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Old Bridges in Madeira Island – Identification and Diagnostic

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Abstract

In Madeira Island there are several old bridges mostly of stone masonry and some of concrete, which are a valuable historical heritage, wand hich is important to know and maintain. With this in mind, this paper shows the results of a survey study including diagnostic of a wide range of old bridges in Madeira. It was observed that the great part of these bridges is of stone masonry sometimes strengthened by concrete, and that they have some essentially non-structural anomalies, mainly the presence of vegetation. So, they are in reasonable condition, being important the current maintenance works.

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1. Introduction

Madeira Island has a rich heritage of old bridges that matter know and maintain. The construction of stone masonry bridges was a method widely used in the past [3, 7, 8, 11]. Although its construction has fallen into disuse, some of these bridges are still in operation, getting also a heritage value. Its conservation becomes essential, to continue to serve the purposes for which they were built, as well as for the visual importance in the Madeira landscapes that they have acquired [1, 2, 4].

These bridges, like all other structures are losing over time its strength properties and functionality for which they were designed. The repair, maintenance and the safety assessment of bridges are reasons that have led concerns by

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the authorities that manage the road network of the island (Municipalities, Regional Direction of Roads, Via Litoral and Via Expresso) [2, 5, 9].

This paper presents the results of a study that had in view doing the survey and characterization of a wide range of old bridges in Madeira. This study began with a survey (visual inspection and filling an appropriate inspection sheet previously developed) for each bridge. After that, a statistical analysis was carried out in order: i) to physically characterize these bridges (geometry, material, type of structure, etc.), ii) identify and systematize the main anomalies and iii) assess the conservation state.

The identification of these bridges found out that there is a need to carry out maintenance works in some bridges, in order to keep their functionality and safety requirements.

2. Bridge Identification

2.1. Sheet Developed for Visual Inspection

Before identify and present the survey of old bridges in the Madeira Island, it was necessary to create a visual inspection sheet. This sheet shows some similarities to the sheet of Estradas de Portugal (EP) [6, 9, 10], especially with regard to the criteria adopted to identify to classify the conservation state.

In order to facilitate the introduction of information acquired during inspections, sheet was divided into five parts: i) Structure Identification / Geometric Properties, ii) Description of Components / Anomalies / Possible Interventions iii) Conservation State, iv) Comments and v) Photographic Record.

2.1.1. Structure Identification / Geometric Properties

With the first point of visual inspection sheet was intended to record the geographical location of each bridge (e.g. township, road it belongs, watercourse identification and geographical co-ordinates). When possible was gathered information about the construction period, designer and owner. It is also intended to record the typological and geometric characteristics (e.g. use type, structure type, bridge type, material type, full length, full width and maximum height) of the bridge under study.

2.1.2. Description of Components / Anomalies / Possible Interventions

In this point of the visual inspection sheet was aimed to describe the main components of old bridges analysed, including the deck, abutment, arch, column, cutwaters, guardrails and pavement, as well as the anomalies presented in these elements. It was aimed to include the previous repair works (e.g. rehabilitation, strengthening and maintenance) of the bridges. And in cases where some damage in the bridges was found some possible interventions have been proposed.

2.1.3. Conservation State

The third part of the visual inspection sheet was planned to classify the conservation state of the various components of the old bridges in the Madeira Island. Like EP [6, 9, 10] was defined a conservation classification to indicate the wear conditions and deterioration of the structure. It was defined in a scale ranging from 0 to 5, 0 representing an optimal condition (indicating that the components are in good conditions) and 5 a very bad condition (which may be dangerous to use the bridge). This classification was initially assigned to each component and after to the overall bridge. The rules adopted to assign the conservation classification do not differ much from those applied by the EP (Table 1).

2.1.4. Comments

The fourth part of the visual inspection sheet intended to write down relevant information about the bridge not made in other sections.

2.1.5. Photographic Record

Finally, the fifth part of the visual inspection sheet was intended to put the most important pictures of the bridge.

Table 1. Description of the conservation state.

