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# **GEOTECHNICAL ACCIDENT AT KM 87 OF FEDERAL ROAD BR-116/RJ – TERESOPÓLIS- BRAZIL – CAUSES ANALYSIS AND RECONSTRUCTION SOLUTIONS**

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## **SUMMARY**

1. Road History
  2. Problem description and geotechnical accident
  3. Accident's studies
  4. Conclusions
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## **ABSTRACT**

This technical paper's objective is to present causes analysis of a geotechnical accident occurred at km 87 of road BR-116/RJ, as well as shows the proposed solutions to recover road body and the location current status.

Studies and researches developed have been described and based on them, solution proposals and recommendations were prepared in order to reconstruct that segment.

At the end of this paper, there is a list of adopted procedures after the earned experience from the accident and also the road's status at the accident's location.

*Keywords: Causes and solutions for reconstruction in geotechnical accidents.*

## 1. ROAD HISTORY

Road BR-116/RJ, segment between intersection with BR-393/RJ and intersection with BR-040/RJ – from km 2,1 to km 144,4, was created at the end of 1950 with the objective of linking through roads Brazil' southeast and northeast regions, working as an alternative to railroad transportation between the two regions.

This road section crosses regions with multiple kinds of relief, according to the following distribution: from km 2.1 to km 60, rolling terrain; from km 60 to km 90, mountain region; from km 90 to km 1, cliff region (Teresópolis ridge of mountains); from km 110 to km 104, mountain region; from km 104 to km 118, rolling terrain; from km 118 to km 144.4; plain region.

Regarding height variability, its initial point is 250m over the sea line, with elevations reaching 1110m plateau at the cliff region. Further, there is a reduction on altimetric values reaching elevation 60 at km 104 and finally, between this location and km 144.4, another reduction until it reaches the minimum value around elevation 12, next to BR-040 (km 144.4).

The road was constructed with 2 traffic lanes and small shoulders, suffering further modifications/extensions until it reaches the following configuration: from km 2,2 to km 103,8, track with a single traffic lane (width between 3,5 and 3,6m) and external shoulders adapted afterwards in a separate way, varying from 1,0 to 2,5m. The section from km 103.8 to km 144.4 was duplicated and it was implemented a central separator with vegetable dressing. This part of the road has two tracks, each one with 2 traffic lanes and internal and external shoulders.

Regarding the pavement type, this road is one the few Brazilian roads which presents sections with Portland Cement Concrete revetment (between km 89.6 and km 103.8); executed when the road was inaugurated in 1950 and which has been maintained until now. On the other road sections, the pavement is flexible, presenting variable characteristics according to different periods of construction and maintenance, as well as the availability of materials at the time of each work.

The road was constructed and paved using federal financial resources (National Department of Main Roads), which was also responsible for duplicating the segment already mentioned (in 1972 and 1979). After some years, the available financial resources weren't enough to conserve and maintain the road in good conditions. Facing this issue, as it happened with other federal roads, the Government decided to include the road on the Brazilian Road Privatization Program, in 1993/94.

In 1995, the bidding process was concluded to concede the road to a private company, however, only in March 22, 1996, that road section was handed to the winning bid company (CRT – Rio Teresópolis Concession Company). The concession contract is valid through 25 years, and it has a foreseen investment during of US\$ 450 millions during this period.

The winning bid company had at that moment, four shareholders (OAS Construction Company, Carioca-Christiani-Nielsen Engineering, Strata Concessions and Queiroz Galvão Concessions and Participations), and all linked to traditional Brazilian companies in civil construction business. This configuration was changed in 2002 with

the entrance of pension funds on the shares' composition, representing other Brazilian private investors.

Since its operation started, CRT had a goal to achieve total service quality, being Latin America's first road concession company to obtain ISO 9002 certification. In 1999, they received IBTTA's (International Bridge, Tunnel and Turnpike Association) Toll Innovation Award, a prize annually conceded to worldwide road administrators responsible for innovative ideas which bring more safety to road users.

The road presented an average traffic volume highly variable, depending on the type of vehicle observed, as shown below: km 2.1 to km 90 – 5,000; km 90 to km 104 – 10,500; km 104 to km 122.5 – 12,500; km 122.5 to km 134.5 – 18,000 and km 134.5 to km 144.4 - 31,000.

