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THE PRODUCTION OF THE COMPACTED EMBANKMENT FROM BELO MONTE HPP

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Abstract. *The achievement of producing about 60 million m³ of compacted embankment in just 3.5 years, in the Amazon region, where challenges with weather, logistics due to distances, environmental problems, among others, to allow the construction of the 36 dams / dikes of the Belo Monte HPP has been overcome.*
The purpose of this article is to present a summary of the technical characteristics of Belo Monte HPP, as well as to present the main challenges faced during the execution of the compacted embankment, along with the characteristics of the soil materials, the equipment used for compaction. In addition, to present the results obtained in the Technological Control, besides of the control procedures used to verify the quality of these embankment during its construction.

1 INTRODUCTION

The reservoir of the Belo Monte HPP has two sectors interconnected by a channel, called the Diversion Channel: a sector, upstream of the Diversion Channel, formed by the natural course of the Xingu River, called the Main Reservoir, and another sector downstream, formed by the construction of dams and dikes, called the Intermediate Reservoir.

The Adduction to the main Intake in the Belo Monte Site, from the natural course of the Xingu River, is made through the Diversion Channel, seven Transposition Channels denominated CTPT1, CTPT2, CTPT3, CTTC, CTCA, CTCS and CTSA and three Filling Channels denominated 1, 2 and 3. The channels were excavated along the Intermediate Reservoir in order to reduce the load losses.

For the most part, the Diversion Channels comprised excavations in soil, with lateral slopes below the operation levels of the Intermediate Reservoir. The channels were coated in the bottom with rocking and in some of them, the protection extends to the lateral slopes.

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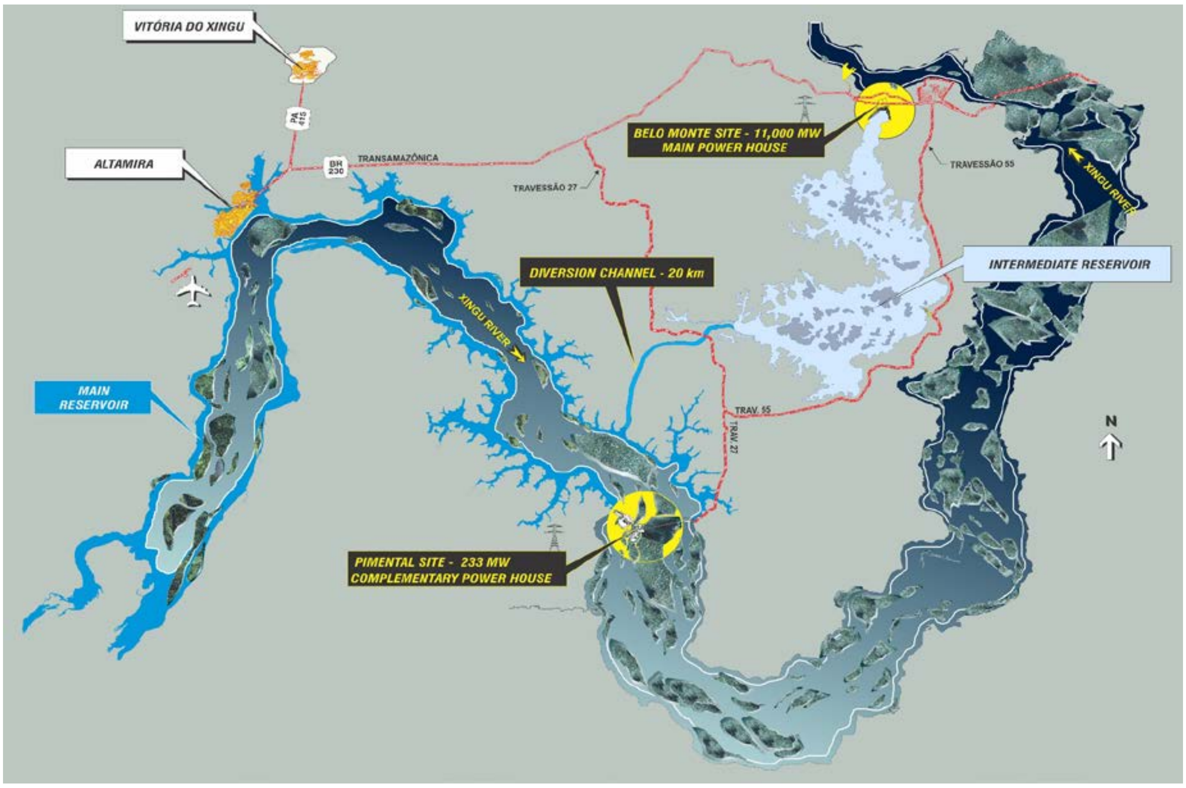

