Original Article

Structural condition survey of ancient bullfighting arenas

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ABSTRACT Bullfighting arenas are a very interesting example of infrastructures that are exposed to harsh environmental conditions and, for economical reasons, frequently do not benefit from periodic maintenance. A set of very ancient (on average 100 years old) Portuguese bullfighting arenas was subject to a qualitative structural condition survey campaign to evaluate their safety under the public live loads. These structures are described both in terms of their shape and functioning and of the construction materials used and added along their service life. The main pathologies detected are presented and the most frequent structural problems concern cracking of the masonry elements, various problems in the concrete elements, degradation of steel and timber and deteriorated roofing. The main durability-connected problems detected were water infiltrations (because of the lack of a waterproofing membrane), various problems involving the external coatings or the soffits of the arches and vaults and corrosion in concrete elements. Non-structural problems concerned mostly deficiencies in the drainage system. A summary of the rehabilitation recommendations is provided, with a strong emphasis on coatings. It is concluded that these very old and striking structures can endure much longer if they are properly maintained.

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INTRODUCTION

In the Iberian Peninsula bullfighting still represents an ancient and well-respected tradition and a very rare brand of sport and art. In the recent decades, even though

Figure 1: The Campo Pequeno bullfighting arena, one of the most charismatic monuments of Lisbon (left) and degraded condition of the interior of the Alcochete arena (with radial arches) because of extreme lack of maintenance (right).

still popular with many hundreds of thousands of aficionados, it has lost its grip and relevance in a modern society and is even under strong attack by animal rights organisations. Nevertheless, the popularity of this activity has gone beyond its traditional home ground (Portugal, Spain and South and Central America) to reach new markets such as North America, Japan and Eastern Europe.

Independently of what one may think of bullfighting itself, the bullfighting arenas represent a very strong mark in the cities where they are located. This is especially true for the ancient arenas from the late nineteenth and early twentieth centuries that represent an important percentage of the bullfighting arenas in Portugal. These very special buildings are often the *ex libris* of their towns (Figure 1, left) and correspond to ancient ways of building that are sometimes not too well known. The financial management of these infrastructures, very often owned by social assistance institutions that use them to finance socially relevant initiatives, is most difficult nowadays as the total number of bullfights per year varies in most cases between three and seven and, with the exception of different types of live shows, there is very little use for them in the remaining time.

Therefore, conservation and maintenance of these structures are often insufficient or even non-existent. Over their many decades of life time, they tend to degrade as they are exposed to harsh weather conditions (Figure 1, right). Furthermore, in seismic countries such as Portugal where seismic design and codes have undergone a significant evolution, the structural safety of these arenas as measured by present codes and procedures cannot be guaranteed. Finally, the fact that when there is a bullfight there are sometimes several thousand spectators inside the arenas has led the Portuguese authority responsible for public shows to ask for a qualitative structural condition survey of the arenas that apparently presented the most serious problems in terms of safety and/or durability.

This paper presents the main results of the structural condition survey of a set of nine ancient Portuguese bullfighting arenas inspected over a 1 year period, and it does not aim at comparing these results with other inspection surveys or previous research on similar subjects, namely inspection/diagnosis methodologies or structural analysis tools. It complements another study (De Brito and Branco, 2006) concerning seven Portuguese more modern bullfighting arenas with a concrete structure. The work consisted mostly of a detailed visual inspection of the structures and a diagnosis of the causes of the main structural/construction, durability-related and non-structural anomalies found, as well as a set of recommendations on how to solve the problems detected and eliminate, whenever possible, their primary causes. The description and statistical survey of these anomalies, causes and rehabilitation measures is preceded by a description of the arenas inspected

Figure 2: Distribution of the bullfighting arenas throughout Portugal and location of the arenas inspected.

in terms of structural materials and typology. The paper closes with a set of conclusions concerning the pathology of this very special type of structure and the maintenance procedures they must be subjected to.