## **2. PROBLEM DESCRIPTION AND THE GEOTECHNICAL ACCIDENT OF KM87**

Since the establishment of the road, several geotechnical problems have been happening throughout its length which goes through a mountain ridge region. Some of these problems became specific case studies in order to search for solutions to allow a safer traffic in the road. The greater problems took place while the road was under the Government's jurisdiction. From the moment the road became administrated by a private enterprise, the concession company adopted some measures of monitoring, conservation and maintenance in order to fit the Road Exploration Program, which established some parameters to be followed aiming to increase safety to vehicles and people.

The exact point of the accident was not known as a dangerous local or as a place which demanded special care under the geological-geotechnical aspects. This information was conquered with the team that monitors slopes and drainage devices. They have been working on the road since it became administrated by the private concession company, in 1996.

The road body, built in the 1960's, was made of cut and fill cross section (part cut, part fill). The cut was ten meters high and the fill was around twenty meters between the level place board and the slope.

Throughout the years, along the Teresópolis city development, this region became a construction area, in the fill side, by high and average income families. Respecting the Right-of-Way and the *non edificandi* area, these families built their houses, some of them with great level of comfort.

Even with the constructions, the region and the road were kept well preserved, according to the concession company's inspection. Later, in June of 2002, the area became part of the Três Picos Forest Park, guaranteeing special care of its soil, fauna and flora.

The area of the problem takes place in a mountain region and it is submitted to heavy rain (around 1300 mm/year), most of it during the months between December and March (summer time). This period faces high temperatures during the day and heavy and windy rain, bringing humidity to the high parts of the relief.

The days before the accident, between February 1<sup>st</sup> and February 7<sup>th</sup> of 2005, high levels of rain were registered (178.5 mm – correspondent to approximately 90% of the average value of the month), which elevated the phreatic water sheet. It was possible to observe this elevation through the flow of deep drainage (deep and longitudinal drains) and after the installation of piezometers in the immediacy of km 87, after the accident.

In the afternoon of February 7<sup>th</sup> (Monday of Carnival), it was noticed cracks in the shoulder's pavement. Due to this situation, an inspection was held by an employee of the engineering department of CRT, who evidenced no damage on the drainage devices. He also evidenced that the water flow through the construction was normal towards its natural flow.

This employee was working in the extra shift due to the Carnival and he provided the cracks' sealing and the placement of signs, isolating the shoulder.

In the beginning of the night of February 7<sup>th</sup>, the Security Department was called by the local people. The officers suspected that close to the culvert flow, there was a disruption of some tubes of the drainage structure. As there was not any confirmation of the problem, nothing was provided in addition of the already adopted measures.

In the dawn of February 8<sup>th</sup>, when the traffic was little and the rain stopped pouring, a collapse of the soil that formed the road body happened. At that moment, there were two vehicles that were dragged by the soil mass and the water slide. The soil mass also reached several houses close to the road, severely damaging some of them.



**Figure 1 – A view from the land sliding location, already with a detour for temporary traffic**

The traffic control center of the concession company was warned of the accident and called one of its vehicles to go to that place. When the service car arrived at the km 87, there were firefighters and the Security Department teams helping the victims who were inside the dragged cars.

Due to the situation, the concession company provided the transference of men and equipments to take care of this emergency.

It was provided the placement of small barriers on the road, in order to block the water reaching the slide area, extending its dimension. At the same time, it was started the distribution of granular material (cobble) on the slide region, in order to retain in. It also was necessary to create a detour to be used by light vehicles, once the road was closed.

This situation made the road users drive inside the urban areas of Teresópolis city and it increased the passage in 20 km or an extension of 40 minutes in the travel time.

Some measures were adopted to avoid that a drainage device flow, specially the deep and longitudinal drains which still carried water from the phreatic water sheet, was able to happen in the slide area. The steps to achieve this goal were: blockade of gulleys, water flow detour and rock-fill at the flow points.

### **3 STUDYING THE PROBLEM**

#### **3.1 INITIAL STUDIES**

After taking emergency measures, CRT Concession Company started researching possible causes for the accident, in order to come up with an analysis of possible solutions for this situation. These procedures had as an objective performing all stages which would make possible for them to sue the road's insurance company looking to receive the premium related to the accident, as agreed in the insurance policy, as well as answer questions made by the Concessor through ANTT (NATT, National Agency of Terrain Transportations, the abbreviation in Portuguese). This organization is responsible inspecting on controlling federal roads under concession contracts.

