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Comparison of Most Used Methods and Costs for Recovering Environmental Liabilities Involving Geotechnical Problems in Brazil and Worldwide

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Abstract. Along the Brazilian federal highways, it is possible to find several occurrences of environmental liabilities. Environmental liabilities are responsible for part of the demand for public investment. Thus, to understand the investment necessary, this work aims to compare the costs demanded to recover an environmental liability in Brazil with worldwide. Besides contrasting the most used geotechnical recovery methods, as a function of the technology employed. To be able to compare one country with another, a generic model was adopted. To obtain data, a cost simulation system was used, with works of engineering available on a web platform. Thus, it can be understood the demand of resources necessary to adequate the non-concessional Brazilian road network. By analyzing the approached data, it is possible to identify the connection between the high demand for resources and the vast amount of nonconformities along the highways, as a consequence of Brazilian legislative history.

Keywords. Recovering costs, Brazilian highways, environmental liabilities.

1. Introduction

In Brazil, more than 60% of all freightage is delivered by roadways [1]. This excessive dependence on a single modal reveals the need to maintain the safety of national roads, both socially and environmentally. Due to a government policy implemented in the 1970s in Brazil by Juscelino Kubitschek, called "*Plano de Metas*"(Goals Plan), the national road network and the automobile industry developed rapidly, with lead to a significant amount of environmental liabilities left without recovery, some of what can still be found today [2].

With this accelerated expansion of the road network, most of the Brasilian highways were implanted before Federal Law No. 6.938 of 1981, which establishes the need for environmental licensing for potentially polluting enterprises. Decree 4340/2002 [3] imposed mandatory environmental regulation of the federal road network, as well as the need to obtain environmental licenses for the operation of all

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road projects implemented before 2002, within twelve months of its publication. As so, Brazil currently needs to adapt more than 56,000 km of its road network [4].

It was only in 2004 that the Ministry of the Environment and the Ministry of Transport signed the Inter-ministerial Ordinance No. 273/2004. The objective of the measure was to adapt the existing federal road network to environmental standards, ensuring its conservation and continuous improvement. The environmental impacts caused during the implementation process, along with the high accident rates recorded during the years of operation and the socioeconomic losses due to poor conservation reinforce the need for maintenance and restoration of the federal road network under environmental requirements [4]. Of all adjustments that need to be made to comply with the new environmental regulations, the vast majority is related to the recovery of environmental liabilities.

2. Background

According to Sánchez [5], environmental liability is the accumulation of environmental damages, which must be repaired to maintain the environmental quality of a given location. However, rather than an environmental obligation, the debt accumulated through liabilities is also a responsibility with society, as it is often related to issues of safety, health and the allocation of public money.

It has been found that the approach to environmental liabilities is different between "developed countries". Most countries, especially developed ones, address environmental liabilities in a preventive rather than mitigative manner. That is, the environmental impacts must be mitigated during the construction time, as not to generate any social or environmental debts. In this way, the contents that approach preventive action on landslides and erosions, rather than correction and mitigation, as in the cases of other liabilities routinely found in the Brazilian road network.

To the purpose of conceptualization, it is possible to divide the environmental liabilities existent in Brazil into two groups, according to the country's reality: the "physical or material liabilities" and the "social, moral or legal liabilities". The physical or material liabilities are most suitable for remediation, while those of a social, moral or legal nature is sometimes difficult to assess and compensate [7]. Physical or material liabilities are characterized by a change in the natural environmental conditions of a region, as a consequence of the implementation of a road system or other infrastructure. These liabilities can be mitigated with engineering projects, mainly in the geotechnical scope.

Regarding the techniques used to recover environmental liabilities, countries make use of very similar same technologies, differing only according to the geomorphological and climatic conditions. For slope stabilities, the most commonly used methods are benching of slopes, counter-berms, retaining walls (conventional gravity, driven piles, drilled shaft walls, tieback walls), mechanically stabilized embankments, pneusol, soil nailing, geotextile wall, gabion, ecotechnological stabilization e proper water drainage.

