Reinforcement evaluation with external pretension of Marcelino Machado bridge, highway BR-135, São Luís – MA

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ABSTRACT

External pretension is one of the existing structural reinforcement methods and is widely used in cases of reinforcements in bridges, including in Brazil, due to the possibility of actively strengthening the structure without the need to change its original section and interrupt its use during the work. The objective of this research is to analyze the structural reinforcement method using the pretension of the steel cord, with hydraulic jacks, used for the recovery and reinforcement of the structure of the Marcelino Machado bridge, in São Luís - MA. The methodology of the study can be divided into two stages: The evaluation of the revitalization and recovery of the bridge through the structural projects used in the reform and the photos of the execution, as well as through the literature review of the advisory literatures that add knowledge to the theme addressed. Thus, throughout the work, the methods for the execution of structural reinforcement through pretension were approached, in which the mechanism helps to annul the presence of pathologies on the bridge that may compromise the structure.

Keywords: Road bridges, External pretension, Structural recovery.

1 INTRODUCTION

Some technological advances emerged in the period of the Second World War, from the year 1949. Engineering, for example, has presented a considerable development with regard to the use of prestressed concrete, since this has wide applicability in large works, such as bridges (VERLY, et. al., 2015).

In several countries due to social and economic growth, there was a need to create larger and more efficient infrastructures to meet the demands of the population. During the useful life of these constructions, structural systems are frequently subjected to natural risks and degradation caused by environmental and mechanical factors that considerably reduce their initial performance (BARONE and FRANGOPOL, 2014).

Despite having a large heritage built on land, it is possible to verify the wear and tear suffered in the structures mainly of bridges in Brazil. Quintino et al. (2020) emphasize the importance of these works of art for the road flow and the production chain in the country. According to the National Department of Transportation Infrastructure in a Management Report presented in 2017, about 97.57% of the bridges were built in reinforced and prestressed concrete.

Special works of art (bridges, viaducts, walkways or tunnels), also known as "OAE", must act in such a way that the permanent actions and mobile loads, of vehicles and pedestrians, work efficiently for a long period (VERLY, et. al., 2015). Therefore, it is necessary to pay attention to the projects and executions of this type of works so that during the useful life of the construction no pathologies appear, putting at risk the integrity of the structure.

Pathological problems in bridges have their origins motivated by failures that occur during one of the three basic stages of the construction process: design, execution and use. (BEBER, 2003). Medeiros (2020) evidence as a problem, the high age of the bridges due to the little information existing at the time of projection and execution, low quality of the materials used in the execution.

In addition to the changes that concrete structures are subject to when they come into contact with the natural environment, since the environment exerts a strong influence on the behavior of the structure in what disrespects the durability of the materials (SANTOS et. al. 2019). An example of problems caused by the lack of maintenance of the works of bridges in reinforced concrete are the cracks, cracks and deterioration of the concrete (PAIXÃO, et al.; 2020).

Thus, structural reinforcement is fundamental when it has the need to increase the resistant capacity or the correction of failures, which after analysis, it was observed that the initial load capacity had decreased (SAAVEDRA, 2010). Some reinforcement techniques can be employed for the correction of design and execution failures, increase or regeneration of the carrying capacity of the structure, reduction of accidents, wear or deterioration.

Among the techniques of reinforcement in reinforced concrete structures, can be mentioned, the complementation of the reinforcements, addition of sheets and metal profiles or the use of composite materials, increase of section by coating of the piece (enveloping), addition and also the addition of prestressed external cables (SOUZA AND RIPPER, 1998).

External reinforcement is one of the existing methods of structural reinforcements and is widely used in cases of reinforcements in bridges, including in Brazil, for the possibility of actively reinforcing the structure without the need to change its original section and interrupt its use during the work. The method consists of the incorporation of ropes external to the structure, longitudinally or transversely, using metal derailleurs, in order to reestablish the original conditions or reinforcing it to withstand loads higher than those projected. The ropes are passed through diverters and tensioned, compressing the concrete and eliminating cracking. (MARIANO, 2015, p. 18).

The objective of this research is to make the analysis of the method of structural reinforcement using the protension of the ropes with hydraulic jacks (technique used to increase the strength of the structure) and the wrapping with concrete of the ropes, used for the recovery and reinforcement of the structure of the Marcelino Machado bridge, whose extension is 450 meters, in São Luís – MA, in the year 2017.