Immediately were hired, and started the technical works, three experienced professionals of the engineering sector (Engineers Rubem Barth, Sergio Lima and José Luiz Cardoso), being the first of them highly experienced in solving geotechnical-geological issue on this road throughout many years, including when the road wasn't even handed to a private company.

They worked separately in order to produce independent reports about the subject.

Topographic studies were also performed in the whole affected area and its surroundings, as well as percussion and rotary soundings in locations previously defined by the consultants mentioned above.

Completing the available elements for the engineers for this initial studies, it's worth mentioning the following documents : updated existing draining register made by the concession company, a survey about the road's right-of-way, monitoring reports of slopes and existing draining and region's photographs before and after the geotechnical accident.

### 3.1.1 *Conclusions made by engineer José Luiz Cardoso.*

In February 28<sup>th</sup>, engineer José Luiz Cardoso handed in a technical report containing his conclusions regarding the earth fill moving and proposing solutions to reconstruct the damaged road section. Below, there's a description of the main points of this document,

- a) The existent earth fill didn't present a deep draining system, even in places where phreatic water sheet was present;
- b) The accident occurred due to a full rupture on the earth fill, reaching the residences located nearby;
- c) The accident's cause was the earth fill's saturation due to the region's pluviometric regimen, human activity and soil's grading;
- d) It's possible to have a relation between the water flow and rock massif movements. For this affirmative to be true, there is a necessity of reliable data availability and a historical register in order to make a correct analysis;
- e) Recommendations to perform soundings and installation of adequate instruments to evaluate water levels. This info will guide to a definition of the geological-geotechnical profile and also of water levels and piezometric variability. With these elements obtained, it will be possible to elaborate a draining and slope stabilization project;
- f) Recommendations to implement 4 wells (with 0.4m diameter) with suction pumps to perform water level reduction, decreasing the rock massif's instability;
- g) Two solutions are proposed to reconstruct the road at the accident's location: one is reconstructing the earth fill and another is constructing a viaduct;
- h) Regarding the first solution, it's necessary to mention the following aspects: the necessity of surveys to define the draining system, temporary traffic prohibition on the road during the draining execution and the difficulty in obtain the necessary volume to execute an earth fill. Having this in mind, this solution isn't recommended in technical and economical ways;
- i) The alternative solution is to construct a viaduct with a 30m central span and 2 lateral spans with 25m, totaling 80 meters. It's also recommended to reconstruct the earth fill's slope and its protection with chipping, besides creating 4 draining wells in the nearby region.

### 3.1.2 *Conclusions made by engineer Rubem Barth*

Engineer Rubem Barth presented a report containing text, photographs, pluviometric data and newspaper articles about the accident at km 87 of BR-116/RJ. Below are the main comments contained in the report:

- a) There was no slope land sliding due to the fact the accident's location upstream area wasn't hit;
- b) The land sliding, of rotational and translational type, occurs, most of the times, after long and intense rains;
- c) The final cause was the action by reloaded waters;
- d) Mentions to rain behavior along with pluviometric data of January and February, the period right before the accident;

- e) Comments to exempt accident's cause from lack of conservation, lack of draining devices, holes in the track or cracked pavement, since none of these signs existed at km 87;
- f) Regarding reconstruction works, it's possible to affirm that the earth fill solution using clay material would cause a high transportation distance to obtain this kind of material, as well as necessary draining and retaining works adequate to the location.

### 3.1.3 Conclusions made by engineer Sérgio Lima

Using report S 2549, the last of the remaining consultants produced his report about the subject. The main topics are explicated below:

- a) From inspections performed on February 8 and 9, it was possible to observe there was a grade culvert at the location and a subterranean drain but both were destroyed. Also, there weren't any caves or any draining courses executed;
- b) The accident was rupture in the earth fill, whose wedge begun 6.0m from the upstream of the internal border on the opposite track of the land sliding side. This soil saturated soil mass, in a near state of liquefaction, reached around 70m from the downstream of the original earth fill, hitting residences beyond the total land requirement;
- c) The earth fill performed 40 years ago is located in a half slope region with intense presence of underground water which arises as riverheads in various levels. In the original report, the main reasons why this water flows can change its behavior are described;
- d) In case a conjunction of adverse conditions occurs, the factors mentioned before may provoke a change in the water flow, which may cause soil saturation, reduced friction and adherence between its particles, causing land sliding with almost liquid mud, probably the cause of km 87's accident;
- e) An accident of this nature is not normally detectable and doesn't present any previous alerts that may allow preventive or correction measures in time. The draining system (deep drains and grade culvert) can be blamed for this accident since it were in good operational conditions and it was under permanent inspections by CRT;
- f) If there was a fail, this should be blamed to the road structure when it was implemented (1967), due to the fact the evolution of percolation water and its destructive capacity have been underestimated and the appropriate draining was not implanted. There is also the hypothesis of any changes on the underground waters' percolation regimen in some place on the road for an unknown reason. Another hypothesis is that, due to the road implementation, there wasn't any water presence that could motivate bigger preventive measures;
- g) It's recommended that temporary measures to recompose earth fill, in case of traffic detours, should be included in the final project for a new earth fill;
- h) It might be necessary to perform retaining works completing the new earth fill;
- i) The construction of a viaduct can be technically viable, without forgetting a solution that guarantees stability to riverhead's earth fills.