DESCRIPTION OF THE BULLFIGHTING ARENAS

There are 71 bullfighting arenas in Portugal (Figure 2), of which 16 have not been active in the last few years. They are concentrated in the south/centre interior regions near Spain (such as in Alentejo) or where the wild bulls are bred (Ribatejo). A number of these arenas have been subject to a qualitative structural condition survey according to the priorities and availability of financing of the licensing authorities.

The location of the ancient bullfighting arenas inspected (Figure 2) is listed below, as well as the year in which they were built and their spectators' capacity (the

Figure 3: Bullfighting arenas of Alcochete (left) and Setúbal (right).

Figure 4: Bullfighting arenas of Figueira da Foz (left) and Caldas da Rainha (right).

Figure 5: Bullfighting arenas of Estremoz (left) and Redondo (right).

Figure 6: Bullfighting arenas of Mourão (left) and Évora (right).

Figure 7: Bullfighting arena of Reguengos de Monsaraz (left) and Caldas da Rainha bulls' pen (right).

average age of the arenas is 95 years and becomes 100 years if the Redondo arena is left out)

- Alcochete (Figure 3, left), 1921, 4076 (BA1);
- Setúbal (Figure 3, right), 1889, 4000 (BA2);
- Figueira da Foz (Figure 4, left), 1895, 6611 (BA3);
- Caldas da Rainha (Figure 4, right), 1883, 3850 (BA4);
- Estremoz (Figure 5, left), 1904, 4200 (BA5);
- Redondo (Figure 5, right), 1957, 4000 (BA6);
- Mourão (Figure 6, left), 1922, 2023 (BA7);
- Évora (Figure 6, right), 1889, 4000 (BA8);
- Reguengos de Monsaraz (Figure 7, left), 1925, 3664 (BA9).

From a structural point of view, these buildings are extremely interesting because, during their often longer than a 100-years lifetime, they have undergone a series of minor and major rehabilitation interventions, to cope with new needs and the materials natural degradation, incorporating different structural and non-structural materials according to different ages and trends, and quite often within a very limited financial state of affairs.

In terms of shape in plan (Figures 3–7, left), the arenas inspected are perfectly circular in four cases, multi-polygonal in two cases and octagonal in three cases, even though some of them have projecting parts that correspond either to the main entrance, exterior staircases or the bulls' pen (Figure 7, right). Several facilities (reception hall, infirmary, offices, sleeping quarters, chapel, stores, stables, ticket-offices, restrooms, bulls' pen and so on) also existed within the arenas. As for structural type, the arenas can be grouped as shown

- BA1 and BA9 have three concentric rings connected by radial walls with arches (Figure 1, right) and vaults;
- BA2 has three concentric rings connected by radial concrete beams (from a 1960s rehabilitation) and brick vaults (Figure 8, left);
- BA3 has four concentric rings connected by radial walls with arches and vaults;
- BA4, BA6 and BA8 have two concentric rings connected by radial walls with arches and vaults;
- BA5 has three concentric rings (the outer one with arches – Figure 5, left) connected by radial walls with arches and vaults;

Figure 8: Degraded brick vaults in Setúbal (left) and schist radial beams and slabs in Mourão (right).

Figure 9: Structural materials: hollow brick in Alcochete (left) and irregular stone masonry in Figueira da Foz (right).

Figure 10: The original timber pavement in the reception hall of the Setúbal arena (left) and cabins roof's structure in the Figueira da Foz arena (right).

- BA7 has four concentric rings connected by radial schist beams, brick walls with arches and schist slabs (Figure 8, right).

The structural materials used in the walls, arches and vaults ranged from hollow (BA1 and BA2 – Figure 9, left) or solid structural brick (BA4, BA5 and BA8), rubble concrete (BA1 and BA3) to irregular stone masonry (BA3, BA5, BA6 and BA8 – Figure 9, right) or a mix of brick and stone masonry (BA7 and BA9). Their coating consisted of limestone or cementitious renders, water-based paint and/or a lime coat, or nothing at all.