Figure 1: General arrangement of Belo Monte HPP.

The Intermediate Reservoir consists of 28 containment dikes that closes saddles or streams thalweg and are distributed along the entire reservoir. In addition to these dikes, in the Belo Monte region, the reservoir is limited by the Versant of the Santo Antonio Dam (VSAD), the Left Closing Dam (LCD) and the Right Closing Dam (RCD), and the Intake in itself.

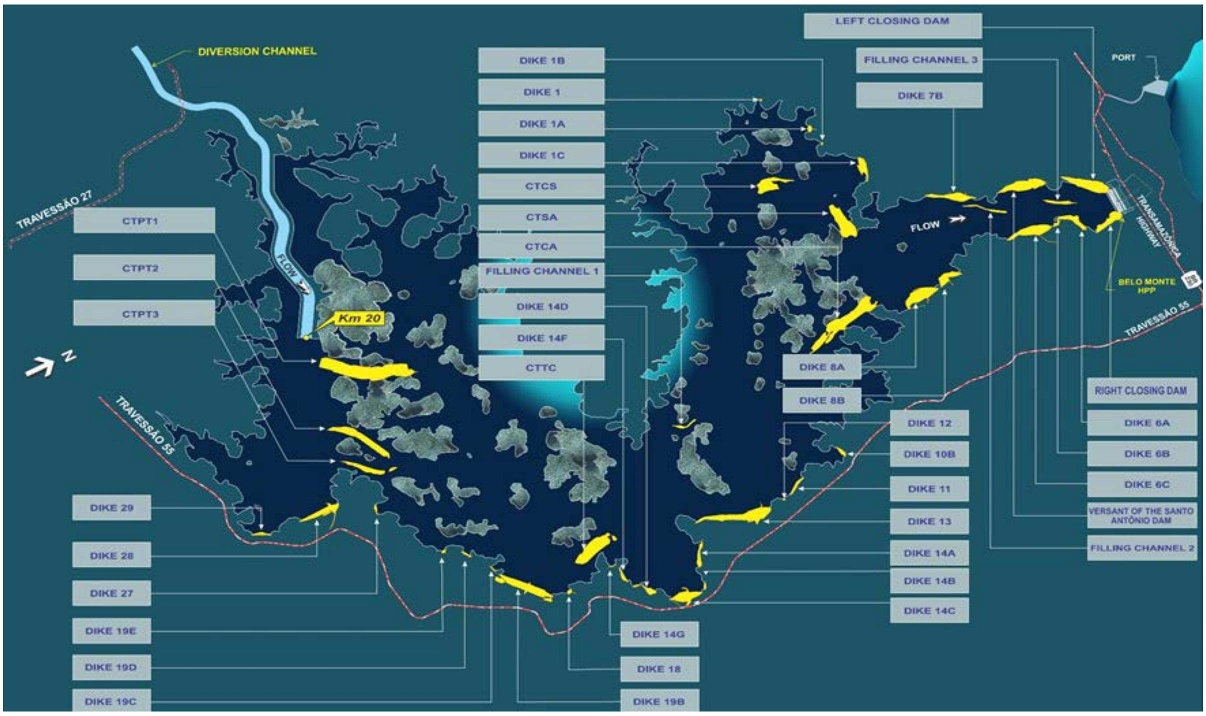

Figure 2: General arrangement of dikes and dams in the Intermediate Reservoir.