2 METHODOLOGY

The methodology of the study carried out can be divided into two stages: The analysis of the revitalization and recovery of the bridge through the structural projects used in the renovation and the photos of the execution, as well as through the bibliographic review of the consultative literatures that add knowledge to the theme addressed.

The evaluation through the structural projects occurred not only from the elements provided, but also from the comparison between the claims presented in the project as the elements that could be seen being executed in the work through the photos.

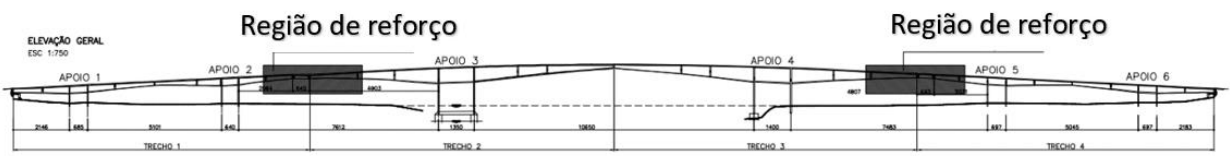
The systematized bibliographic review was used to better select the works that could add greater knowledge and relevance to the theme addressed, such as: scientific articles present in journals, standards, dissertations and published books.

The guiding standards that will be used for the study are ABNT NBR 6118:2014 - Reinforced Concrete Structures - Procedure, due to the fact that it is the main construction material used for the execution of the bridge. ABNT NBR 7187:2021 – Design of bridges, viaducts and concrete walkways must also be consulted for the special conditions due to the purpose of construction and ABNT NBR 7483:2020 – Steel ropes for prestressed concrete structures – Specification, must also be verified for being the chosen reinforcement method.

The Marcelino Machado Bridge connects the island of São Luís in the state of Maranhão to the mainland, on the BR-135, crossing the channel of the Mosquito Strait, connection between the bay of São Marcos and São José, this is composed of two parallel bridges, being the focus of study the bridge (left) towards Bacabeira - São Luís in the state of Maranhão that went through a revitalization process that began at the end of June 2017 and ended in January of 2018.

The bridge has a length of 450 (four centers and fifty) meters, and the emergency effort regions are located between supports 2 -3 and 4-5. Figure 1 shows the key locations for the execution of the bridge revitalization.

Figure 1- Regions of emergency effort



Source: Company responsible for the project, 2017.j

Thus, for the recovery service, the scaffolding under the bridge was installed, as shown in Image 1, for the locomotion of the workers as well as the performance of the services.

Image 1 - Scaffolding for operation of the works.

Source: Authors.

Given this, it is worth mentioning that the process of fixing the metal devices with hydraulic pump equipment for anchoring and deviations of the reinforcement ropes was carried out, soon after the reinforcement blocks internal to the coffin beam were executed in the anchoring lines, positioning the ropes and applying the loads of pretension made by a hydraulic jack, performing the wrapping services of bundles of ropes and metal devices Image 2.

Image 2 - Anchoring of the ropes

source: Authors.

The concrete used was with fck > 35 MPa with factor ≥ 0.50 ara reinforcements internal to the coffin beam, as well as self-leveling grout mortar with the addition of 30% of pebbles for wrapping of bundles of ropes and metal devices, in this way, forms were placed and soon after the concreting as shown in image 3 below.

Image 3 - Of the shapes with the concreting

Source: Authors.

Table 1 shows the details of the materials such as the number of ropes for each specification of cables as the total length of the cables, being for one stretch 2376 meters and for two stretches 4752 meters, having a total of 288 anchors for two sections, being the total weight of the steel CP 190 RB of 3683 kg.

Table 1 - External pretension cables CP 190RB - For a stretch

Cables	Layer	Number of strings Ø 12, 7 mm	Quant.	Cable lengths (m)		Anchors 1 Ø	Strength Next to the monkey (tf/Ø)	Theoretical Elongations (mm)
				Unitary	Total			
Cape C1	1	6	4x	41.00	984.00	48	13.5	..
Cape C2	2	6	4x	33.00	792.00	48	13.5	..
Cape C3	3	6	4x	25.00	600.00	48	13.5	..

Source: Company responsible for the project, 2017.

In addition to these materials, DYWIDAG ST95/105 Ø 32 bars were used for fixing the metal devices and for the reinforcement block. Being so, the total length of bars 620 meters and 8 centimeters equivalent to the weight of 3918 kg, since the total number of nuts is 768 ud.

