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CROSS-BORDER FORTRESSES IN PORTUGAL; INSPECTION AND DIAGNOSIS

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Aiming at promoting careful and heritage-respecting rehabilitation interventions, in line with the recommendations of ICOMOS (International Council on Monuments and Sites), the Rehabilitation Nucleus of the Construction Institute (NR-IC), integrated in the Faculty of Engineering of the University of Porto (FEUP), has participated in several conservation and requalification projects. The development and implementation of a consolidated and holistic methodology of inspection and diagnosis aims to intervene in these historic structures by respecting their authenticity and integrity. This paper focused on the NR-IC experience in the analysis, inspection, and diagnosis of structures with ancient defensive walls existing in Portugal's border, while addressing several practical cases in different contexts and state of conservation. These structures have lost their original defense function, assuming nowadays a symbolic character of historical memory. In some cases, these structures were maintained, although in other cases they were abandoned, having reached the present time quite degraded. In this context, this paper focuses on three cases studies: the Cross-border Fortresses on the river Minho (Portugal-Spain border), the Guimarães Castle, cradle of the Portuguese nationality; and the Peniche Fortress representing maritime defensive structures. The wall's structural system is characterized as well as the distinct inspection and diagnoses approaches recommended for each structure. Particularly, the systematization, recording, and processing of information is described and commented during the inspection phase, taking into account the large size of most of the structures involved.

Keywords: Structural inspection, structures, defensive walls, forts.

Introduction

The fortified remains of national defense such as the Guimarães Castle, the Minho River Fortresses or the Peniche Fortress are part of the landscape and the daily life of the populations with the tranquility of centuries of existence. Culturally, these elements constitute the materialization of the past: a nebulous population of Moors and Romans, of kings and princesses, of heroic deeds and picaresque episodes that shape historical memory, this element so indispensable to the construction of identity. Nowadays, however, due to time and history vicissitudes, castles, towers, fortifications, strongholds and forts no longer play the same central role in everyday life as they did in other eras. Even so, they often continue to be the object of multiple and different looks, whether these are distracted, indifferent or, on the contrary, admiring, curious and worried.

Therefore, the preservation of this heritage is essential to ensure that these cultural identity testimonies can be seen by the next generations. In this context, this work presents the methodology used in the inspection and structural diagnosis of the Guimarães Castle (Costa, and others, 2008; 2009), the military structures integrated in the Master Plan of Cross-border Fortresses of the River Minho (Andrade, 2005; Santos and others, 2005) and the Peniche Fortress (Arêde and others, 2017).

Identification of the fortifications

Guimarães Castle

The Guimarães Castle, shown in Fig. 1, the paradigm of the Portuguese nationality origins and of the figure of the 1st King of Portugal, is one of the most representative monuments of the Portuguese medieval imagination and its Independence. It is a castle of military architecture, being the emblematic image of the Portuguese medieval castles due to its association with the kingdom origins. The current structure is, however, the result of reconstructions carried out since the second half of the 13th century.

The castle has a plan with the approximate shape of a faceted shield. Its walls, in ashlar granite, are reinforced by four towers and torn by arches that define the doors. At the north and south ends, the castle wall extends slightly, being in other times connected to the wall that protected the city. An alure, accessed by stairs in the towers, runs along the upper part of the walls, crowned by pointed pentagonal battlements. Access to the Keep is guaranteed by a wooden bridge that connects it to the alure. In the northern section of the walls are visible the ruins of the old fortress, probably from the 14th century, which probably had two floors, according to the existing exterior windows.

The Keep, built during the reconstructions in the second half of the 13th century, is in the center of the square of arms with a quadrangular plan and about 27 meters high.

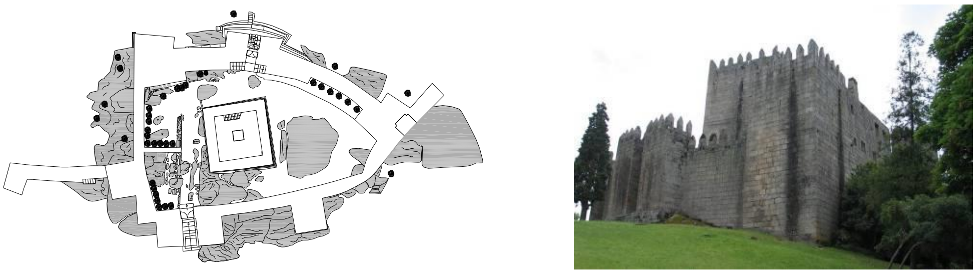


Fig. 1 Plan and general view of the Guimarães Castle.

The Cross-border Fortresses of the river Minho

Varying in form and type of construction, the cross-border fortifications of the river Minho include: rock castles, Fig. 2), in which it is the territory where they are located that stands out and which, due to their location and constructive solutions, were intended to ensure the defense of key points such as roads and passages; and the stone or earthern fortifications that contributed to reaffirm the border opposition line to the kingdom of Spain Fig. 3, and Fig. 4.

a) *b)*

Fig. 2. Fortresses in stone masonry in the border with Spain.