2 CHARACTERISTICS OF THE INTERMEDIARY RESERVOIR DIKES

The dikes have a homogeneous section in compacted soil and were constructed with colluvial soils and residual migmatito soils from the borrow areas located, in the great majority, within the area now flooded by the reservoir, minimizing the environmental impact.

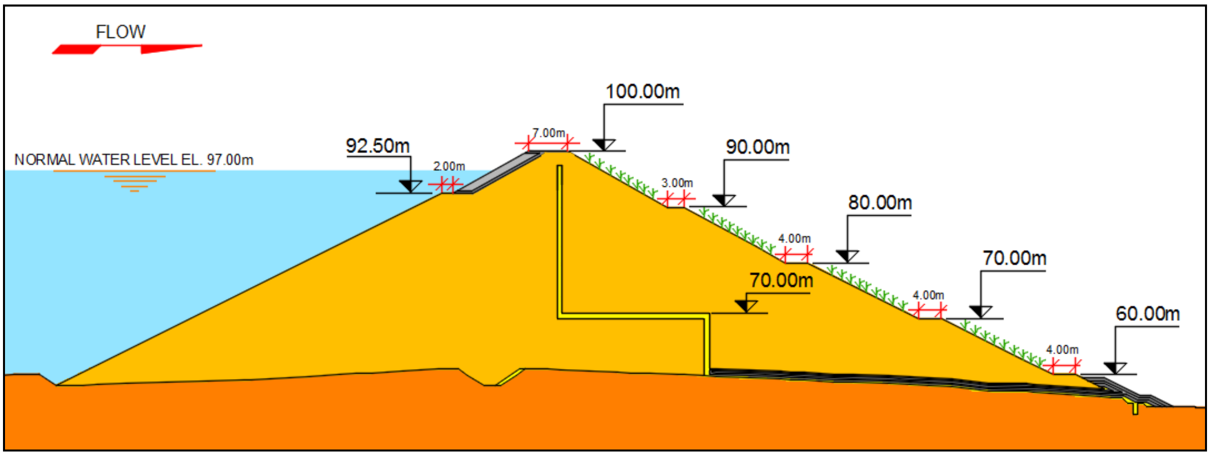

Figure 3: Typical Section of Intermediate Reservoir Dikes.

Under the upstream backrest, a trench exploratory/insulation was carried out in order to investigate, mainly, the occurrence of canaliculi. Its depth was, in principle, established at 3.00 m, with the possibility of deepening it to 6.00 m, depending on the frequency and magnitude of the canaliculi. The trench was also provided with the launching of a layer of sand on its downstream slope, in order to prevent the transport of fines through the smaller canaliculi. In the trench was also planned the treatment of canaliculi by means of injection of cement by gravity.

The internal drainage system consists of a 0.70 m wide vertical sand filter and, on the foundation, a horizontal drainage mat of 3 or 5 layers of granular materials, with protection at the outlet downstream, a foot drain fitted with transitions and rocking.

3 CONSTRUCTIVE ASPECTS

Table 1 shows the dynamics of the construction of the compacted embankment in the Intermediate Reservoir, with 46 million m³, which corresponds to 76.6% of the total volume executed in the whole project (60 million m³). It is noticed that in the first two years of the work, the advance was limited to about 22% and that 78% of the embankment were built in the last 2 years.

The difficulty of advancing in the first 2 years of construction may be justified by the following factors: (i) challenging logistics, (ii) implementation and adaptation of access roads to the sites, (iii) implantation of pioneer sites, (iv) implantation of definitive sites, (v) liberation of the areas to start construction of the structures - environmental, land ownership, archaeological prospecting, plant suppression, etc.

As for the logistics challenge, just remember that Belo Monte HPP is located on west of Pará, in the municipality of Vitória do Xingu, distant about 50 km from the city of Altamira. Access can be made via land via the Transamazônica Highway (BR-230), via river from Belém to the city of Vitória do Xingu and by air.