The original pavements were in timber (some still exist) and have been replaced by either cement mortars on top of earth and/or debris fillings supported by vaults, the original timber pavements over a wooden structure (Figure 10, left) or slabs in reinforced concrete or precast prestressed joists (with ceramic hollow vault bricks) built

Figure 11: Degraded and unstable metallic railings in Évora (left) and original timber seats also in Évora (right).

Figure 12: Seats in reinforced concrete cast *in situ* in Alcochete (left) and 'reinforced' hollow brick in Setúbal (right).

some decades after the initial construction. Coatings of these pavements were either non-existent, made of cement-based mortar or ceramic tiling. The original pavements over the bulls' pen (in timber – Figure 7, right – or solid ceramic small vaults supported by I-shaped metallic beams) had almost always been removed and replaced with very thin reinforced concrete, precast prestressed joists slabs or even 'reinforced' hollow bricks (coated with cement-based renders and/or common paint), supported by either brick/stone walls or concrete/metallic beams.

Preventive maintenance strategies are planned, cyclical maintenance actions. The original timber staircases had also been replaced in almost every case with reinforced concrete structures. In pitched secondary roofs, metallic or asbestos-cement corrugated sheets or ceramic tiles were used, generally supported by wooden or metallic trusses.

In most of the arenas, a covered area was built some decades after the initial construction to house spectators' cabins (Figure 10, right). This structure was supported either by metallic or reinforced concrete columns and the outer structural ring, and the roof was made of ceramic tiles, metallic or asbestos-cement corrugated sheets supported by metallic trusses or of concrete (both conventional and precast prestressed joists) slabs and beams (coated with cement-based renders and/or common paint).

Parapets are usually the original ones or at least several decades old. They are metallic (Figure 11, left), made of rendered hollow bricks or decorative ceramic tiles/bricks.

The seats, in most cases originally in timber (Figure 11, right), had been replaced by reinforced concrete cast *in situ* (BA1 and BA3 – Figure 12, left) or prefabricated, 'reinforced' hollow brick elements (BA2 – Figure 12, right), precast prestressed joists and hollow bricks (BA4) or cement mortars on top of earth and/or debris fillings supported by vaults (BA3). They were simply supported by the radial structural elements. Their upper surfacing, if any, consisted of a cement-based mortar, sometimes with

Figure 13: Original seats in stone in Figueira da Foz (left) and, in Estremoz, directly on the ground (right).

Figure 14: Large crack of the outer wall of the Estremoz bullfighting arena resting over eighteenth century fortress walls (left) and people living inside the Reguengos de Monsaraz arena (right).

a coating of water-based paint or lime, but never a proper waterproofing system. The lower surfacing, if any, consisted of a cement-based render either painted or lime coated. In the cases where the original seats remained, they were made of stone (BA3, BA4, BA5, BA7 and BA8 – Figure 13, left), solid brick (BA6) or ceramic tiles (BA8 and BA9), uncoated, painted or with a painted render coating, usually on top of earth and/or debris fillings supported by vaults or schist slabs (in the case of BA7). In the Estremoz arena (BA5), part of the perimeter of the stone seats (schist) lies directly on the ground (Figure 13, right). The same happens in Redondo (BA6) with solid brick seats coated with a painted render.