Classification	Explanation
0	Great state of conservation. There is no need to perform any repair or maintenance. Properties of materials and execution perfect.
1	Good state of conservation. It is not necessary to carry out repairs. They may be detected some imperfections without importance to durability and behaviour of the structure.
2	State of conservation reasonable. There may be need for non-priority repairs. They can be detected a few imperfections with some importance in durability and behaviour of the structure, but do not justify immediate repairs.
3	Bad state of conservation. Repairs are needed. It presents anomalies that may question the functionality and durability of the structure.
4	State of Conservation bad to very bad. Priority repairs are needed. Component with this classification presents a defective functionality that puts into question the durability and the behaviour of the structure, not satisfying the service level to which the bridge was designed.
5	Very bad conservation state. The structure has deficiencies which jeopardize the safety of users. Immediate repair or replacement of the damaged materials is needed.

2.2. Analysed Bridges

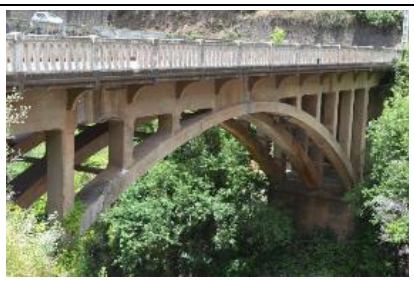
Initially, it was made an historical record of the different bridges, seeking available information for specific material for consultation in the appropriate agencies (e.g. Regional Archives, Regional Direction of Roads and Municipalities of Madeira).

Later inspections were carried out visiting the old bridges in Madeira Island, consisting mainly of masonry stone. They were identified and selected a total of 65 bridges distributed throughout the region (Fig. 1).

Fig. 1. Location of old bridges assessed in Madeira.

Madeira Island consists of 10 municipalities, being Funchal and Santa Cruz those with largest number of analysed bridges (18 and 12 bridges, respectively). In turn, the municipalities of Calheta and São Vicente (2 bridges each) are those with fewer. This is due to a higher development on the South Coast of Madeira over the centuries. Table 2 presents some examples of old bridges analysed.

Table 2. Examples of bridges analyzed.

Bridge Name	Bridge type	Structural type	Building material	Image
Ponte Caminho Velho da Igreja	Bridge	Simple Arch	Stone masonry	
Ponte Monte	Bridge	Extended masonry	Stone masonry and concrete	
Ponte ER222 Madalena do Mar	Bridge	Simple Arch	Concrete	
Ponte Ramal do Caminho Nº23	Pedestrian bridge	Simple Arch	Stone masonry	
Ponte Estrada Monumental São Martinho	Underpass	Multiple Arch	Stone masonry	

3. Description of the Bridges

After research and seek information of historical documents, conducting visual inspections and filling the visual inspection sheets of the old bridges in Madeira Island, a summary table was done to facilitate global analysis of the results.

Fig. 2 presents the different bridge types in Madeira Island. It appears that most of the bridges identified in the region are the bridge type (45). Note that were even identified hydraulic passes, underpasses and pedestrian bridges.

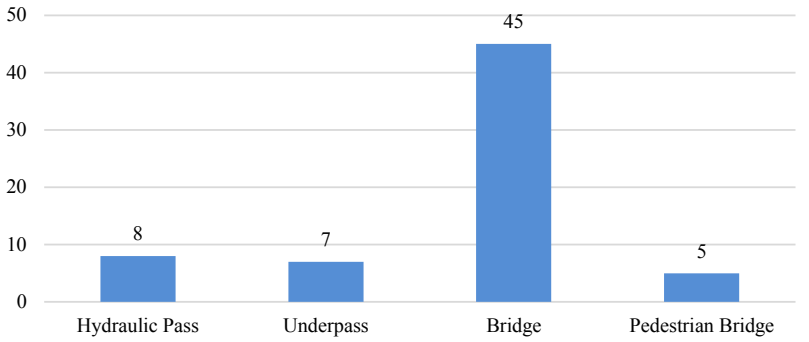


Fig. 2. Number of bridges by bridge type.

Regarding the structural type, Fig. 3 shows the predominance of bridges executed with simple arch, evident in 45 of the studied structures. This is due to the simplicity of construction of this structural scheme. On the other hand, frame and multiple arches proved to be few common in the 65 works of art analysed.