In order to make feasible the construction of the Belo Monte Hydroelectric Plant, four construction sites were implanted: Belo Monte Site (Main Powerhouse), Pimental Site

(Complementary Powerhouse and Xingu River Bus), Diversion Channel and Bela Vista Site (Dikes Construction of Intermediate Reservoir). To get a sense of the size of the work, it should be noted that the distance between the Belo Monte Site and the Pimental Site is about 50 kilometers, a distance that is repeated between the Belo Monte Site and the Diversion Channel.

From the Transamazônica Highway (BR-230), the beds are accessed by the *Travessão 27* and *Travessão 55* (vicinal roads) meaning more than 80 kilometers of roads. The works of adaptation of Travessão 27 were initiated after the release of the Installation License in June 2011 and the works of adaptation / implementation of Travessão 55 were started in 2012.

Structure	Anual Volume Reached (m³)				Total
	2012	2013	2014	2015	
VSAD		1.022.180	3.572.992	1.435.421	6.030.593
RCD		124.857	737.872	412.717	1.275.446
LCD	326.396	3.440.271	3.853.984	229.705	7.850.356
Dike 1				5.120	5.120
Dike 1A			40.233	100.589	140.822
Dike 1B				5.972	5.972
Dike 1C			140.753	703.713	844.466
Dike 6A		147.719	91.354	781.148	1.020.221
Dike 6B		16.611	1.156	18.345	36.112
Dike 6C		712.455	1.892.062	1.529.887	4.134.404
Dike 7B			454.943	1.331.741	1.786.684
Dike 8A			1.604.557	3.623.228	5.227.785
Dike 8B			352.992	1.511.578	1.864.570
Dike 10B			185.935	33.799	219.734
Dike 11			154.063		154.063
Dike 12			4.642		4.642
Dike 13		1.659.723	2.825.264	1.272.674	5.757.661
Dike 14A		52.811	350.883	926	404.620
Dike 14B			34.954		34.954
Dike 14C		197.403	1.735.181	631.917	2.564.501
Dike 14D		68.052	200.249	190.045	458.346
Dike 14F		138.617	21.426		160.043
Dike 14G		15.350	1.903		17.253
Dike 18		78.609	12.893	1.688	93.190
Dike 19B	769	1.718.443	831.292	1.611.325	4.161.829
Dike 19C		15.504	4.559		20.063
Dike 19D			2.095	60.688	62.783
Dike 19E				39.811	39.811
Dike 27				62.647	62.647
Dike 28		284.673	28.426	1.195.680	1.508.779
Dike 29		32.895		174.974	207.869
TOTAL	327.165	9.726.173	19.136.663	16.965.338	46.155.339

Table 1: Anual Volume of Compacted Embankment.

As the implantation of the sites and the access roads advanced, the works of land and rock also advanced. In 2012 the activities of common excavation, foundation treatment and construction of embankments of dikes and dams was still incipient. In 2013, the advance of the compacted embankment was indeed relevant, reaching the mark of 9.7 million m³, about 21% of the total.

At the beginning of 2014 there was a major challenge ahead: the execution of 36 million m³ of embankment in just 2 years. The schedule of the work provided for the beginning of the filling of the Intermediate Reservoir was 11/15/15. At the time, taking into account the existing difficulties, the climate was skeptical about the viability of these large volumes in such a short period of time. The objective of this article is to present a brief description of the actions taken during the years 2014 and 2015 to enable the construction of 36 million m³ of compacted embankment of the dikes and dams of the Intermediate Reservoir in such short term.

4 THE EQUIPMENT AND LABOUR RESOURCES

Labor and equipment resources, can undoubtedly be considered, as one of the important factors that enabled the accomplishment of the goal of construction of compacted embankment. By 2014, at the peak of the project, approximately 37,000 employees and 5,400 units were directly involved in the construction of the Belo Monte HPP

The training of local labor was also a defining characteristic of the work. The Capacitar Program was an initiative of the Belo Monte Constructor Consortium (CCBM), which promoted training of new professionals from the surrounding municipalities. About 14,000 professionals were trained and more than 10,000 were admitted by the Constructor Consortium to work on the sites of the hydroelectric plant.