Some of these structures present very interesting/unusual features such as

- BA1 has several 3 m tall rubble concrete columns;
- The interior vaults of BA2 are made of unreinforced first generation concrete and some of the original timber pavements and staircases are still functioning normally;
- BA3 still contains in limited areas the original cast iron beams that supported the seats;
- BA4 was rehabilitated as early as 1920 and the present masonry structure replaced a wooden one;
- Part of the foundations of BA5's outer ring lies on top of the eighteenth century fortress walls of the city of Estremoz (Figure 14, left) and part of the intermediate ring functions as a bearing wall;
- BA6 was built as recently as 1957 but using archaic materials and techniques (for example stone foundations) and the topography of the ground was used to dispense with a structure to support the seats in three quarters of the arena's perimeter;

- BA7's structure is made mostly of schist elements including one-piece beams with spans up to 3.30 m long; a recent collapse had caused part of the structure to be replaced by a common column-beam-slab concrete sub-structure;
- Both BA8 and BA9 arenas' inner space was still used as housing for socially deprived people (Figure 14, right); BA8 was planned to be totally refurbished in the summer of 2005.

RESULTS OF THE QUALITATIVE STRUCTURAL CONDITION SURVEY

General remarks

From the description above, it can be concluded that a large part of the Portuguese bullfighting arenas was built between the end of the nineteenth century and the beginning of the twentieth century. Usually they were made of quasi-circular walls of stone or brick masonry that supported timber seats.

Throughout the twentieth century these arenas underwent refurbishments that consisted mostly on the replacement of the timber seats with masonry structures (more recently concrete elements). Other interventions also led to the inclusion or restructuring of internal sub-structures also generally in concrete.

Given their age, the arenas' structures will have great difficulties in complying with present structural safety codes, namely the Portuguese codes of 1983. In this context, the structural condition surveys described here aimed essentially at qualitatively evaluating the safety of the structure and in particular that of the spectators' seats under live loads. The following principles were taken into account

- without resorting to complex analyses, it is consensual that the structural safety concerning the occurrence of a very strong seism is not fulfilled; however, the probability of the simultaneous occurrence of a seism and a bullfight (in average only six occur per year in each arena leading to an almost nil quasi-permanence value of the live load) is so extremely low that it can be disregarded;
- the safety of the spectators seats concerning the design value of the live load has been tested frequently as most bullfights fill the arenas; in other words, actual load tests have been performed without any accidents in the past and only specific calculations for each situation can unequivocally demonstrate structural safety as defined by the codes; other public entertainment facilities decades old have not been subject to such an analysis.

In this situation, the loss of safety of the seats can only result from their physical deterioration along time or from an accident that may have occurred in the meantime. Therefore, based mostly on visual observation, condition surveys have as their practical goal to detect structural degradation or accident-prone situations that may lead to hypothetical short or middle term unsafe conditions of the seats under the live load of the spectators.

The bullfighting arenas structural condition survey campaign was carried out in order to detect anomalies of two main types: those associated with problems of mechanical behaviour and those resulting from the degradation of the materials with time. The pathologies found were then divided in three groups: structural or construction pathologies, durability anomalies and non-structural pathologies. An analysis of the frequency and variety of the pathologies found is presented next for each group.

Table 1: Structural pathologies detected in the structural condition survey of the bullfighting arenas

<i>Description</i>	<i>Frequency (%)</i>
1 – Cracking in masonry arches/vaults	100
2 – Corrosion of metallic elements	89
3 – Deteriorated roofing	78
4 – Cracking of concrete elements	67
5 – Cracking of masonry walls	56
6 – Radial cracking of the benches at the supports	56
7 – Degraded timber elements	56
8 – Loss of elements from the arches/vaults	44
9 – Over-deformation of benches	33
10 – Scaling of stone	33
11 – Porous concrete	22
12 – Partial elimination of structural elements	22
13 – Lack of verticality of structural elements	22
14 – Cracking of non-structural walls	22
15 – Open expansion joints	22
16 – Over-deformation of walls	22

Figure 15: Cracking in masonry arches in Alcochete (left) and vaults in Figueira da Foz (right).

Figure 16: Cracking of masonry walls in Estremoz (left) and over-deformation of walls in Mourão (right).