3 RESULTS AND DISCUSSIONS

3.1 METAL DEVICES

The external protension has been applied to the reinforcement of bridge beams and is considered the best known method in the repair of OAE, providing better service performance, greater resistance to bending and shear (ALMEIDA and HANAI, 2005). In the first retrofit, metal anchors and metal diverters are usually used. The technique involves anchoring the cables outside the structure and then pulling them, and there may be deviations in their trajectory, through the diverters (PINHEIRO, 2018).

The metal devices were made of ASTM A588 steel, and the anchors were used to fix the tensioning device of the prestressed cable, maintaining the pretension force applied by the hydraulic jack, preventing the cable from returning to its original position and causing loss of tensions (CHOLFE and BONILHA, 2018). On the other hand, the metal derailleurs, fixed to the structure by means of special straight protended bars, allow to vary the position of the cables along the span, considering the minimum radius of curvature of the cables inside the diverters, because the disregard can cause damage to the steel and the plastic sheaths or in the metallic tubes, which can cause losses of protension by friction (ALMEIDA, 2001).

The deviated straight cables are known as polygons and are widely used in situations of external protension where the cables are not in contact with the structure, except at the anchor point and deviation, where they will eventually introduce forces in the opposite direction to the requested (PINHEIRO, 2018). The anchoring devices are fixed in the structure and started the pretension when injected the cream of cement inside the sheaths, after concreting and hardened, the cables will be placed in the sheath, being the cables pulled by hydraulic jacks and fixed in the anchoring plates, through the wedges, where they will compress the concrete (CAUDURO, 2003).

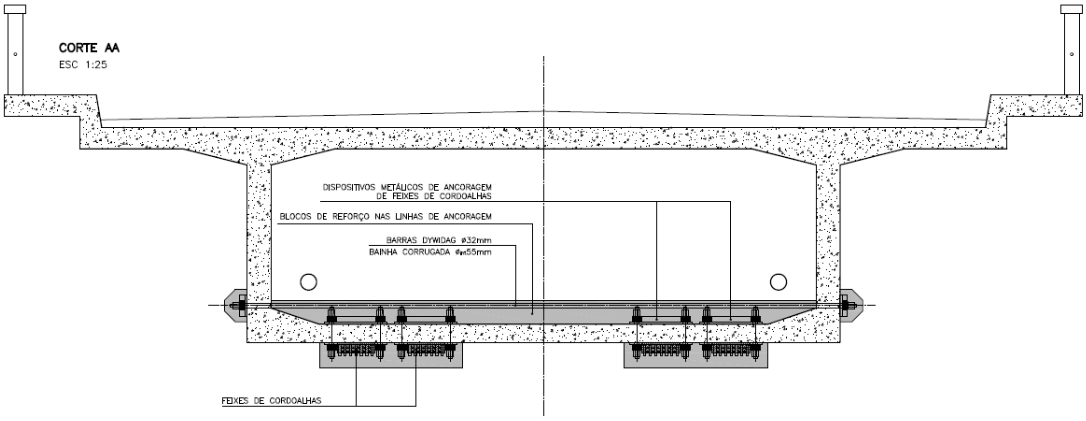
3.2 REINFORCEMENT BLOCKS ON ANCHOR LINES

It is of paramount importance the perfect execution of the anchorage in a pretension system, considering that the induction of a special state of tensions in ropes is made in order to improve the structural behavior of the piece where the concrete is molded already containing the steel pulled against the anchor blocks (LUCHI, 2001).

Especially the cables do not have significant adhesion to maintain the protension, and a poorly executed anchorage can cause failure in the structure as a whole. And according to (CAUDURO, 2003), the anchor lines with groups greater than six cables must contain additional structural reinforcement.

And as shown in the figure below, internal reinforcement blocks of the coffin beam are executed on the anchoring lines, where the metal parts are fixed with DYWIDAG 32 mm bars.

Figure 2 - Cutting Anchoring System



Source: Company responsible for the project, 2017.