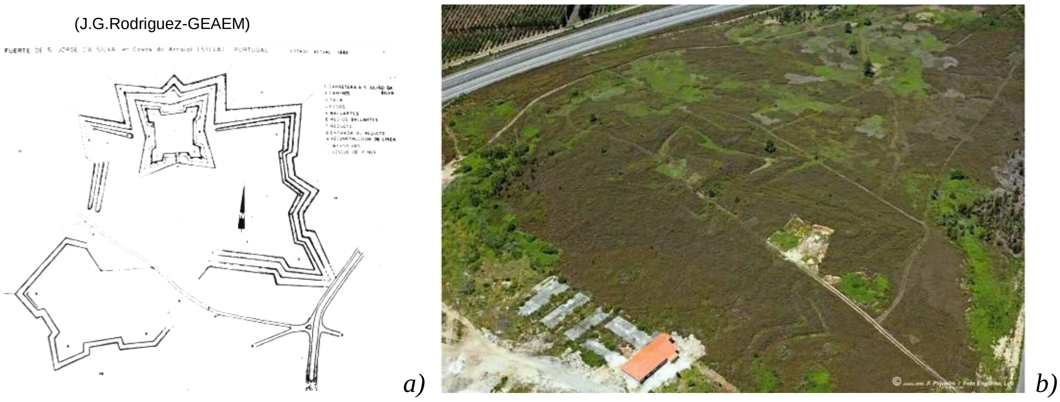


Fig. 3. Earthern Fortresses near the border with Spain: layout (a) and aerial photography (b)

Fig. 4. Survey (a) and aerial photography (b) of Fort of Gandra.

Peniche fortified complex

The Peniche fortified complex, Fig. 5, began to be built in the 16th century. The great Lisbon earthquake of 1755 destroyed part of the wall, and the area where the wall collapsed is still called “broken”. The Fort plan layout is an irregular polygonal plan with bastions and is built with ashlar and limestone masonry with variable thickness in height. Inside the fortress there are, in addition to the old structures, reinforced concrete buildings built in the mid-20th century when the fortress was transformed into a political prison. Thus, the same fortress has associated historical moments relevant to the country's independence and the establishment of a democratic regime; presently it houses the National Museum of Resistance and Freedom.

Fig. 5. Fortified complex of Peniche.

Methodologies for structural survey and interventions

The inspection methodology used by NR-IC, for safety assessment of stone masonry structures, is based on the ICOMOS charter recommendations for "Analysis, Conservation and Structural Restoration of Architectural Heritage". It has been used in numerous conservation and rehabilitation projects, as well as technical inspections on different construction types in order to contribute for a sustained intervention on built heritage, focusing on the phases of Analysis (involving the technical inspection) and Diagnosis of historical constructions, Fig. 6. A particular focus is given to the Analysis phase, with the main goal of assessing the construction's overall condition, such as observed damage levels recordings, geometric recordings and photography. The Diagnosis phase, that helps on defining both technologies and materials better suiting the characteristics of the construction under study, is essential for a correct intervention and it will be exposed. In fact, when proceeding to a sustainable rehabilitation of a heritage construction, taking into account its architectural, historical and constructive values, the development of a careful diagnosis is paramount.