### 3.2 FINAL STUDY

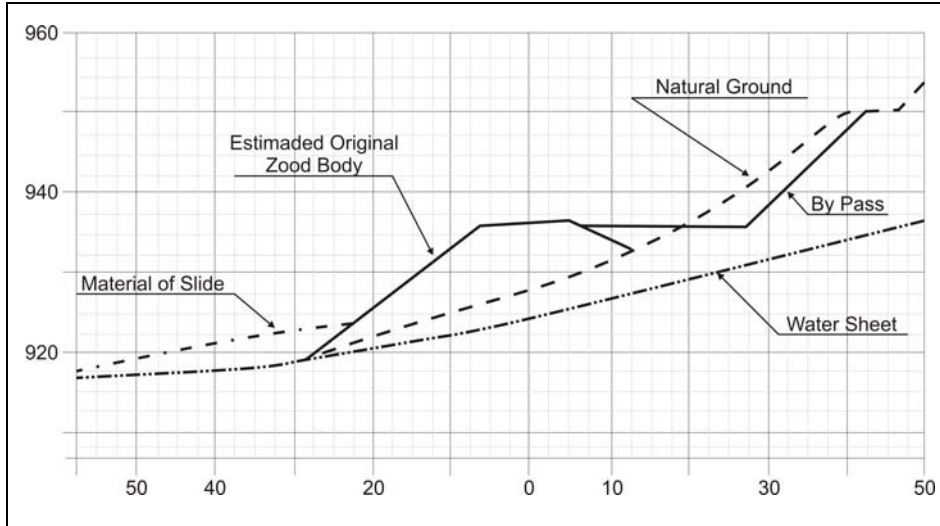
Along with the initial studies developed by CRT, ANTT (concession's inspection organization) created a commission to investigate the accident and produce a report about its possible causes and prepare recommendations to be adopted by the concession company.

The commission, which this paper's author was part of, during its working period, analyzed all documents already mentioned, besides hearing all those who worked on interventions before, during and after the accident. Based on this, it was concluded there was a necessity of adding a soil mechanics specialist to the group in order to produce a quality final report.

To fulfill this need, Professor Maurício Erlich from Rio de Janeiro's Federal University was hired and elaborated a technical report by the end of March, 2005. In this report, it is possible to highlight the following topics:

- a) Based on topographic surveys and performed soundings on the accident's location, the land sliding region's cross-sections were approximately reconstructed, allowing perform a more deep analysis than the ones in the early studies;
- b) The existence of an earth fill layer made with silty clay soil with a 5cm thickness was verified and under this layer there was a 10cm thickness layer of silty thin sand, probably a part of the natural terrain. The rupture's depth coincided with the bottom of this sandy layer;
- c) On figure 2 are water levels elevations observed on soundings. The hydraulic load is variable according to the measurement point and it clearly shows an uphill flow gradient to the slope's downstream. The flow gradient between February 21 and February 26 was around 0.2. Considering a permeability of  $10^{-5}$  m/s (thin sand permeability) there is an increase on the percolation front of 0.17m per day;
- d) Under the correspondent conditions from February 21 to February 26, the phreatic water sheet was lower and didn't make any sub pressure at the earth fill's bottom. Nevertheless, at the moment when the rupture occurred this was not existing situation. Before the collapse, there was a possibility of underground water flow confinement, considering the earth fill was made with a lower permeability material (silty clay soil) over a layer of natural sandy soil more permeable (silty thin sand), which wasn't long enough to reach the earth fill's bottom, as the soundings indicate. There was no evidence of existing a draining course at the earth fill's bottom;
- e) As normally expected, after the rupture with the end of the water flow confinement, it was possible to observe a process of phreatic water sheet reduction. Measurements made with piezometers at sounding location SP-02 (SR-04) proved this true, since the water level position was at elevation 925.3 on February 21 and on March 12 it had changed to elevation 924. On other piezometers, the performed measurements also indicated water level reduction on the days after the accident, since it practically has stopped raining. This would should the occurrence of some artesianism at that location and also a pressure relief process throughout time;