Structural or construction pathologies

During the bullfighting arenas structural condition survey campaign, various structural anomalies were detected, both problematic only from an aesthetic and functional point of view and hinting at structural safety problems. Table 1 presents the statistical survey of the frequency and variety of these pathologies.

By analysing Table 1, one can conclude that the most frequent anomaly in the ancient bullfighting arenas that were inspected, occurring in every case, is cracking in masonry arches/vaults (1) (Figure 15), almost twice more frequent than cracking of masonry

Figure 17: Partial elimination of structural elements in Setúbal (left) and scaling of stone in Figueira da Foz (right).

walls (5) (Figure 16, left). Both anomalies are to be expected in ancient masonry structures, either in stone, brick or both. This is because of two main reasons: the great stiffness of these elements, particularly susceptible to imposed deformations (because of foundations settlement, hygrothermic effects or seismic action); and its lack of tensile strength that easily leads to cracking. Foundations settlement seems to be the main cause of the cracking of walls and, in some of the structures analyzed, it indicated serious structural problems. Even though more frequent, cracking of the arches and vaults was in most cases directly caused by the water infiltrations from the benches that leached the binding mortar between the elemental components, bricks or stones. However, in some cases, cracking was critical and it could lead to the formation of mechanisms. Its very high frequency proved two points: maintenance was badly needed and the arches and vaults are even more susceptible to cracking than stones, being significantly slender.

A situation that came up twice (22 per cent of the cases) and was particularly worrying was over-deformation of walls (16) (Figure 16, right). Such event may be a pre-collapse symptom caused in one case by the foundation rotation of the eighteenth century fortress section of wall on top of which the arena lies and in the other by excessive axial loading. Another anomaly with potential grave consequences is the partial elimination of structural elements (12) (Figure 17, left). It was detected twice and was caused by the frequent and not always careful refurbishing operations these infrastructures underwent during their long life cycle and the fact that nothing has yet resulted from it just proves their structural redundancy.

Two other anomalies are direct causes of weakening of the masonry structures: scaling of the stone elements (10) (Figure 17, right), found in one-third of the assessments, and the loss of elements from the arches/vaults (8) (Figure 18), detected in 44 per cent of the arenas. The first one, caused by freeze/thaw cycles and frequent contact with water associated with a friable nature of the material, is especially worrisome in one of the arenas, whose structure is totally made of schist and has undergone very important losses of cross-section in main structural elements. The loss of elements is a further step from cracking of the arches and vaults and therefore may lead to their collapse in the long run, especially if the water infiltrations that caused the anomaly in the first place, by eroding the mortar between the bricks/stones, are not dealt with.

Both anomalies concerning the spectators' benches, radial cracking of the benches at the supports (6) (Figure 19, left) and over-deformation of benches (9) (Figure 19, right),

Figure 18: Loss of elements from the arches in Estremoz (left) and vaults in Setúbal (right).

Figure 19: Radial cracking of the benches at the supports in Reguengos de Monsaraz (left) and over-deformation of benches in Alcochete (right).

Figure 20: Corrosion of metallic elements in Évora (left) and degraded timber elements in Setúbal (right).

occurring respectively in 56 per cent and 33 per cent of the cases assessed, are directly connected with the masonry structure that supports them (in the case seen in Figure 19, right, the over-deformation is because of the excessive flexibility of the precast reinforced slabs that make up the seats). As a matter of fact, the settlement of the arches and vaults between the radial walls that support the benches both increase the deformation of the benches and cause rotation of the benches in the supports that crack at regular intervals near the top surface.

Corrosion of metallic elements (2) (Figure 20, left), occurring in 89 per cent of the cases (the only one where it was not detected had had all metallic elements repainted recently), and degraded timber elements (7) (Figure 20, right), occurring in 56 per cent

Figure 21: Cracking of concrete elements in Figueira da Foz (left) and porous concrete in Setúbal (right).