As for rock stabilities: catchment, gabion, buttresses, surface protection, tiebacks e proper water drainage. Moreover, for erosion control, the most common methods are masonry, rip-rap, soil hardening, and ecotechnological protection [6]. It is worthy of note that there is a worldwide tendency to adopt ecotechnological stabilization and protection.

Thus, when an environmental liability of a physical or material nature is identified, it must be recovered as quickly as possible, to reduce potential associated risks, according to its installation or progressive increase. If full recovery is dollar-cut possible, compensatory measures should be adopted, as well as actions for mitigation, delay or impact reduction.

In a study published by Silva et al. [8], one can take knowledge of the number of environmental liabilities observed along the Brazilian federal highways. The study presents an analysis of a database obtained through the collection of environmental liabilities along non-concessionary stretches of a Brazilian highway (BR-116). According to the study, in approximately 1000 kilometers of highway, more than 332 liabilities were collected. Within those, 60% were related to geotechnical problems such as mass movements and erosion.

Until 1974, the Brazilian resources destined to projects involving the road sector were obtained directly through the collective resources of the Union. Since that date, due to a fiscal crisis of state and federal governments, the allocation of resources began to be disputed with other areas. Thus, the road system was contemplated with low levels of public investments, insufficient for its due adequation. Therefore, it is estimated that to supply the sector's demand, it would be necessary to invest more than 180 billion Reais (45 billion American dollars) [9].

When questioning the reasons why it is necessary such a significant amount of resources for the recovery of road liabilities, some point out that the costs of works in the countries of Latin America are lower than in countries of Europe. That difference relates to associated costs with labor, as the example of news published by Mandua magazine: *Información, opinión y cultura al servicio de la construcción* [10]. The paper also states that the high costs demanded by the road sector in the countries of America are a consequence of problems with corruption.

Therefore, the present study reveals an approach about the high demand for resources necessary to adequate the non-concessioned Brazilian road network.

3. Methodology

This topic describes the methodology used to obtain a reference value to compare the costs of recovery works of environmental liabilities in Brazil and other countries. Besides, it also addresses the metrics adopted to represent the costs encountered.

A cost simulation system was used to obtain data, with works of engineering available on a web platform. The Platform is given through a website called *Generador de Precios Argentina* [11], prepared by the Spanish company CYPE Engineers S.A. It provides cost analysis for various countries in Latin America, using a separation between new projects, rehabilitation and for urban spaces. The last update of the values in the Platform occurred in the year 2015.

By selecting the characteristic of the work, several types of works are listed, preparatory work, demolitions, carpentry, retaining walls among several others. Of these, the retaining walls are restricted to a masonry wall, cyclic concrete, bending wall and contained by struts. The input data are the wall's shape and height, whether the concrete is to be prepared on site or ready mixed concrete, the constructive method, site aggressiveness, concrete strength, aggregate size, steel type, and type of spacer.

As output, one obtains the necessary materials, equipment, and labor quantities, already with unit cost and description of the technical characteristics to be adopted. Figure 1 shows the input fields for a bending wall.