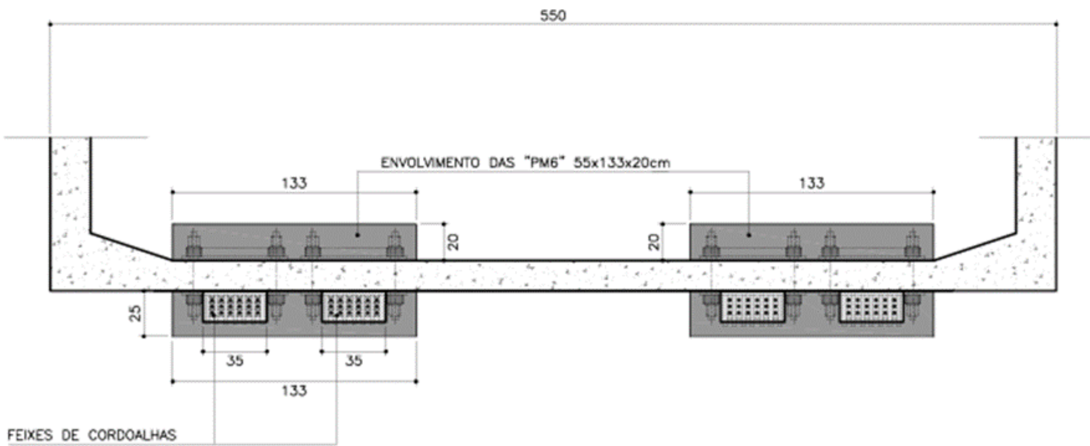
The DYWIDAG system is based on the use of special tensile-resistant steel bars, with components that distribute the applied load with the aid of anchorage in the prestressed structure (DSI, 2015).

3.3 POSITIONING OF THE ROPES AND APPLICATION OF THE PRETENSION LOADS

As can be seen in Figure 3 that represents the cross-section of the coffin beam and Image 4 where it is possible to see the fixation of the strings on the lower face of the main beam, the strings were distributed longitudinally along the entire lower face of the bridge in four bundles with 12 strings each, supported by metal anchoring devices and diverters, lined up rectilinear (BASTOS 2019).

Along the entire length of the bridge, aiming at the introduction of an axial effort in this region, in addition to a bending moment contrary to that caused by the weight of the OAE and the variable loads to which the structure is subjected. This technique is a post-tension, depending on the mode of application as a reinforcement instrument, requiring its own means of dimensioning (SOUZA and RIPPER, 1998).

Figure 3 – Cross-section of the coffin beam



Source: Company responsible for the project, 2017.

Picture 4 - Fixing of the strings

Source: Authors.

The application of the pretension loads was performed with the use of a hydraulic set jack and protension pump. The DYWIDAG bars were prestressed with 30tf per bar, and after the pretension, the cement cream was injected into the holes of the stringers through the planned devices. On the other hand, the strings were prestressed only after curing the cream injected into the holes of the DYWIDAG bars, at both ends, applying a load of 8tf per rope.

The wrapping service consists of the injection of cement cream in the sheaths, according to Bastos (2021) this process ensures mechanical adhesion between the pretension reinforcement and the concrete, in addition to protecting the ropes against corrosion. Taking into account that the bridge is in a coastal region that according to ABNT NBR 6118/2014 is classified in the class of environmental aggressiveness III, with risk of deterioration of the large structure, so the involvement of the ropes was an important step in the execution of the reinforcement.

3.4 RECOVERY OF SURFACE ANOMALIES

The pavement has many technical functions, we can highlight the ability to resist and distribute the vertical forces of traffic, the rolling conditions, which provide comfort and safety to people, resisting the horizontal forces of wear (LITAIFF et al., 2022). Problems in the asphalt pavement, pathologies, can arise due to a deficient design, inadequate construction techniques or lack of maintenance, because such constructions suffer deterioration with exposure to weather and traffic requests, being necessary the reform or repair of these problems on the road surface may need to be reinforced or rehabilitated (FILHO et al., 2020).

According to Litaiff et al. (2022), the method of pavement restoration should start from an engineering project, this should consist of the removal of a part or all of the thickness of the pavement, and may eventually reach the subbed, being fully implemented the new structural layer, its nature, composition and specifications must correspond to the corresponding properties of the area adjacent to the rest of the floors, as depicted in image 5.

Image 5 - Cutting anchoring system

Source: Authors

Above all, it is of fundamental importance to expose the armor in the damaged place, leaving it exposed to facilitate access behind them, as shown in the image above. For recovery of anomalies some basic requirements must be used, with regard to the products used, such as adhesion, compensated retraction, low permeability, compatible modulus of elasticity, mechanical resistance and resistance to aggressiveness to chemical and environmental attacks, and to finish, it is essential to enable its complete cure.

4 FINAL CONSIDERATIONS

Thus, throughout the work was approached the methods for the execution of structural reinforcement through pretension, through the information existing in relevant studies already published. From the data visualized in the project it was found that the protension of the ropes provides better service performance and greater resistance to flexion and shear, in which the mechanism helps to cancel the presence of pathologies in the bridge that may compromise the structure.

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