Figure 22: Lack of verticality of structural elements in Setúbal (left) and open expansion joints in Figueira da Foz (right).

of the cases (in most of the others there were no visible timber elements), are two other anomalies concerning traditional materials known for their limited durability. Lack of maintenance is the major reason for all the instances when these problems occurred even though in most of the cases the age endured by the materials and elements, many decades, more than had proved their worthiness.

On the contrary, the recent additions to these infrastructures, mostly in reinforced concrete, have had a rather disappointing performance durability-wise. In fact, cracking of concrete elements (4) (Figure 21, left), porous concrete (11) (Figure 21, right) and lack of verticality of structural elements (13) (Figure 22, left), the latter in both cases in concrete columns occurred in 67 per cent (the exceptions were arenas very recently maintained or where there were no concrete elements), 22 per cent and 22 per cent of the arenas, respectively. This poor behaviour is mostly because of the following causes: the susceptibility of reinforcement to corrosion, the poor quality of concreting and in particular of the reinforcement cover, the lack of protection of the exposed elements, the water infiltrations from the benches and poor workmanship in general. All these causes are made worse by the lack of maintenance, common to all the other materials.

Other anomalies typical of modern constructions include open expansion joints (16) (Figure 22, right), in 22 per cent of the cases, cracking of (hollow brick and mortar) non-structural walls (15) (Figure 23, left), also in 22 per cent of the cases, and deteriorated roofing (3) (Figure 23, right), in 78 per cent of the situations analyzed. The relatively

Figure 23: Cracking of non-structural walls in Caldas da Rainha (left) and deteriorated roofing in Alcochete (right).

Figure 24: Water infiltrations from the benches in Caldas da Rainha (left) and in Figueira da Foz (right).

Table 2: Durability-related pathologies detected in the structural condition survey of the bullfighting arenas

<i>Description</i>	<i>Frequency (%)</i>
1 – Water infiltrations from the benches	100
2 – Biological growth in walls, arches or vaults	100
3 – Lack of waterproofing membrane in benches/roofing	100
4 – Cracking of external coatings	100
5 – Humidity/peeling in external coatings	89
6 – Cracking of benches overcoat/pavement	78
7 – Corroded steel reinforcement in concrete elements	67

low percentage of occurrence of problems with expansion joints is deceiving as they happened in all the arenas where later additions of concrete structures included these joints. These light non-structural walls are less subject to cracking than the robust masonry walls as their foundations do not tend to settle as much. Finally, the very frequent problems with roofing surfaces, independently of their materials (ceramic tiles, metallic or asbestos-cement corrugated sheets or concrete) all relatively recent, were due mostly to lack of maintenance but also of protective layers such as waterproofing membranes and insulation.

Durability pathologies

During the structural condition survey campaign of the bullfighting arenas, several durability pathologies were registered such as degradation of coatings, lack of waterproofing system and so on. The statistical survey of the frequency and variety

Figure 25: Lack of waterproofing membrane in benches in Estremoz (left) and roofing in Figueira da Foz (right).

Figure 26: Cracking of benches overcoat in Setúbal (left) and pavement in Estremoz (right).

of these pathologies is presented in Table 2, where the first striking characteristic is that all the individual pathologies occur in all or almost all the arenas in a coherent pattern.

By analysing Table 2, two pathologies that are more cause than anomaly themselves, water infiltrations from the benches (1) (Figure 24) and lack of waterproofing membrane in benches/roofing (3) (Figure 25), are present in every instance. Cracking of benches overcoat/pavement (6) (Figure 26), even though occurring in only 78 per cent of the cases, falls in the same category and was caused by different problems: settlements of the ground or the structure below, mechanical actions, shrinkage, overuse, solar radiation, imposed deformations of various origins and decay. As a matter of fact, none of the arenas' benches had been provided with a waterproofing device to prevent water from penetrating downwards through the joints or cracks of the benches overcoat, the benches themselves, the arches and the vaults (in some cases, such as when the seats were made of schist slabs, there is no easy and effective technical solution to this problem but, in others, there simply had been no willingness to invest), thus causing the water infiltrations that themselves caused many other problems in the structural and non-structural elements below.