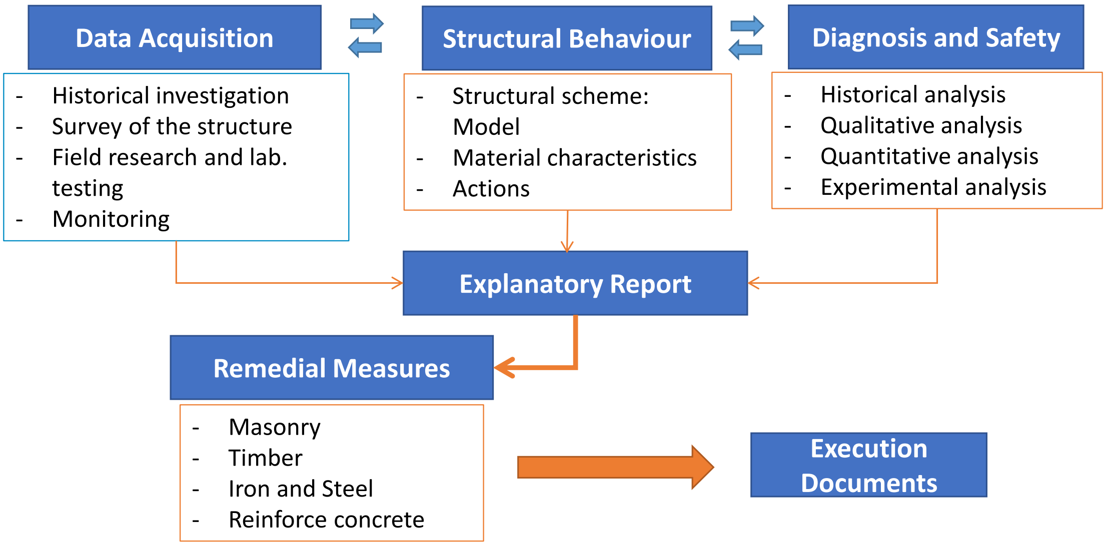


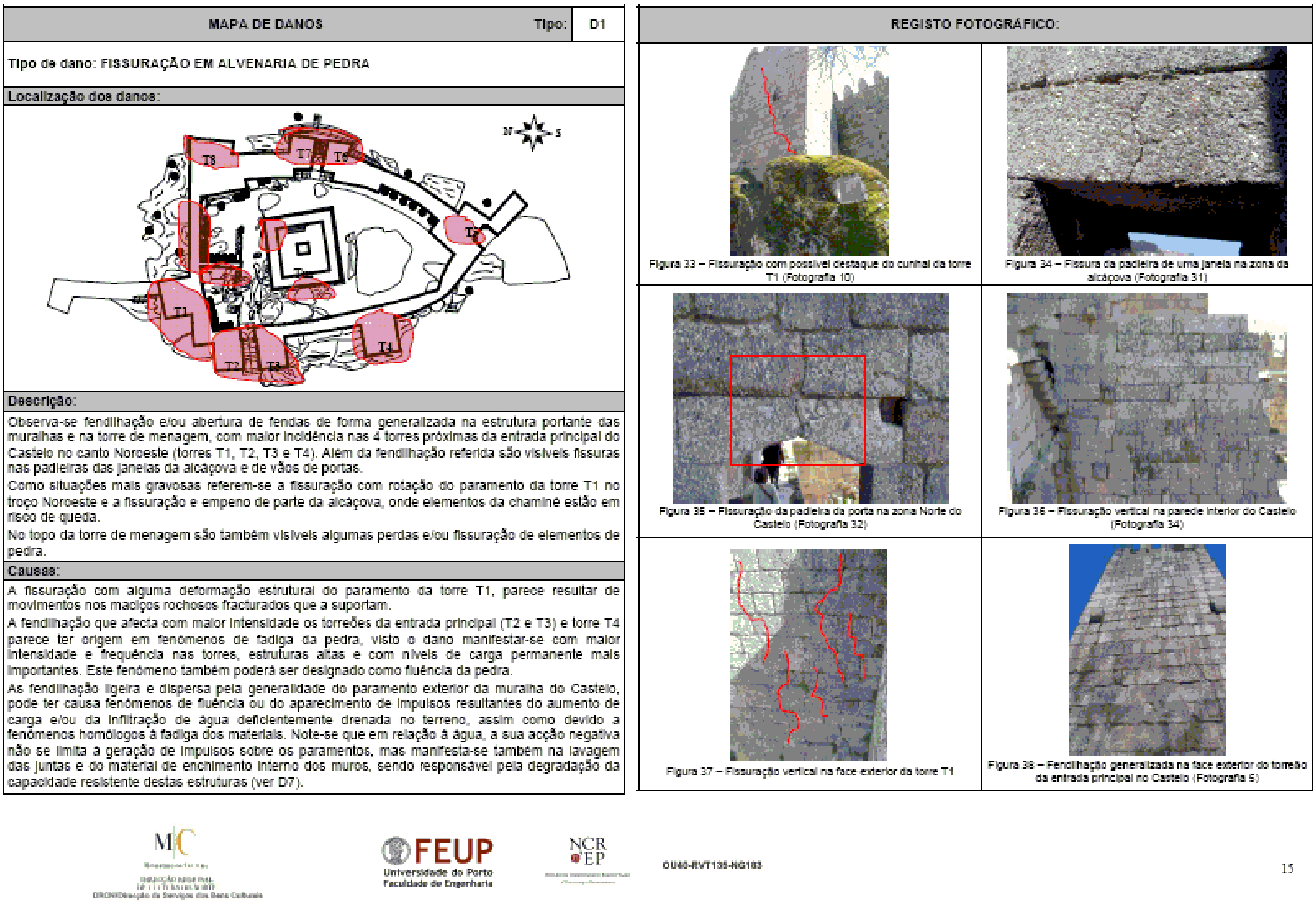
Fig. 6. Inspection methodology.

Guimarães Castle

Structurally, the Guimarães Castle has load-bearing walls in granite stonework, generally with good arrangement. It has 8 towers integrated in the walls and a central keep with much larger section and height than the other towers. As shown in Fig. 7, the wall towers are designated from T1 to T8, with Tm being the keep. The main entrance to the castle is located between the T2 and T3 towers and the "betrayal" gate is between the T6 and T7 towers. The area of the wall marked by A in Fig. 7 refers to what remains of the fortress wall. This identification was used in the inspection procedures, allowing for a more targeted and, consequently, more effective registration of damages. Thus, in a first phase, the damages were identified and located in maps by type of damage; in a second phase, a form per element was made for the most affected elements in order to compiles all kinds of damage that occur simultaneously on the same element. This recording approach allows to describe each damage, to identify its occurrence location and additionally, for each element, to associate the record of all its damages thus providing the information of its overall structural state.

Fig. 7. Identification of the elements of the Castle of Guimarães.

The damages identified and listed below were: D1 – Cracks in stone masonry; D2 – Opening of joints; D3 – Deformation and/or structural warping; D4 - Lack/Loss of material; D5 – Loss of joint mortar; D6 – Degradation of wood; D7 – Material degradation due to presence of vegetation and/or moisture; D8 – Degradation due to presence of crusts, efflorescence and/or biological pollution; D9 – Visual degradation, and D10 – Constructive deficiencies. Fig. 8 shows an example of the inspection form for damage D1.