5 EQUIPMENT AND TECNOLOGICAL INCREMENTS

The acquisition of a fleet of new equipment, with high technology resources, played an essential role, contributing to the achievement of production world records. With the support of the world's leading equipment manufacturers, the equipment has gone through a world-class maintenance process, with well-structured workshops and even laboratories for lubricant analysis. Remote monitoring of operating conditions using applications such as Caterpillar / Trimble, VisionLink and Mercedes-Benz Fleetboard is also noteworthy.

The Smartcargo, heavy equipment fleet monitoring and control system, and Simova's ConstruMobil electronic sewer system were also used for the purpose of: (i) optimizing production; (ii) increase productivity of equipment; (iii) reduce maintenance costs and other overheads.

The equipment used for compaction of embankment sites had a heavy weight (CAT 825H 32,7 t and CT300 Dynapac 21 t compactor roller), high power traction, which could reach speeds of up to 15.6 km/h (CAT 825H) and 21 km/h (Dynapac CT300). The higher weight/higher velocity combination, thus applying higher energy, allowed the increase of the thickness of the compacted layers. The definition of the compaction parameters took into account the definition of the translucency velocity of better yield, which did not overturn the surface soil layer and did not detract from the increased densities.

The grids used to homogenize the released soil, also underwent a process of tests and evaluation in experimental tracks. From the obtained results, it was possible to increase improvements that guaranteed the effective treatment of the layers of launched soil, having as main gain the increase of the dimensions of the discs.

The use of articulated off-road truck (type CAT 740B) in the common excavation and cleaning of the foundation of the structures, also deserves attention. This equipment allowed the work to be advanced in areas of difficult access, minimizing the need to construct service accesses, both in the excavation regions and in the material disposal regions (Dumping Ground). Another important differential in this equipment was its capacity of material transport, about 23 m³, which guaranteed a considerable increase of productivity.

Figure 4: Equipment utilized on the compacted embankment constructions.

6 SUPPORT AVAILABLE IN THE CONSTRUCTION SITE

The basic criterion adopted in the planning and implementation of the four sites at the Belo Monte Hydroelectric Plant was to provide adequate accommodation to workers, which included the provision of essential services and care for the quality of life of the people involved. The implantation of housing in the construction sites minimized the anthropic impacts in the region, avoiding the daily transport of large contingents of workers in the route between the city of Altamira and the construction sites.

The camp building sector had the following main constructions: (i) concierge/control, (ii) kitchen/canteen, (iii) housing, (iv) parking, (v) medical outpatient clinic, (vi) industrial and collective laundries, (vii) coexistence and leisure center, (viii) school for adults and (ix) infrastructure support - sewage treatment plant, wastewater treatment plant, landfill, waste area, etc.

The industrial building sector has the following main constructions: (i) engineering offices, (ii) ambulatory, (iii) parking, (iv) warehouse, (v) mechanical workshop, (vi) gas station (viii) carpentry center, (ix) concrete plant and (x) crushing plant.

7 ITINERANT SUPPORT

In 2014, the embankment project progressed simultaneously in 17 structures, increasing to 25 structures by 2015, with the challenges of personnel logistics, equipment and supplies for these works scattered over an extension of more than 30 kilometers.

In the service fronts, several types of support were required: (i) canteens, (ii) rest areas, (iii) sanitary facilities, (iv) electrical maintenance, (v) mechanical maintenance, (vi) topography, (viii) laboratory tests, etc.

An important differential of the execution of the embankments of the dikes and dams was the "itinerant" support present in the work. At the height of the project, in addition to the three central canteens in the main sites, there were five more air-conditioned mobile canteens scattered around the building, which optimized the movement of employees.

The same happened with laboratory tests for the technological control of the construction of compacted embankment, the results of which were obtained quickly in one of the 10 labs (4 central and 6 roving) strategically positioned throughout the work. A quality control system, therefore, was structured to meet the demands of large volumes of compacted embankment and productivity challenges.

