.

## 9 DISCUSSION

First of all, we noticed clearly our limitations to contract, and how limited we are, due to our heavy structure, typical of a state-owned company, to achieve a new contract.

As learned lessons, some homework has been done to prevent the repetition of the problems discussed in this paper. At first, a workgroup was formed. As a result, a study on critical river basins, formerly performed by the IPT, was updated and generalized, showing if the works have been performed at the right places. The results are not yet available.

Another aspect was that Transpetro's geotechnical crew started asking itself "are we doing the right thing?", a question that ultimately led to the hiring of international consultants to help us assess the response. So far, the geotechnical crew identified no particular wrongdoing and pursued the works and studies commenced after the rains.

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