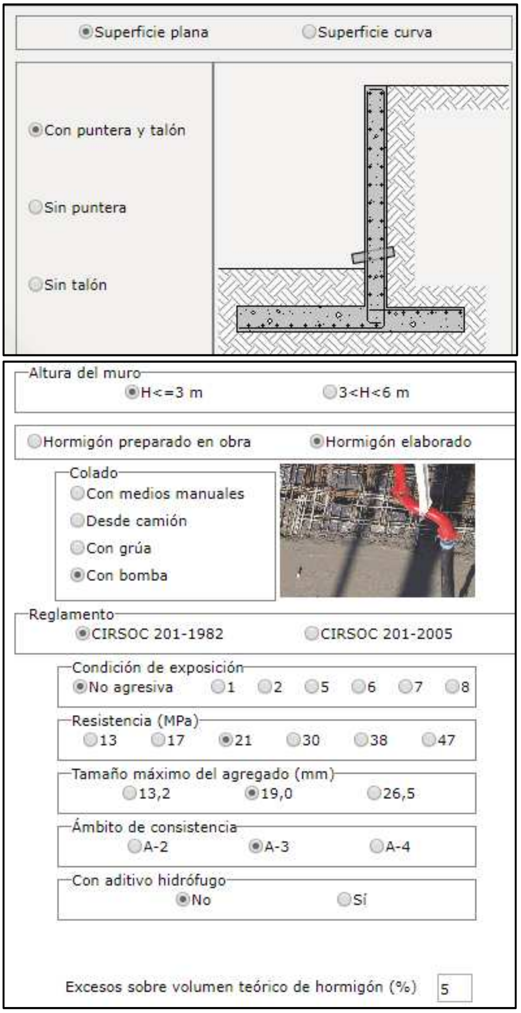

Figure 1. Input fields for a bending wall built in Argentina.

As output data, *Generador de Precios Argentina* supplies the material quantity required, reference prices of unit costs for each material or service, partial prices (obtained by multiplying the quantity by unit cost), the portion of charges on the final cost and the final cost. It is noteworthy that the current norms of each country are respected. The previous Figure 1 shows quotations in Argentina, according to Argentinean Standard of Concrete Structures, CIRSOC 201. In Brazil, the costs presented by *Generador de Precios Argentina* are based on the ABNT NBR 6118 standard, which is the current norm for structures with reinforced concrete.

To be able to compare one country with another, a generic model was adopted, since, as mentioned above, the techniques for recovering environmental liabilities in a global context are similar. Therefore, it was adopted to construct a containment structure in a flexible retaining wall constituted by reinforced concrete.

The generic model adopted was a flexible retaining wall, chosen for being a worldwide known alternative, and due to the fact of using as main constituents basic elements of the civil construction, such as steel and concrete. The calculation of the quantitative was considered for a cubic meter of wall. The generic model can be observed in Figure 1. Thus, it was assumed that costs for other engineering works, mainly geotechnical engineering, would present similar behavior.

For entry values in the *Generador de Precios Argentina*, a height of fewer than 3m was considered for the model, with similar executive procedures and materials of the same or similar physical and mechanical characteristics, depending on the country.

Based on the data obtained by the website, it was possible to obtain the total costs for execution of the containment in different Latin American countries (Argentina, Spain, Mexico, Chile, Colombia, Ecuador, Panama, Uruguay, Bolivia, Paraguay, Guatemala and Brazil), as well as costs in Spain, used as a representative of an European country. Costs were normalized based on the dollar cut (12/10/2018) so that a comparison could be made between different countries, even though most have different currencies.

It is important to point out that the values obtained by the program had to be corrected, in all the countries, due to minimum armor. Considering a minimum reinforcement rate of 4% of the concrete area, it determined the amount of approximately 100 kilograms per cubic meter and the calculations in the Price Generator were kilograms per cubic meter. So, some corrections were necessary. Also, the final budget is not complete, because the cost composition of the site does not consider the form and the team required to assemble the form, giving a lag in all values considered.

4. Results and discussions

Based on the results provided by the site it was possible to, in addition to the total costs, obtain the discretization of costs concerning the expenses with the material, machinery, labor, and charges. It was not possible, however, to obtain the value of the equipment needed to construct the generic work for Mexico and Spain through *Generador de Precios Argentina*. Since this cost in other countries was up to 3%, it was understood that disregarding the machinery for the countries would not significantly change the final results. The collected data were organized in Table 1.

Figure 2 intends to present a visual comparison of the Brazilian condition with other countries of Latin America, and with the European country. The graph shows the total costs and highlights the average total value of the data sample. The black line represents the total cost values for constructing the generic work in the countries that make up the sample in question. Also, a red line is to be a reference for the average value of total costs.

Based on the results (Table 1 and Figure 2), it can be seen that the costs of a generic geotechnical containment work in Brazil are a little above the average of the other countries considered. The average total cost was around 223 American dollars, and the cost in Brazil was around 251 American dollars. It is also possible to see that the cost of labor in the European country is higher when compared to Latin American countries.

Table 1. A cost comparison of a generic work in different countries.