MAPA DE DANOS	Tipo: D1
Tipo de dano: FISSURAÇÃO EM ALVENARIA DE PEDRA	

Localização dos danos:

Descrição:

Observa-se fendilhação e/ou abertura de fendas de forma generalizada na estrutura portante das muralhas e na torre de menagem, com maior incidência nas 4 torres próximas da entrada principal do Castelo no canto Noroeste (torres T1, T2, T3 e T4). Além da fendilhação referida são visíveis fissuras nas padieiras das janelas da alcáçova e de vãos de portas.

Como situações mais gravosas referem-se a fissuração com rotação do paramento da torre T1 no troço Noroeste e a fissuração e empeno de parte da alcáçova, onde elementos da chaminé estão em risco de queda.

No topo da torre de menagem são também visíveis algumas perdas e/ou fissuração de elementos de pedra.

Causas:

A fissuração com alguma deformação estrutural do paramento da torre T1, parece resultar de movimentos nos maciços rochosos fracturados que a suportam.

A fendilhação que afecta com maior intensidade os torreões da entrada principal (T2 e T3) e torre T4 parece ter origem em fenómenos de fadiga da pedra, visto o dano manifestar-se com maior intensidade e frequência nas torres, estruturas altas e com níveis de carga permanente mais importantes. Este fenómeno também poderá ser designado como fluência da pedra.

As fendilhação ligeira e dispersa pela generalidade do paramento exterior da muralha do Castelo, pode ter causa fenómenos de fluência ou do aparecimento de impulsos resultantes do aumento de carga e/ou da infiltração de água deficientemente drenada no terreno, assim como devido a fenómenos homólogos à fadiga dos materiais. Note-se que em relação à água, a sua acção negativa não se limita à geração de impulsos sobre os paramentos, mas manifesta-se também na lavagem das juntas e do material de enchimento interno dos muros, sendo responsável pela degradação da capacidade resistente destas estruturas (ver D7).

REGISTO FOTOGRÁFICO:

Figura 33 – Fissuração com possível destaque do cunhal da torre T1 (Fotografia 10)

Figura 34 – Fissura da padieira de uma janela na zona da alcáçova (Fotografia 31)

Figura 35 – Fissuração da padieira da porta na zona Norte do Castelo (Fotografia 32)

Figura 36 – Fissuração vertical na parede interior do Castelo (Fotografia 34)

Figura 37 – Fissuração vertical na face exterior da torre T1

Figura 38 – Fendilhação generalizada na face exterior do torreão da entrada principal no Castelo (Fotografia 5)

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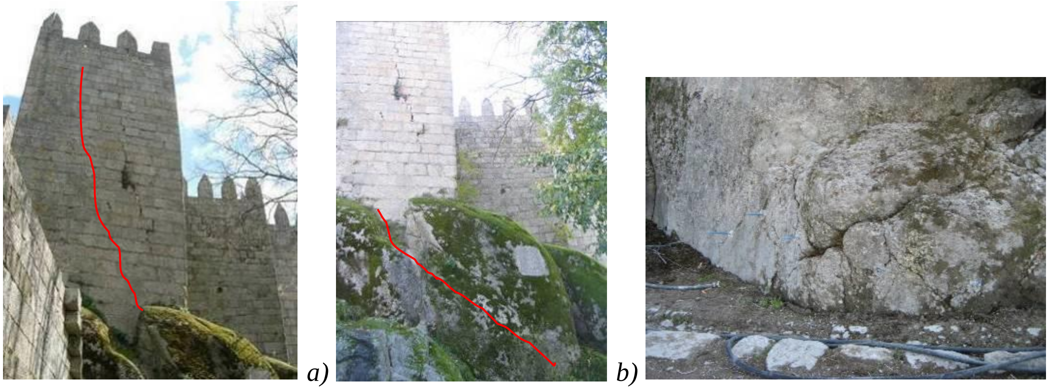
Fig. 8. Example of the inspection form for damage D1.

After the inspection, the constructive elements considered most affected were the T1 tower and the A fortress wall, for which urgent intervention was recommended. Particularly for the T1 tower, which presented joint openings with a V-shaped development (with apex at the corner base) and corner detachment by rotation, further studies were carried out. On the north face of the same tower, simultaneously with the joint opening, localized fracture of some ashlar stones was also observed, probably due to stones' compression crushing caused by the stress increase resulting from the corner rotation. As causes of these damages, alterations to the rock mass outcrop were pointed out, since both the T1 tower and the other towers and walls of the Guimarães Castle are founded thereon, Fig. 9. This rock mass, which is almost 3.5m high in the support area of the T1 tower corner, presents an apparent joint/fracture and severe degradation at the base. The fracture positioning in the rock mass is in line with the direction of the joint opening observed in the North facing, where it is more pronounced.



a) b) c)

Fig. 9. a) Corner detachment; b) fracture of the support massif; c) severe degradation of the base support of the rock massif.

