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Seismic vulnerability of the Algarve coastal region

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ABSTRACT: The Algarve is the national area, the most exposed to the action of the Bank of Gorringe, place to which are allotted the epicentres of higher magnitude earthquakes that ravaged Portugal in particular 60-63b.f., 1033, 1356 and 1755. However, despite being characterised by a reasonable geographical uniformity, the territory of the Algarve presents considerable variation at the level of impact occurred, both of a general historical analysis, and with respect to specific occurrences. The case studies chosen, regardless of the geological similarity, territorial proximity, and the high degree of devastation that they underwent, are primarily characterised by the divergence of the answers operated in the post-disaster context. From the complete abandonment of the settlements to the immediate reconstruction, the use of pre-existence to the full redefinition of the clusters structure, the Algarve offers a wide variety of approaches when considering how this region adapted to the seismic phenomenon.

1 INTRODUCTION

1.1 *The region and its historical seismicity*

The Algarve locates in the extreme south of the country. It is characterised by a predominantly Mediterranean climate influence. It presents a long and smooth coastline with solar exposure to the south. Its terrain is gradually developed from its mountain line, which protects it to the north from the Atlantic winds, forming the national area with lower rainfall index. Its coastal area has the densest occupation of the region, populated by clusters with intermediate dispersion. Its main urban centres are often developed from sea or estuary ports, displaying a clear presence of the Islamic occupation. The Algarve is also illustrated by a strong historical seismicity, presenting earthquakes that caused extensive damage in the built structure of the region. The earthquakes of 1722 and 1755 seriously affected the Algarve coast, with intensities of IX and X (MCS). Existing reports corroborate the significant seismic activity of the Algarve region, both in terms of quantity and in terms of intensity. The impact recorded affected its entire coastal strip, with no differentiation between Western or Eastern area, regardless of the Atlantic or Mediterranean influence, which also reinforces the theory of the prevailing spread from the Gorringe Bank (LNEC, 1986).

Its orography, exception made for the Atlantic angle and the mountainous line break, also enhances the vulnerability to tsunamis that in cases such as *Faro*, *Lagos* and *Santo António de Arenilha*, proved to be the main cause of devastation (Victor Mendes, 2006).

Table 1. Main earthquakes in the Algarve region (LNEC, 1986).

Year	Intensity*
1719	X
1722	IX–X
1755	IX–X
1856	VIII
1858	VI–VII
1969	VIII

*Mercalli Scale (MCS)

1.2 *The architectural diversity of the Algarve coast*

Although experiencing an improved variety throughout the region, the geology of the Algarve also turns out to condition the structural weakness of traditional nature buildings. The settlements implanted in sandy soils, of great erosive vulnerability and low density, generally have a high degree of destruction, as documented, more than once, in *Sagres*, *Vila do Bispo* or *Bensafrim*. In these cases it was frequent the use of rock bases, in sandstone, of dark reddish colour, usually called 'Silves stoneware'. These foundations were built in massive *socos*, existent in smaller buildings and of a single storey, generally clustered in row.

Constructively, the western end and the base of the mountain area are characterised by the use of non-specified stone walls, punctuated by the use of reddish sandstone and limestone masonry (with significant expression also in the floors and in the trim of the openings), with greater presence in urban areas. The composition of limestone and clay soils also

Figure 1. Rocky integration as structural *soco*, *Vila do Bispo* (credits: CI-ESG, 2013).

Figure 2. Trim reinforcement with *lambaz* brick (Credits: CI-ESG, 2013).

Figure 3. Rammed-earth building with reinforced plinth course, *Bensafrim* (Credits: CI-ESG, 2013).

determined broad application of lime as the main binder, and the profusion of ceramic materials such as tile and solid brick (SNA, 1961). These elements thus compensate the structural weakness of the crude masonry cloths, as well as the development of specific components in *lambaz* (solid) brick for use in openings reinforcement or discharging arches.