**Figure 2 – Cross section representing land sliding at km 87**

f) Based on the cross-section obtained (Figure 2), the hydraulic load was calculated on underground water capable of collapsing the earth fill. By the calculations made, the rupture value should correspond to the hydraulic load at elevation 935,7 in the road's level. This value is perfectly compatible with water level measurements and with local habitants statements about water accumulation upstream on the track on the accident's day (the water level should have increased up to this elevation, promoting its surgency). Water flows downstream the earth fill's bottom before and after the accident also showed high underground water pressure when the accident occurred. This way, we have a consistent diagnosis showing that the sub pressure made by water was the rupture's main cause. The calculations presented below prove the statement mentioned above. Considering figure 3, inserted below, we have at collapse's imminence:

$$M/U = \frac{\sin \alpha}{\tan(\phi - \alpha) + \cos \alpha}$$

Being  $U = P_{avg} \times L$

Where  $M =$  earth fill's weight;

$U =$  resulting from water pressures at the earth fill's bottom;

$\alpha =$  Natural soil's inclination

$\phi =$  Soil's friction angle

$P_{avg} =$  average pressure at the earth fill's bottom; and

$L =$  earth fill's width.

The corresponding values are:

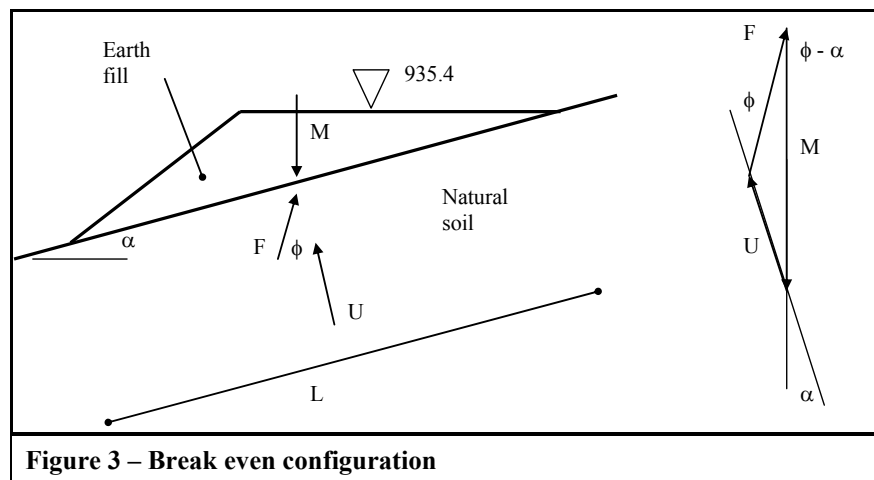
$$\alpha = 12^\circ \text{ and } \phi = 30^\circ$$

**Resulting in  $P_{avg} = 53 \text{ kN/m}$**

Total water load at the earth fill's bottom medium point ( $h_{total}$ ) would be:  
 $h_{total} = z + P_{avg}/\gamma_w$ ; where  $z$ = elevation at an specific road point, therefore

$$z = 935,4 - 5,0 = 930,4\text{m and } P_{avg}/\gamma_w = 53/10 = 5,3\text{m}$$

It's possible to conclude that  $h_{total} = 935,7\text{m}$  (hydraulic load which would lead to lead to earth fill's rupture) matches the road's gradient elevation



g) Probably a conjunction of factors caused the sub pressure increase at the earth fill's bottom. This only happened due to an exceptional underground water flow cause by heavy raining, and/or a reduction on the draining capacity of the earth fill's terrain.

h) The draining system's capacity may suffer some accretion throughout time, due to the precipitation of percolation water' dissolved salt and by the drag of soil solid particles that may block flow channels. This hypothesis could explain the draining capacity reduction at the earth fill's bottom. There are some narratives about this kind of reduction especially on earth dam draining. In spite of this, there's no way to prove that at this geotechnical accident this reduction was really relevant. To be possible to confirm this statement, it would be necessary to analyze current and initial soil conditions through permeability tests. Nevertheless, it's not possible to perform this research since the land sliding destroyed the terrain's structure next to the earth fill's bottom also due to non-existence of registers regarding terrain's initial conditions at the moment the road was implemented.