A closer look at the rock masses supporting the castle structures revealed that these were vertically cut, apparently by using dynamite, as suggested by the visible marks. These cuts, carried out within the scope of the urban arrangement of the castle surroundings in the mid-1940s, weakened the rock masses, in some cases leaving them supportless. In addition to the changes in the support conditions of the structures, the rock masses became even more vulnerable to erosion effects due to changes in the conditions of rainwater drainage. Therefore, it is considered that these cuts were responsible for some of the damage observed in the towers and walls, namely the detachment of the corner of the T1 tower. Fig. 10 a) shows a hole in a rock mass that might have been done to introduce a dynamite stick, as often used for thinning and cutting rock masses. Fig. 10 b) and c) presents images of the T1 and T2 towers that allow the visualization of the type of structure of the towers. During the inspection, and because it was considered to be an indispensable element, a survey of the dimensions of the T1 to T8 towers was carried out. Due to lack of knowledge on the construction process inside the towers, it was necessary to make a specific survey in the T1 tower (Arêde an others, 2017) in order to determine the face type and thickness of the wall, as well as the constitution of the interior filling; the location of the survey is indicated in Fig. 11 a). It is worth mentioning that part of this tower development height wise was rebuilt during interventions carried out by the former historic heritage institution called “National Monuments” in the mid-1930s/40s.

a) b) c)

Fig. 10 (a) Mark of rock cutting with a dynamite stick; (b) Tower T1; (c) Tower T2

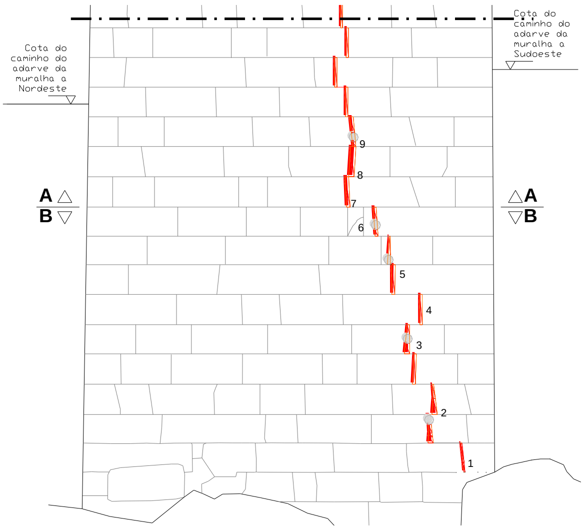
The survey carried out at the top of the tower, Fig. 11 b) and c), allowed to verify that the constructive process of the tower's facades is carried out in rows of granite stonework of about 50 cm, made of stones of approximately 50 x 60/65 cm2 and with variable length between 100 cm and 140 cm. The stones’ positioning in the wall face alternates between the stone placed in a row and the stone to bond faces. The infill of the tower is completed with smaller granite stone and apparently black earth.

In the walls’ faces and in the weakest area of the North façade, a survey of the joint openings and the observed cracking was carried out. In this survey, performed by stonework rows that were numbered from the base to the top, the wall thickness was also assessed, whenever possible. The introduction of a rod in the joints, allowed to see that, in some places, it entered about 2.0 m into the tower interior.

As a final output of the inspection, summary tables were made for the most affected elements where the most relevant damages and the associated risks were described.

a) *b)* *c)*

Fig. 11. Surveys on the top of Tower T1



(a) indication of rows

Details of stone rows

(b) row 6

(c) row 7

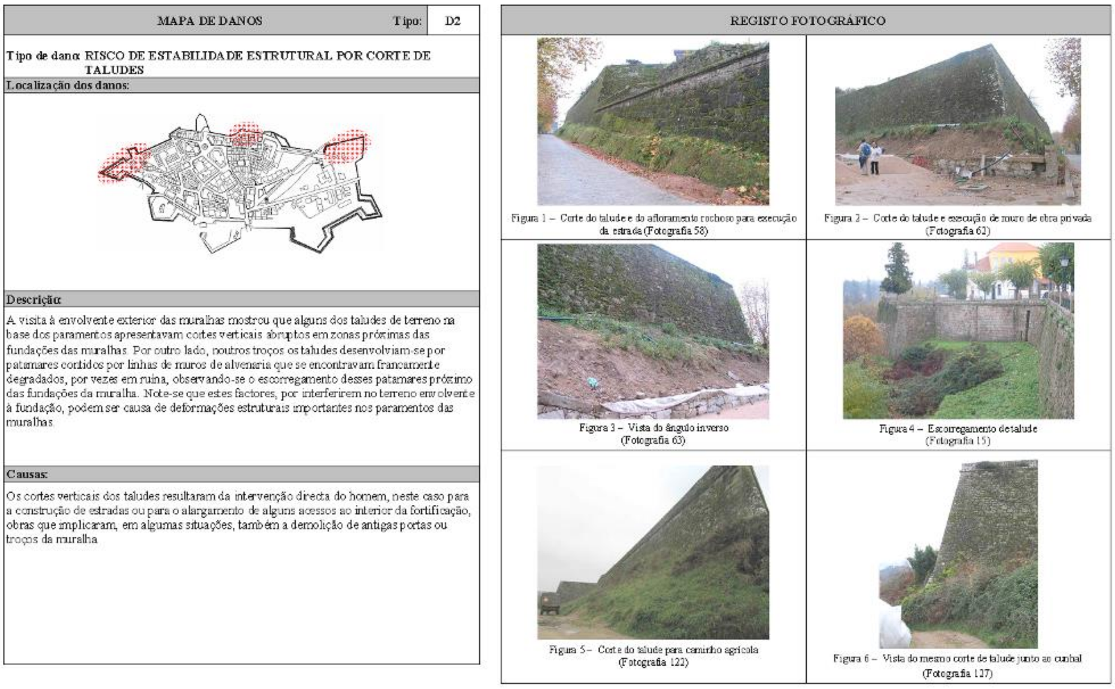
Fig. 12. Geometrical survey of the cracks of the North façade of tower T1