In structural terms, it should be further emphasised their combined application in the development of dome and vaulted roofing systems, which spread across the territory, and although considered generally, as it is the roof terrace, it is also often associated with specific locations given the observed systematic (for example in the case of *Fuseta* in *Olhão*). As in the neighbouring Alentejo regions using rammed-earth constituted, for many years, the traditional benchmark system for most of the rural areas, particularly in isolated buildings. The analysed architectural typologies are also analogous to that region, dominating the buttresses and the masonry vaulted structures placed at the base of the buildings as the main earthquake-resistant elements. As in the above-mentioned vaulted systems, the use of rammed-earth corresponds currently to a less observable construction technique, due to its pronounced disappearance or the significant altering of the existing examples (Caldas, 2010).

From the referenced seismic occurrences, this text will address the direct consequences of the earthquake of 1755, the depth of the physical and cultural impact that it left the region. However, it should be noted the occurrence of 1969 as part of a recent memory in the locations of the western area, although without explicit implications for their constructive cultures (Vasques, 2002).

Tavira encompasses the cases of high impact with moderate destruction, whose recovery of the building takes place almost immediately after to the occurrence. Within this condition can be classified, for example, the cases of *Loulé* and *Castro Marim*. At the other extreme, are found the cases of cities like *Silves*, *Faro* and *Lagos*, whose cities were severely destroyed, and the reaction of the population more time consuming and complex. Moreover, *Lagos* represents a situation of total abandonment, whose reconstruction occurs after a significant gap, and subject to distinct chronological phases (Victor Mendes, 2006). Finally, *Vila Real de Santo António* will be characterised as a unique case, representing a strategic paradigm at the national level, aimed at the implementation of the *Pombal* reconstruction system, both in urban and technological terms (Mascarenhas, 2009).

2 LAGOS

2.1 *General framework: The destruction of the city and its resurgence*

The development of Lagos, as most of the Algarve coastal cities is related to maritime activities, with its economic heyday at the time of Portuguese discovery. The urban core is divided into two parishes: the Parish of Santa Maria, where traces of Roman *Lacobriga* persevere, with orthogonal grid and blocks of approximate dimensions; and the Parish of San Sebastian, which has a more organic route, and an irregular urban fabric.

Figure 4. "Gaioleiro" system in Lagos (credits: Laura Felix, 2015).

Lagos took on great importance in the XV century by virtue of the Portuguese discoveries, becoming the most significant maritime base of the ships that sailed the Mediterranean and the Atlantic.

Over the centuries, several earthquakes affected this city, and the 1755's earthquake was the most devastating. With the earthquake and the tsunami that followed it, the city was practically devastated. As a direct consequence, this city is abandoned by the Governor and the army that was staying in Tavira, being no longer the capital of the Kingdom of the Algarve.

The delay in its reconstruction; the economic decline; the instability caused by the French invasion and the fighting between liberals and absolutists contributed to its economic and urban stagnation. Only amidst of the XIX century was resumed the process of urban reconstruction, aided by the economic prosperity of the expansion of the canning industry, and the growth of local businesses.

In the 60s, the tourism development will contribute to the beginning of the most intense urban expansion phase, which features significant part of the current form of the city.

2.2 *Characterization of Lagos historical centre*

The features of built area of the historical centre of *Lagos* were decisively affected by the 1755's earthquake, remaining only a few buildings. The most identified traditional buildings date back to the late eighteenth, nineteenth and twentieth centuries.

Currently, the historical centre of *Lagos* has a multitude of buildings formally and technologically dissonant. In terms of construction process, about 47% of the buildings are of reinforced concrete, being the remaining 53% of traditional construction. Of these, 40% are in stone masonry, while the remaining 13% are in brick or adobe mud.

The extramural northern area of the centre, bordering the old mesh, corresponds to a newer construction sector, with a totally different scale from the original. The blocks present variable forms and areas, strongly influenced by the steep topography and the access roads.

The north intramural area, adjacent to the walls, has elongated blocks with different characteristics from the rest of the city, adapted to the setting of the wall itself, and the adjacent access roads.