Country		Total	Materials	Machinery	Labor	Charges
Argentina	$	131.56	92.9%	2.5%	3.3%	1.2%
Spain	$	195.18	83.7%	-	14.9%	1.4%
Mexico	$	124.95	94.9%	-	3.9%	1.3%
Chile	$	176.77	86.4%	0.5%	11.9%	1.2%
Colombia	$	159.26	86.5%	0.4%	11.7%	1.4%
Ecuador	$	233.17	90.6%	0.4%	7.8%	1.1%
Panama	$	221.99	86.9%	0.5%	11.2%	1.4%
Uruguay	$	447.80	95.9%	1.6%	1.3%	1.2%
Bolivia	$	264.23	94.0%	3.0%	1.7%	1.3%
Guatemala	$	241.53	91.4%	0.4%	6.8%	1.4%
Brazil	$	251.07	94.8%	2.1%	2.2%	1.0%

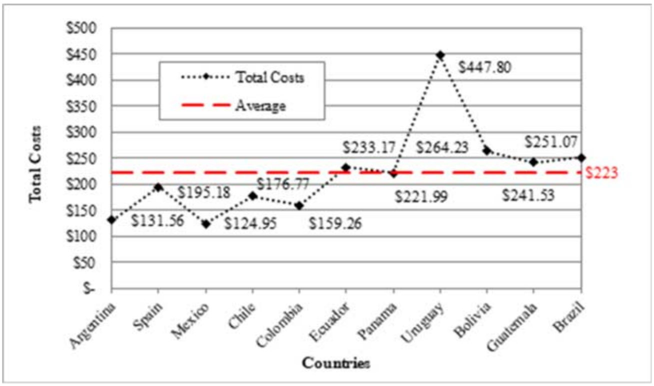

Figure 2. Variation of total costs to average cost from different countries.

It is interesting to confront the data obtained from the news published in the magazine Mandua: *Información, opinión y cultura al servicio de la construcción*, which, as mentioned, points that labor costs in Latin countries are lower than in European countries, which reduces the total cost of projects. The labor force in Spain, representing the European country, is higher than the other countries in the sample, but the costs of materials reveal a similarity in the total values. The high values found regarding the expenses with materials are explained due to the high tax rates applied to this type of product in Latin countries.

Based on the data, it can be seen that Mexico was the country with the lowest total cost (124 American dollars) and Uruguay was the one with the highest total cost (447 American dollars). It is also noteworthy that, although Uruguay presented the highest cost for the execution of the generic model, it was also the country that presented the smallest portion of cost referring to labor.

Although Uruguay's total costs resulted in more than triple of Mexico's, along with more divergences between values for the other countries, the reasons for such deviation have not been studied. The fact is justified since the values were only raised to fit Brazil concerning the other countries of the sample.

5. Conclusions

Environmental liabilities are socio-environmental debts that need to be eradicated, to guarantee the safety of road users and the environment. Along the Brazilian federal highways, it is possible to observe several occurrences of environmental liabilities. Of the occurrences, most are considered physical or material liabilities, that is, they are recoverable through construction works, mainly geotechnical works.

Assuming that other solutions for recovering environmental liabilities would present similar behavior, the present study can be considered as a basis to understand the values that Brazilian government requires to adapt the federal highways in the laws in force in the country.

From the results obtained, it can be observed that, about the costs to construct the generic project in question, the Brazilian costs are above the average, when compared to Latin American countries and the European country.

Thus, the high investment needed to adapt the road system in Brazil is explained by the fact that there is much nonconformity along the kilometers. This fact can be verified by observing Brazilian federal highways. It is also pointed out by data presented by Silva et al. (2018).

A large amount of liabilities is a reflection of the country's history, which experienced rapid growth of the road network, without the necessary regulations being in force. Furthermore, a point to be considered is that Brazil, as mentioned above, is very dependent on the road modal for freight and people mobility, and thus, the country has a high density of the road network.

As a conclusion, Brazil is in a similar situation to the world scenario, when considering the technologies used to recover environmental liabilities and the costs of recovery. However, one of the reasons for the high demand for resources needed to mitigate the demands of the road sector is the significant number of nonconformities.

As a recommendation for future studies, it was found that there is a need for studying the reasons why some countries work cost twice as much to another, as well as the differentiation between the composition of unit costs and differentiation in the requirement of the different norms in force.

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