Cross-border Fortresses of the river Minho

The cross-border fortresses of the river Minho (Portugal-Spain) exist in great variety, having very different technical characteristics and construction processes. In the inspections carried out, an attempt was made to adapt the resulting information to the objectives of the study. In the inspection process, the fortresses were divided into 3 groups according to their similarities in terms of structure and construction process. Thus, the fortresses were divided into rock castles, traditional fortresses with granite walls, and earth forts, the last two typologies being presented hereafter.

Traditional fortresses of granite facings

In these fortresses, characterized by several lines of defense developing along more or less high walls in granite, visual inspections with a structural scope were carried. For each fortress, after the identification and description of the load-carrying structure, those considered most relevant were recorded in damage forms (Costa, Guedes and Paupério, 2005). In these forms, Fig. 13, in addition to the in plan location of the damage, there is also a brief description associated with the identification of its probable cause. Also, the interconnection between different types of walls (crossing or extension of medieval walls with bastions) were identified and marked as additional and fundamental information to the inspection process.


MAPA DE DANOS Tipo: D2

Tipo de dano: RISCO DE ESTABILIDADE ESTRUTURAL POR CORTE DE TALUDES

Localização dos danos:

Descrição:
A visita à envolvente exterior das muralhas mostrou que alguns dos taludes de terreno na base dos paramentos apresentavam cortes verticais abruptos em zonas próximas das fundações das muralhas. Por outro lado, noutros troços os taludes desenvolviam-se por patamares contidos por linhas de muros de alvenaria que se encontravam francamente degradados, por vezes em ruína, observando-se o escorregamento desses patamares próximo das fundações da muralha. Note-se que estes factores, por interferirem no terreno envolvente à fundação, podem ser causa de deformações estruturais importantes nos paramentos das muralhas.

Causas:
Os cortes verticais dos taludes resultaram da intervenção directa do homem, neste caso para a construção de estradas ou para o alargamento de alguns acessos ao interior da fortificação, obras que implicaram, em algumas situações, também a demolição de antigas portas ou troços da muralha.

REGISTO FOTOGRÁFICO

Figura 1 – Corte do talude e do afloramento rochoso para execução da estrada (Fotografia 58)

Figura 2 – Corte do talude e execução de muro de obra privada (Fotografia 62)

Figura 3 – Vista do ângulo inverso (Fotografia 63)

Figura 4 – Escorregamento de talude (Fotografia 15)

Figura 5 – Corte do talude para caminho agrícola (Fotografia 122)

Figura 6 – Vista do mesmo corte de talude junto ao cunhal (Fotografia 127)

Fig. 13. Example of a damage form.

For larger structures, whether with high wall sections and/or at various levels, a photographic survey and a structural analysis were carried out by sections, Fig. 14. For each section under study, identified in a plan, in these forms it is shown a photographic record and a summary table that relates the damage recorded in the structure and its intensity of occurrence (low, medium, or high). In this way, in addition to the damage forms, a much more intuitive relationship is obtained between the damage, its intensity, and the place of occurrence, allowing for a more effective general identification of the state of conservation of the structure and the determination of critical points. It is noteworthy that, currently, the external slopes are not considered as an integral part of the structure and therefore, generally present a very poor maintenance. This situation is exacerbated by the indiscriminate cuts, resulting from the opening of streets or the execution of nearby constructions, this being a factor that enhances structural instability.

The importance of the historical and architectural studies that integrated the execution of the Master Plan is highlighted, and that proved to be of extreme importance in the identification of critical structural points such as those of connection between wall panels from different periods and the identification of construction techniques associated with different periods.