The Centre downtown area, where are confined the most relevant public spaces, has an organisation in compact blocks of smaller dimensions. The original nucleus of this area is the first walled perimeter, presenting very specific features and emphasising the regularity of the mesh that consists of small blocks. These blocks have sizeable patios, arranged laterally to buildings with exterior walls of great expressiveness. The central area has a more uniform mesh. The layout is structured by city permeation routes and their perpendicular branches, defining blocks with different dimensions. The area adjacent to the walls, but outside the walls, presents a mostly free building space. It is possible to observe the City Park, spaces with private gardens, still in a much more degraded area covered with ruins and poorly constructed. Finally, the extramural area, south of the centre, consists of isolated equipment and public gardens, and a significant portion is occupied by Military Camping Park.

With regard to volumetric, the historical centre of *Lagos*, and despite the transformation of the urban fabric that occurred between the late 60s and early 70s, there is a high prevalence of buildings of 1 and 2 floors, totalling approximately 75% of the total edified set. Despite greater number of floors buildings are a small percentage, it is noteworthy the visual impact they cause in relation to the remaining urban fabric. They become totally unrelated to the primitive type. These new buildings often result from the grouping of several plots, and the withdrawal of the patio, an element that was part of any type of housing in the city. The early alignment disappears, as well as building-street relationship. Construction materials are most often of low quality, having no correspondence with the vernacular building of the city. The vernacular buildings that characterise the core feature sloping roofs, varying from roof of only one water, a gable roof, hipped roof or several water and mixed coverage (terrace or roof terrace and roof of a water). The buildings present for the most part, rectangular plans in L or U, and visible wedge in clenching of several blocks. The spans of the main façades feature stone or mortar linings, and when the furnish is mortar, it is painted, as the *soco*. The spans are of small size, and sometimes misaligned. Unique elements are observed in these buildings, such as the verge (in buildings of 2 or more floors) or double eaves (common in 1 floor buildings). Sometimes it is also possible to observe structural reinforcement elements, either independent or transversal to the building systems.

2.3 *Seismic-resistance in Lagos*

Despite the massive destruction of the buildings in the historical centre of *Lagos* and its resulting abandonment, the research carried out allowed the identification of buildings prior to 1755. Some of these

Figure 5. 'Telhado de Tesouro' in Tavira (credits: CI-ESG, 2015).

buildings, slightly raised in relation to the streets and generally aggregated in row, show significant slope facades produced by gradually reducing the wall section height to its top trim.

As for the buildings constructed post-earthquake, reinforced plinth course, buttresses, bearing arches and 'gaioleira' (Fig. 4) walls were identified. However, despite its high number identified, the location of these elements is scattered and punctual, revealing no direct linkage with any constructive technique or architectural typology.

The analysis to some ruins also enabled the testing of a correlation between the construction method and its time of construction, allowing a better identification and understanding of the buildings of the same era. Some ruins presented the use of 'gaiola' systems on the walls of moiety. These systems were extremely simplified, generally without the presence of diagonal elements, and composed only by the vertical wooden elements (plumbs) and the horizontal elements (windowsill), sometimes reinforced with the inclusion of some metal elements.

The application tethers, transversely to the main façades, are also a frequent presence.

Inside of some buildings it was also possible to identify additional locking elements, such as transverse walls with wooden skeleton and brick filler, cross half-timbered walls and crossed floors.

3 TAVIRA

3.1 *General Context: The progressive rationalization of the medieval matrix*

Tavira is located on the Mediterranean coast line, shifted to its eastern side. It stems from its port vocation, given the natural protection of the salt marshes of the *Ria Formosa*. It is structured from two distinct cores, deployed in areas of rugged hillside, which develop along both banks of the River Gilão.