The same itinerant concept was applied to the other demands of the work: (i) topography, (ii) construction maintenance, (iii) electrical maintenance and refrigeration, (iv) mechanical maintenance, (v) The support structures were repositioned whenever necessary, to meet the dynamics of the enterprise.

8 TECNOLOGICAL CONTROL

The following will briefly describe some points considered relevant to obtain the good results observed in the execution and the release of the embankment layers of dikes and dams, as far as Technological Control.

8.1 Technological Control Data Management Web Tool (AutoLab)

- Through the use of the AutoLab management software, the release of the squares gained agility, since all the data were inserted directly in the program and it provided, just in time, the results of the tests of degree of compaction and humidity deviation, and it is not necessary for the laboratory to draw graphs and make interpolations.
- The implementation of the management program also allowed an adequate control of the data of the execution of the layers. From the analysis of the reports generated by the system it was possible to:
- Identify the occurrence of layers rework, their frequency and even the responsible in charged for the squares where the deviations occurred;
- Establish more targeted training to correct identified deviations;
- Definition of constructive methods and standardization of activities;
- Obtaining the ideal number of passes for each roller model used in embankment;
- Correlate the results of rejected materials by moisture deviation, outside the specified limit, with the places of origin of the material (deposits);
- Treat data in real time, ensuring greater reliability of results.

8.1 Compression control

The values of the degree of compaction were on average 98.0%, with standard deviation around 1.5%. The results of the top/base control of the layers also showed compaction difference, from top to bottom, around 1.0 to 1.5%.

9 OPERATIONAL EXCELLENCE

In order to promote a coordination of the lean production system, based on the philosophy of the Toyota production system, the NEO - Operational Excellence Nucleus - dedicated to the compacted embankment program was implemented in 2013. From this work was established the pull planning, as well as the ideal rhythm of work, in order to avoid wastes, overproduction, stocks and rework. Among the various actions, highlights:

- Definition of the ideal size of workplaces due to the sequencing of activities;
- Balancing resources per work place according to the ideal size of each lot;

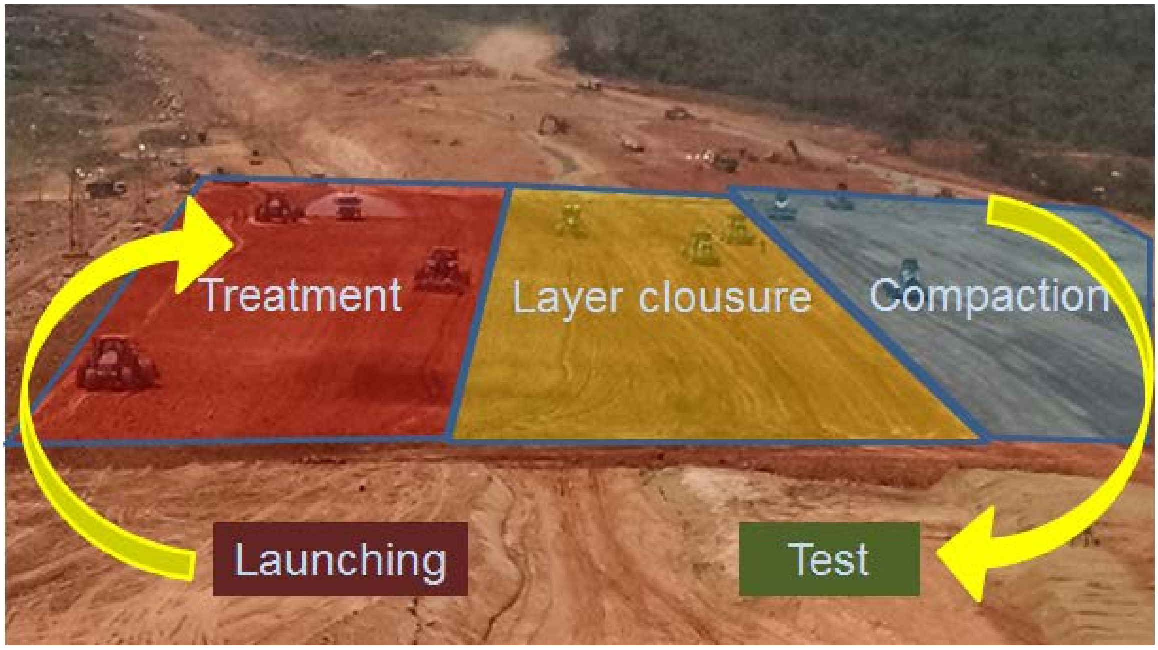

Figure 5 - Definition of workplaces.