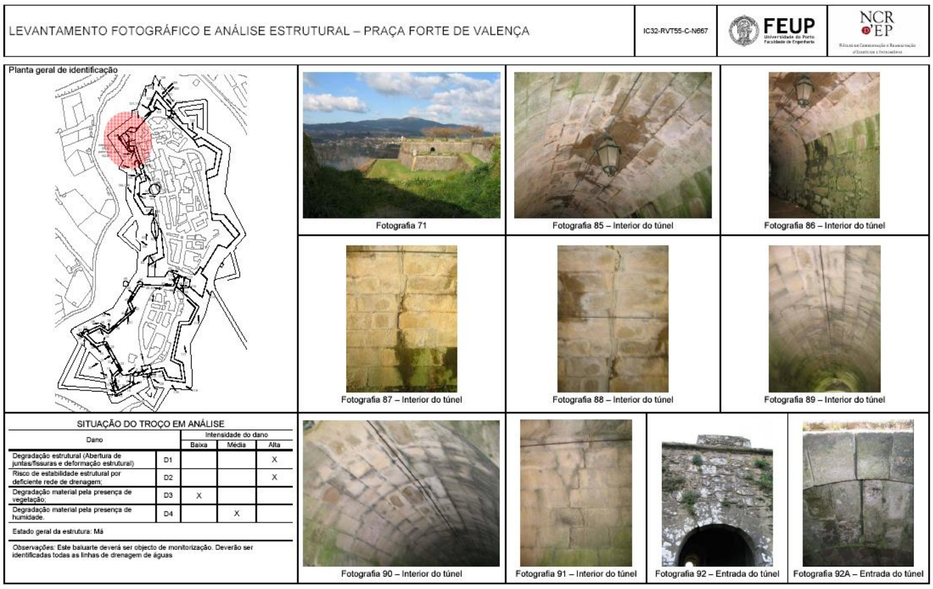


Fig. 14. Example of a photographic survey and structural analysis.

Earthen fortresses

The earth forts, despite their strategic importance for the defense and attack of the territory, are today doomed to oblivion and destruction, requiring therefore a more detailed analysis. These earth forts, built during the war, followed the war theories in an exemplary way, presenting perfect geometric configurations, often in the form of a star, Fig. 4 and Fig. 5.

The inspection process of these earthen forts, and since many of them were "lost" and their existence forgotten, fundamentally passed through their identification, localization on the ground, and their inventory. Some of them were no longer even mentioned in the documentation of the municipalities and, in these cases, the information provided by the local populations was essential. The aerial visit to the site proved to be fundamental in the identification and perception of these enormous forts.

Its construction in a material so-called "torrão", a mixture of cobble of different granulometries, clay and silt, suggests enormous earth movements, given the dimensions of these forts and the necessary mixture of ingredients for the execution of the "torrão". The earthen fortresses were built with materials from alluvial terraces (according to the geological map of the area where the forts were built) that were generated by watercourses tributaries to the river Minho, which have now disappeared, as well as movements associated with the glacial cycles of the Pleistocene, and that are typical of this region (Teixeira, 1953).

Thus, ingeniously, the well-worked and compacted soil materials were transformed into important defense and attack strongholds, with self-supporting slopes that, later, if the situation so required, could be lined with granite stonework. Of these forts, reference is made to the fort of Gandra, already identified in Figure 5 and shown again in Fig. 15, where, in addition to the well-defined star and with a point already cut by a road, it can still be seen what may have been a trench in an advanced line, this being the only trace that this fort would have dimensions much larger than what is presently seen. In an oblique photograph and taking the construction on the right side of the road as the scale, it can be assessed the dimension of the slopes of these structures.

Associating the war theories with the material that was at hand, an effective construction technique was achieved: the mixing and crushing of the "torrão", eventually with some watering of the final layer, which translates into a material with good consistency and with a waterproofing protective layer that prevents its breakdown. Any intervention carried out in these forts will have to go through the preservation of the construction material and the filling of the existing holes with the original material, and not the uprooting of vegetation that favors the disaggregation of this material.

Fig. 15. Views of the Gandra Fort.

Fortified complex of Peniche

The buildings that include the fortified complex of Peniche were divided into 3 zones identified from 1 to 3 in Fig. 16:

Fort – Walls with bastions and their casemates

Buildings – structures that are part of the Fort, whether from the beginning of construction (casemates) or from alterations inherent to the adaptation to a political prison (reinforced concrete building blocks)

City Wall – front walls with bastions that protect the city.

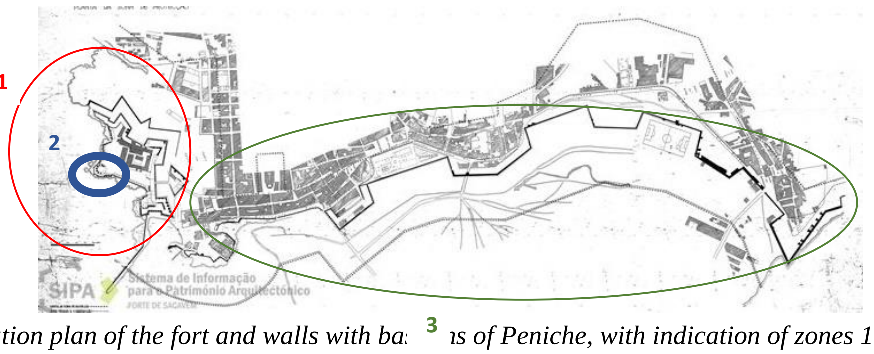


Fig. 16. Implantation plan of the fort and walls with ba[...]ns of Peniche, with indication of zones 1, 2, and 3 (retrieved from: www.monumentos.pt).

In the fort (Zone 1), a total of 48 sections of the different walls were identified in plan, which were inspected from the outside and the interior, having identified for each face the existing damage, as well as the corresponding evidenced intensity. In Zone 2, the different buildings within the fortress were marked from A to K, and the different associated construction processes were recorded, as well as the damage and occurrence intensities, Fig. 17. The same methodology was applied to the city wall line, Fig. 18. The inspection procedures were similar to those mentioned above, with this fortress having the particularity of housing constructions from different periods, to be preserved due to its importance for the collective memory.