Hit violently by the 1755's earthquake, it quickly recovers thanks to the internal action of its population, which performed a process of spontaneous reconstruction process, resorting to the use and reuse of ruined buildings. In the geographical centre of Tavira, it is clear the sedimentation of the chronological strata in the buildings, with obvious intersections of medieval structures and post-earthquake construction. The centre is characterised particularly by the threading of the set of streets crossing the river axis. These areas, of a more dense occupation than the upper area, exhibit linear aggregates or elongate block with two street fronts, moving away progressively from medieval genesis matrix, which confers to it a more regular layout.

3.2 *The built typology: The height of the building cross to the plot*

The core of *Tavira* consists mainly buildings developed in height from two to three floors, with a narrow and elongated rectangular plan, which occupies the entire plot. They have dimensions slightly greater than the built area implanted in the highest parts of the slope. They have the particularity of presenting multiple roofs, of four waters, built on the same volume. It is called "treasure". According to Ribeiro (2013) these examples date back to the perpetuation of a constructive tradition of the golden age of its owners, expressing an external influence of the oriental, a common character of most dynamic port cities. The inner partitioning typically corresponds to a single cover unit, adopting an internal organization of cross fragmentation, which will lose the social role as the compartments move away from the main facade. The floors, always different, represent a great regular composition, by employing a significant number of arched solutions in the execution of their spans.

3.3 *From the regional building system to the specific coverage system*

From the buildings of the central core of Tavira, despite its proximity to the River *Gilão* waters, there are no known specific characteristics of implementation of its foundations. Yet, there is a clear tendency to enjoy the rocky integrations, of Jurassic limestone, for the start of buildings, and thus avoiding the vicinity of the alluvia marginal of the river. The exterior walls use a constructive system of stone masonry, of rough apparatus, determining a section of significant thickness. They present also, however, a more elaborate treatment in stone elements at the wedges of the buildings. They have structural interior walls, using the same building system, arranged transversely to the building, and lined with the inner beams of the covering. The peculiar system covers of "treasure", clearly a response to optimise the dimensioning of the spans woodwork, allows a more efficient distribution of its own load, as well as the increase of general fastening of the building. The spans of the main facades have stonework fittings, sometimes with slightly arched lintel. Independent structural reinforcement elements or transverse to the construction systems applied are not observed.

Figure 6. "Gaioleiro" system in Vila Real de Santo Antonio (credits: CI-ESG, 2015).

Figure 7. Covering system sustained by arches in Vila Real de Santo António (credits: CI-ESG, 2015).

4 VILA REAL DE SANTO ANTÓNIO

4.1 *General context: The implementation of the 'Pombalino' model*

The development of *Vila Real de Santo António* is part of the strengthening strategy of national occupation on the border with Spain. As the vast majority of the Algarve coastal region, it was based on fishing subsistence. However, it will be their customs status, which will give it a significant predisposition to trade, and accordingly its individual character. This area assumes the location of the former Village of *Santo António de Arenilha*, near the Guadiana bank, which has been devastated by the 1755's tsunami. The construction of the new village starts from the implementation of a core set by the *Casa do Risco das Obras Públicas*. It presents the direct application of the urban model of 'Pombalino' downtown, conveniently suited to the scale and resources of the region, in the mesh configuration, in the aggregation systems, and in the architectural typology. The urban mesh is implemented parallel to the river, providing the elongated blocks in a north-south direction. The blocks are compact, dominated by longitudinal fronts of great regularity, with roofing and façade of a single expression.

4.2 *The process of adaptation of the income building.*

Without the size and the resources of the capital city, the income building of 'Pombalino' downtown was too ambitious for the context of the Algarve village. Not only would it be needed to adjust the investment from the point of view of the real estate value, as it would also be appropriated to correct the functional program, as the occupational density was not justified, given the amount of available land. The buildings that acquiesce the urban front of the most important streets, near the dominant longitudinal axis or Central Square, follow more closely the application of the 'Pombalino' modular systematic, albeit with substantial reduction in the maximum number of floors.