- Implementation, inside the compartment of the roller, of a device to control the number of passes, reducing the occurrence of overcoating of layers or lack of compaction;
- Creation of equipment patrols - a group of trucks dedicated to a bulldozer - associated to the definition of the origin and destination of the materials - deposit / launching place - guaranteeing the production rate (Time Takt);

Figure 6 - Identification between transportation equipment and load equipment.

- Standardization of truck load maneuvers in the fields;
- Standardization of the width of access platforms, both the entrance and exit of workplaces, as well as deposits and dumping sites;

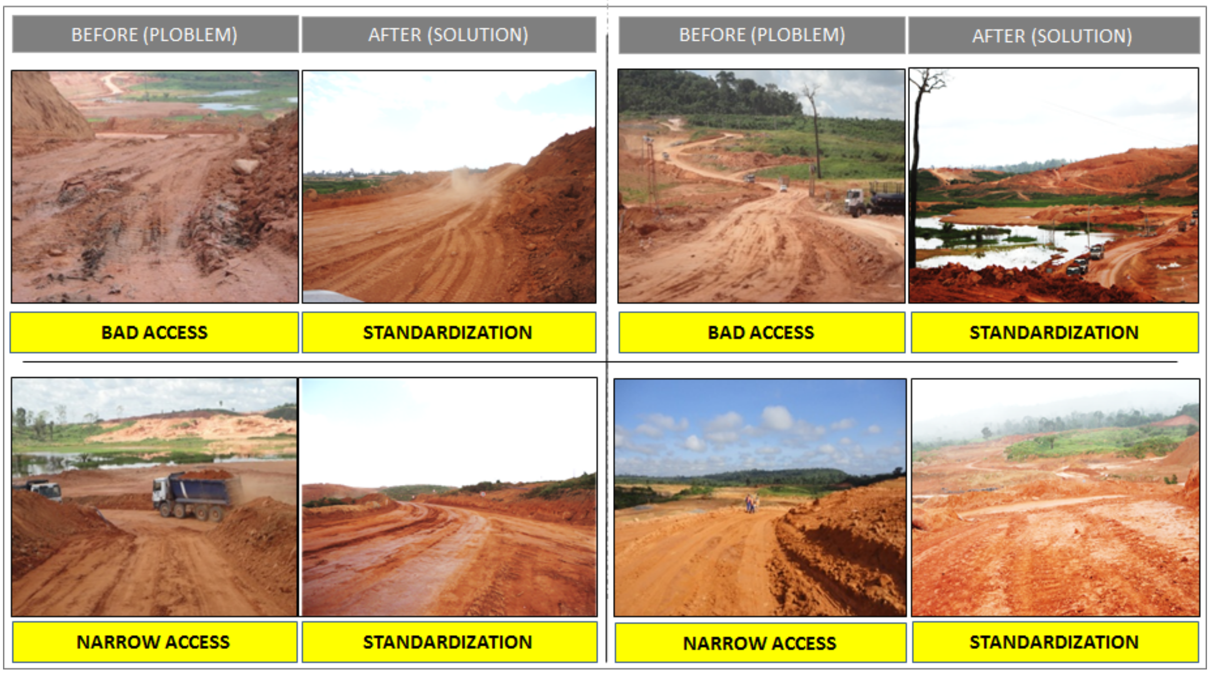

Figure 7 - PCS (Problem / Cause / Solution) of accesses.