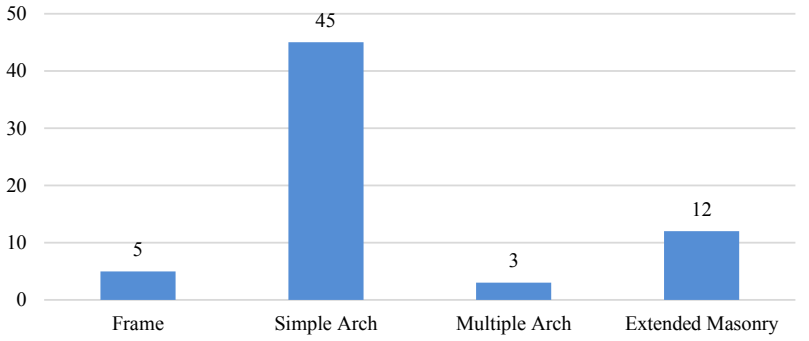


Fig. 3. Number of bridges by structural type.

Fig. 4 shows the percentage of bridges by total length of the structure. It is worth mentioning that the total length considered to the bridges correspond to the distance between the front of the abutments. It was observed that 45% of bridges studied have overall lengths between 6m and 12m, while only 2% have lengths exceeding 100m. This is due to the fact that in Madeira the valleys are much narrowed, so were not built very long bridges.

Regarding the type of material used in bridges under study (Fig. 5), they considered two aspects, namely the abundant material on structure and the applied in the interventions made. The Fig.5 show that 49% of bridges under study are built using stone masonry and concrete. Already 37% are composed of stone masonry and only 14% are built by concrete. It should be noted that about half of the analysed structures are made with stone masonry and concrete due to rehabilitation interventions already carried out over the life of the stone masonry structures.

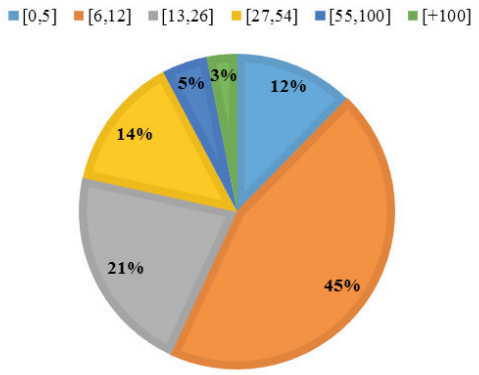


Fig. 4. Percentage of bridges by total length.

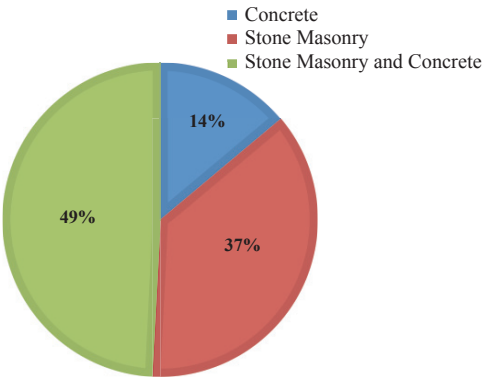


Fig. 5. Percentage of bridges by building material.

4. Bridge Conservation State

Then, the conservation state of the bridges was analysed. The most common anomalies were identified during visual inspections of the bridges, as well as its maintenance needs and the condition of the structures. In order to facilitate the reading of the following figures, it was considered the following structural and non-structural anomalies (Table 3).

Table 3. Classification of the anomalies.

Type		Description
Non-structural anomalies	ANE1	Vegetation and biological pollution
	ANE2	Presence of water or humidity
	ANE3	Mortar loss in joints
	ANE4	Degradation of stone material
	ODO	Clogged drainage systems
	IOD	Inexistence of drainage systems
Structural anomalies	FP	Cracking in the pavement
	AE1	Infra-excavation and erosion of foundations
	AE2	Longitudinal and transverse cracks
	AE3	Support displacement
	AE4	Damage to the wing walls
	AE5	Detachment and rupture of elements
	Cor.	Corrosion in reinforcement or guards

Fig. 6 shows the percentage of bridges with specific anomaly. It was found that 85% of the studied structures presents non-structural anomalies, being the most common anomalies: the presence of vegetation and biological pollution (ANE1 - 85%), presence of water or humidity (ANE2 - 38%), mortar loss in joints (ANE3 - 38%) and the degradation of stone material (ANE4 - 32%).