They are usually of two levels, with a significant improvement of the coverage, which can vary between 4 and 6 water solutions. They present orthogonal rectangular plans of great symmetry and geometric systematization, which is expressed especially in the configuration of the facades. The plans, significantly narrower than the original model, vary between 1 and 2 subdivision levels, according to the parallel alignment to the main facade. The vertical difference between levels is evident, reflecting the typology used for the solution of the openings. Unlikely, in the horizontal level there is uniformity of treatment, both in the internal organisation and between different housing units. The side streets, especially the most remote of the central area, admit a typological variety, and may contain smaller residential buildings, or they may also integrate functional additions to the main building, which would be located on the opposite street. These streets lose therefore their block façade uniform character, assuming a large formal dynamism.

4.3 *The simplification of the 'gaiola' system*

The buildings, built according to the 'Pombalino' model, turn naturally to the cage system, with a significant reduction of the wooden skeletons sections and the corresponding stone masonry. The wedges and the spans are fully implemented with limestone fittings. The ground floor, only built in stone masonry, takes back the structural *soco*, using a covering system sustained by arches. The upper floor refers to the combined 'Pombalino' system (with the caveats already mentioned), integrating in several cases, the systematic application of metal tethers on the facade, especially in the anchorage of the upper floors pavements. The remaining buildings or their wall-backing supplements are of great constructive simplicity. These resort to ordinary masonry stone or brick systems. In these buildings, the application tethers across the main facade, is still often, though not carried out systematically.

5 FINAL REMARKS

Considered generally as a regional unit in terms of seismic vulnerability, the Algarve presents a great variety of processes and approaches from the impact caused by the major earthquakes.By its geographical and geological nature, the coastal strip represents the area of the most significant records.

Tavira, Lagos and Vila Real de Santo António represent three paradigmatic approaches in what the reaction to the 1755's earthquake is concerned. Tavira is a chaos of spontaneous reconstruction, regenerating and maintaining the structure built typologies and the local constructive technique. Lagos conveyed a traumatic process, conditioned by a long abandonment and a time consuming and asymmetrical reconstruction process, with traces of traditional elements and techniques, yet without the consolidation of a specific building culture that incorporates assumedly this problem. Vila Real de Santo António constitutes a rupture with the constructive culture, established by the full replacement of the typological model and the techniques employed in the region. However, the spread and permeability of the 'Pombalino' systems applied, along with the awareness of the hand labour, enabled a process of adaptation and adjustment to local conditions and resources. This contributed to the integration and effective dissemination of some elements in the processes of traditional construction of the Algarve region.

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REFERENCES

Caldas, J. V. (2010). *Cidade e mundos rurais. Tavira e as sociedades agrár*ias. Tavira: Câmara Municipal de Tavira.

GECoRPA (2000). Sismos e Património Arquitectónico – Quando a terra voltar a tremer. *Revista Pedra & Cal*, 8.

Gonçalves, A., 2009. Vila Real de Santo António: planeamento de pormenor e salvaguarda em desenvolvimento. In Monumentos, 30, 40-53.

Gonçalves, A. (2007). Caracterização do Núcleo Pombalino. *ECDJ*, 9, 18-35.

LNEC (1982). *Construção Anti-Siìsmica: Edifiìcios de Pequeno Porte.* Lisbon: Laboratoìrio Nacional de Engenharia Civil.

LNEC (1986). *A Sismicidade Histoìrica e a RevisaÞo do Catalogo Siìsmico.* Lisbon: Laboratoìrio Nacional de Engenharia Civil.

Mascarenhas, J. (2009). *Sistemas de Construção – V: O Edifício de rendimento da baixa pombalina de Lisboa*. Lisboa, Portugal: Livros Horizonte

Ribeiro, O. (2013). *Geografia e Civilização. Temas Portugueses.* Lisboa, Portugal: Letra Livre

SNA- Sindicato Nacional dos Arquitectos (1961). *Arquitectura Popular em Portugal*. Lisboa: SNA

Vasques, J. C. (2002). *Lagos e a Instabilidade Sísmica*. *Relatório do Centro de Estudos Marítimos e Arqueológicos de Lagos.* Lagos: CEMAL