#### 4. CONCLUSIONS

Analyzing all mentioned documents along with ANTT's commission final report, it was possible to conclude that:

- a) The geotechnical accident occurred, as shown in the Final Study, mainly due to sub pressure excess at earth fill's bottom. This caused the formation of a preferential land sliding surface. The rain excess during days and months prior to the accident and a probable reduction on subterraneous drainage capacity provoked water level elevation, which caused a decrease in soil resistance and initial damages, resulting in the whole conjunct to collapse;
- b) Measures developed by the concession company, since the first signs of movement, were the normal ones to be done. At that moment, only with visual observation of the existing cracks, it wouldn't be possible to predict the accident's extension. It's worth mentioning the Teresópolis Emergency Management team also understood that there wasn't any high risk involved;
- c) Concluding, besides the Emergency Management team performed the inspection at the location and produced a technical report, the concession company is fully responsible for the road's section integrity, as well as all needed measures to preserve road safety;

#### 5. CURRENT SITUATION

While the studies and reports were being produced, the concession company created a draining system at the region and constructed a detour for temporary traffic circulation while the final engineering solution was being decided. The company also started studying ANTT's recommendations to that location, such as creating pluviometric stations and a meteorological warning system integrated with suitable operational measures, besides protecting nearby areas to avoid other issues until the conclusion of a project to reestablish normal vehicle traffic at that BR-116's section.

To select a final solution for the location, the concession company hired engineer José Luiz Cardoso, who developed studies and projects recommending the construction of a viaduct and implementation of sub-horizontal drains where the geotechnical accident happened.

The viaduct works were projected with an 80m extension (a 30m central span and 2 lateral spans with 25m) and occurred between June and November 2005, under PREMAG Engineering responsibility. The company executed excavated pile type foundations with 1.0 and 1.4m diameters (average length of 25m) and used intermediate structured prepared *in loco* along with a superstructure made from pre-molded beams completed with a slab executed at the location.

Regarding recommendations to create pluviometric stations, the concession company established a contract with Rio de Janeiro's Federal University and National Meteorology Institute, an agreement that has been in force since June 2006 and will last, initially, to December 2008.

According to this agreement, three climate stations (at km 40, km 90 and km 101) and one pluviograph (at km 104) were installed and are at full operation. Besides these devices, piezometers and inclinometers were installed to complete the climate phenomena warning system.

The concession company, helped by an engineer who works on the road for almost 30 years, made a historical survey of all geological-geotechnical accidents occurred on the road for the past 20 years before the concession begun.

Also, the National Meteorology Institute is making a historical survey regarding all pluviometric stations on the region and will provide this data to Rio de Janeiro's Federal University.

All these elements and those who will be generated throughout the mentioned contract, will be useful to keep track of climate phenomena and also to relate events like this with geological-geotechnical issue that may appear in the most critical region of this road (between km 85 and km 110). From these relations, it will be possible to adopt operational and engineering measures in order to avoid geotechnical accidents like the one occurred at km 87 of BR-116/RJ.

## **BIBLIOGRAPHIC REFERENCES**

- ANTT Agência Nacional de Transportes Terrestres (2005) – *Relatório da Comissão de Apuração do acidente com aterro do km 87,0 da rodovia BR-116/RJ*, Rio de Janeiro, Brasil.
- Barth, R. (2005) – *Relatório técnico sobre o acidente do km 87,0*, Rio de Janeiro, Brasil.
- Cardozo, J. L. (2005) – *Relatório técnico do aterro do km 87,0 da BR-116*, Rio de Janeiro, Brasil.
- CRT Concessionária Rio-Teresópolis (2007) in <http://www.crt.com.br>.
- CRT/ANTT/INMET/UFRJ, S. (2006) – *Contrato para Monitoramento das condições climáticas associadas às condições geológicas-geotécnicas da Rodovia BR-116/RJ e seu entorno*, Rio de Janeiro, Brasil.
- Lima, S. (2005) – *Relatório sobre o acidente do km 87,0*, Rio de Janeiro, Brasil.
- UFRJ Universidade Federal do Rio de Janeiro (2005) – *Lauda Técnico do Deslizamento de aterro BR-116 km 87,0*, Rio de Janeiro, Brasil.