With regard to structural anomalies these are fortunately much rarer, emphasizing the cracking in the pavement (FP - 49%), detachment and rupture of elements (AE5 - 14%) and longitudinal and transverse cracks (AE2 - 6 %). It was found that the source of these anomalies was due to the lack of periodic maintenance and excessive loads to which these bridges were subjected.

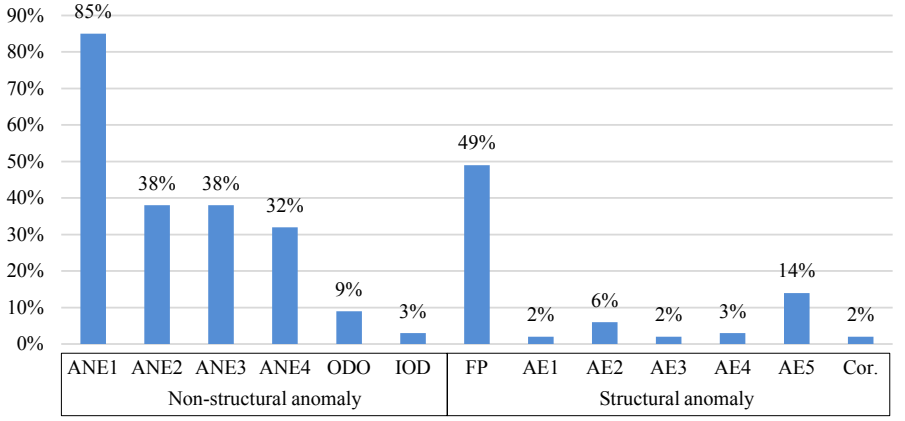


Fig. 6. Percentage of bridges by anomaly.

Fig. 7 shows the distribution global conservation state observed in 65 bridges analysed. The most common conservation states of the bridges are of type 1 and 2. For these classifications Table 1 indicates the need for non-priority repairs, but some maintenance should be performed in order to assure the durability and the behaviour of the structures. The types 3 and 4 (18 bridges) do not refer to structural problems, but the absence of guardrails. A rating of 5 was assigned a currently inactive bridge.

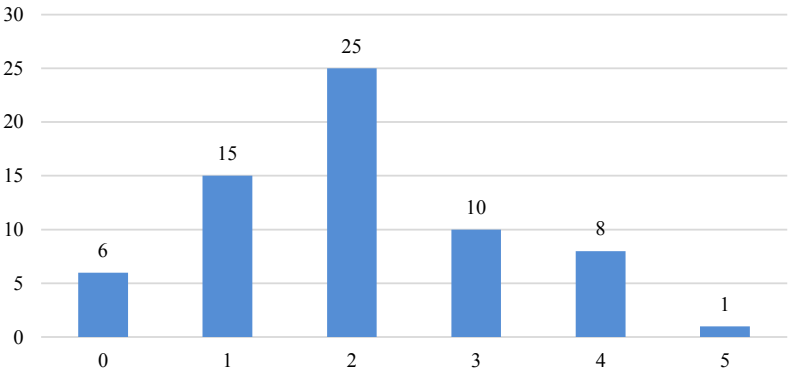


Fig. 7. Number of bridges by conservation state.

5. Conclusions

This paper aimed to make an identification and diagnostic of 65 old bridges on the Madeira Island. Thus, it was found that many of the bridges are made by stone masonry, however due to the many repairs in the past, actually about half of the bridges analyzed are the mixed type (stone masonry and concrete). About half of these bridges have a length less than 15m and most of them are simple arch type.

Relatively to the anomalies observed in bridges analysed was observed that the majority of bridges have non-structural anomalies, mainly the presence of vegetation and biological pollution, presence of water or humidity, loss and degradation of mortar stone material. Regarding to the structural anomalies, except for pavement cracking, these are much less common, highlighting the detachment or rupture elements and the presence of cracks. These defects have arisen due to the absence of periodic maintenance or due to excessive loads that these bridges were subjected.

With regard to the analysis of the conservation state it was observed that the conservation state prevailing in these structures are of type 1 and 2, thus indicating the need for non-priority rehabilitation interventions in the medium and long term. Bridges with type 3 and 4 do not present structural problems, but lack of guardrails.

In this work it was found that there is not a bridge management system (BMS) for these old bridges, so it is suggested to perform a BMS, between the Municipalities and the Regional Road Direction, which will allow managing the maintenance of all the old bridges more effectively.

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