Fig. 17 – Notation of the sections of wall of the Fort and Buildings in its interior.

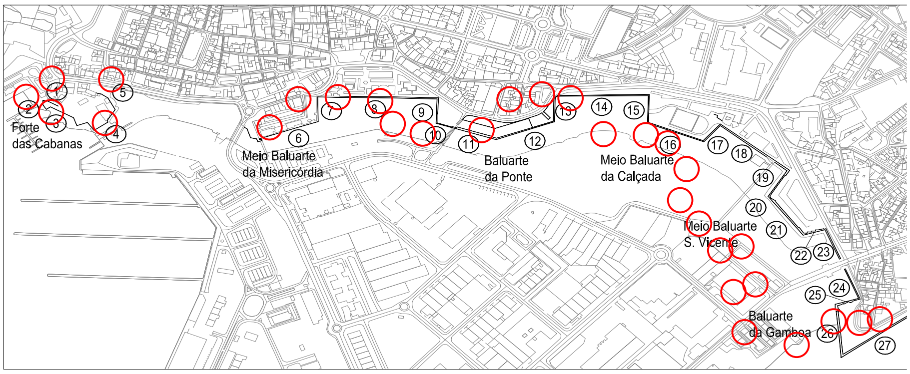


Fig. 18 – Notation of the sections of City Walls.

For each section of the walls (Zones 1 and 3) and for each building, the damages were identified, and the respective damage maps were made, structured by type of anomaly recorded during the inspection survey and identified with the letter D further associated either with the letter M for the damage to the Fort and City walls or the letter E for the Buildings. Thus, DM corresponds to damage in the Fort and City Walls and DE to damage in Buildings; several damage types were listed for the Fort and City walls (12) and for the buildings (7). Fig. 19 shows an example of the map of damage "DM2 - Risk of structure stability due foundation degradation" and the analysis of a city wall section with damages' identification and their intensity degree (Low/Medium/High).

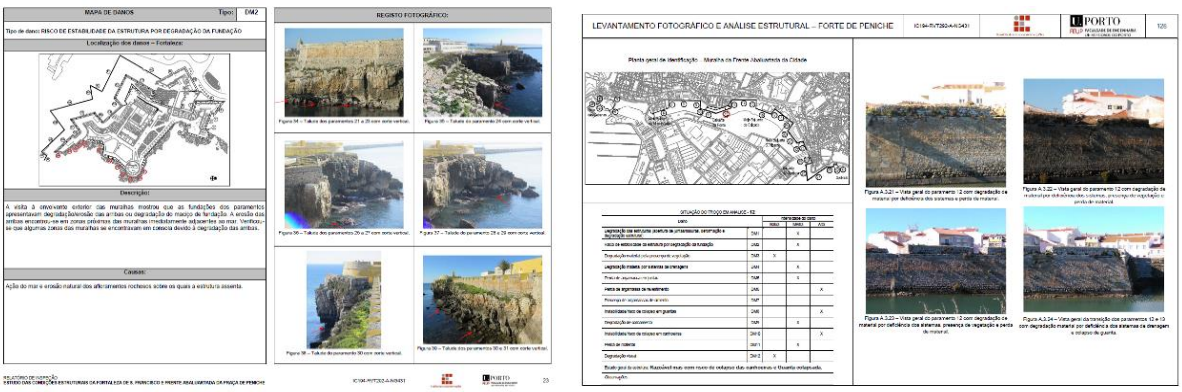


Fig. 19 – Example of a damage map and of the structural analysis with different intensities of damage
Regarding the reinforced concrete buildings, where the political prison operated, these were subject to a specific inspection process, aiming at their rehabilitation based on authenticity and integrity criteria, naturally ensuring structural safety conditions. Some photographs of the conservation state of some of the buildings, which were later rehabilitated, are presented in Fig. 20.

Fig. 20 – Former political prison buildings and their material/structural degradation

Final considerations

In this work, the procedures used in the inspection and diagnosis of a vast set of fortified military structures were presented, highlighting the importance of a good organization and systematization of the information for the accomplishment of appropriate diagnosis and interpretation of the structural situation of the monuments. In this way, decision-makers can decide in a sustained way about the need for an intervention.

The inventory of new military structures associated with a constructive system not very common in the North of the country, as in the case of earthen forts, proved to be an asset in the development of the work. The inspections made it possible to identify, in addition to other important damages, the cutting and sliding of the slopes and foundations of the fortresses, as well as the cutting or degradation of the rock outcrops supporting the structures, further affected by the effect of climate change, as one of the most widespread damages and responsible for the loss of stability of structures. The rise of sea waters associated with climate change can be problematic, particularly in coastal fortresses. It is important to call attention to the good maintenance of the rock masses and slopes, which support these structures. Although they are treated as not part of the supporting structure of the monuments, they proved to be fundamental for their stability, being in fact, their integral part.

It should also be noted that multidisciplinary teams and their interaction in this type of work results in added value in the final work.

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