- Signaling of accesses and visual identification of workplaces;
- Implementation of a training and monitoring program for drivers in training, with the participation of multipliers (more experienced drivers);

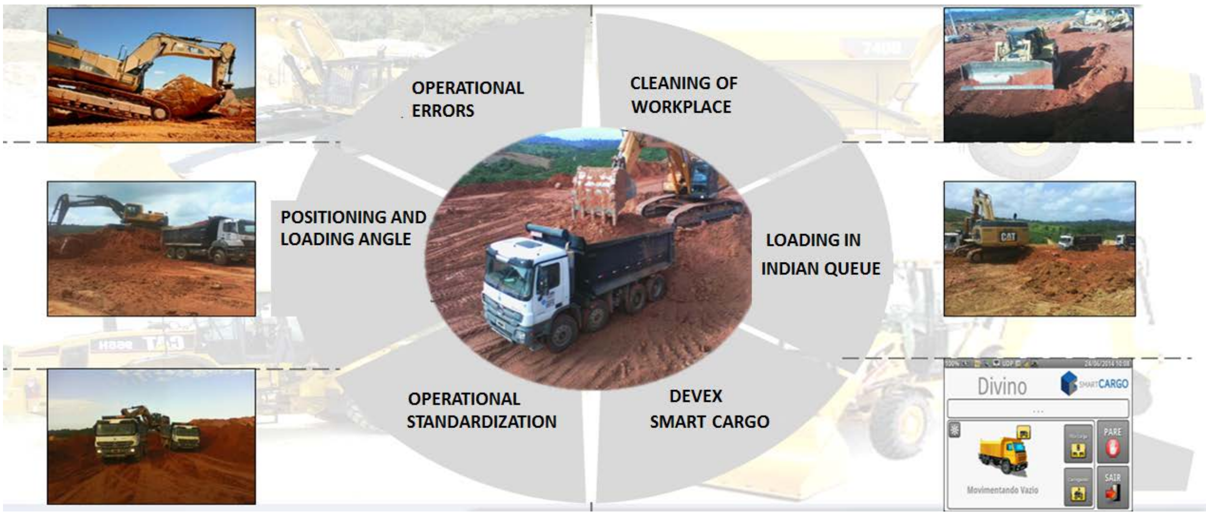

Figure 8 - Operational Development Training based on NR 11 – Excavator.

- Implantation of support points close to the service fronts aiming to reduce the time of displacement of the teams;
- Reduction of the spacing between the layer thickness indicators in the launching areas, as well as the use of reflective adhesives on the crossbars, improving their visualization and their effectiveness during the nightshift.

10 CONCLUSION

The filling of the Intermediate Reservoir at the end of 2015 was only possible with the completion of compacted filling of the dikes and dams, which moved an impressive 46 million m^3, almost 80% of this volume during the last two years. Challenges encountered in the first years of the project's implementation involved environmental issues, expropriation and clearing of areas, archaeological surveys, advances in plant suppression, highlighting the enormous difficulty of logistics, great distances and poor access conditions.

Enabling the implementation of large volumes of compacted embankment required a series of coordinated actions that included labor training, acquisition of a fleet of new equipment, state-of-the-art technology, support from major equipment manufacturers, use of remote monitoring of operational conditions, electronic appropriation system, etc.

The construction of the Belo Monte Hydroelectric Plant counted with a good infrastructure in its four construction sites, which had two main core: accommodation and industrial. However, the great differential observed in the execution of the compacted embankment was the concept of itinerant support, which allowed a rapid repositioning of the resources to meet the dynamics of the work.

AutoLab management software has established itself as a great ally of the procedures related to technological control, an indispensable item in the quality of compacted embankment. In addition to gaining agility in obtaining test results, the program ensured an adequate control of landfill layer data, reducing rework, allowing targeted training, pointing to the need to define constructive methods and standardization of activities, among other important gains.

The creation of the Operational Excellence Nucleus (NEO), dedicated to the compacted landfill program, constituted an essential action to obtain the results presented in this article, as it avoided waste, overproduction, stocks and rework. The definition of the ideal size of the squares, the balance of resources per square, the creation of equipment patrols, the standardization of service maneuvers are examples of the effectiveness of NEO.