The external coatings, where cracking (4) (Figure 27, left) was detected every time and humidity/peeling (5) Figure 27, right) nearly always, as well as the soffits of the arches and vaults and the wall outer surfaces where biological growth (2) (Figure 28, left) always occurred, also suffered the consequences of the anomalies described before. Humidity and water, both coming from the benches or from dribbling of rain, create the

Figure 27: Cracking of external coatings in Redondo (left) and humidity/peeling in external coatings in Setúbal (right).

Figure 28: Biological growth in walls, arches or vaults in Caldas da Rainha (left) and corroded steel reinforcement in concrete elements in Alcochete (right).

Table 3: Non-structural pathologies detected in the structural condition survey of the bullfighting arenas

<i>Description</i>	<i>Frequency (%)</i>
1 – Drainage system deficiencies	100
2 – Deteriorated metallic railings	33
3 – Vandalism/faulty rehabilitation works	33
4 – Lighting system deficiencies	11

perfect conditions for the degradation of the coatings and joints, the loss of salts of the bricks and joints and biological growth. Several consequences of this process are: the loss of material in mortars, paint and joints, preceded or followed by cracking, and ending in the fall of bricks and stones (reported above) and exposure of the masonry structural materials (solid brick and stone) to the weather conditions, leading to further infiltrations and degradation.

Corroded steel reinforcement in concrete elements (7) (Figure 28, right) occurred in the same 67 per cent of the cases when cracking of these elements was reported in the structural pathologies sub-chapter. The causes are also the same as they are two stages of the same deterioration process of the steel, left unprotected within the concrete because of a deficient cover.

Non-structural pathologies

During the structural condition survey of the bullfighting arenas, some non-structural pathologies were registered such as deficiencies in the drainage and lighting systems,

Figure 29: Drainage system deficiencies in Alcochete (left) and in Évora (right).

Figure 30: Lighting system deficiencies in Setúbal (left) and deteriorated metallic railings in Évora (right).

deterioration of the railings and so on. In Table 3 the frequency and variety of the main pathologies of this type are presented.

The analysis of Table 3 leads to the conclusion that there were deficiencies in the drainage system (1) (Figure 29) in all the bullfighting arenas assessed. These deficiencies were associated with insufficient slopes of the drains/benches, leading to water stagnation, clogging or deterioration of the drainage pipes or even, in some cases, their non-existence. It must be pointed out that this pathology, together with the lack of waterproofing membrane in benches, is directly related with structural or construction pathologies, such as cracking and loss of elements in masonry arches/vaults, corrosion of metallic elements, degraded timber elements and scaling of stone, as well as with durability pathologies, such as water infiltrations from the benches, biological growth in walls, arches or vaults, corroded steel reinforcement in concrete elements, and cracking and humidity/peeling in external coatings.

Also from the analysis of Table 3, it can be concluded that functional anomalies such as deficiencies of the lighting system (4) (Figure 30, left) and deteriorated metallic railings (2) (Figure 30, right) show up less frequently, in 11 per cent and 33 per cent of the cases, respectively. This is the type of problem that the inspection body for inspecting entertainment activities/facilities is more focused on and therefore are eliminated more frequently by the arenas' owners through maintenance. Usually, when the metallic railings are considered unsafe, the seats nearby are shut up from the public. Some cases of deteriorated timber elements were non-structural and concerned doors and window frames in bad need of maintenance or even too degraded for recovery.

Finally, situations of vandalism/faulty rehabilitation works (3) (Figure 31) were reported in one-third of the arenas assessed. Vandalism is a social phenomenon common

Figure 31: Vandalism in Setúbal (left) and faulty rehabilitation works in Alcochete (right).

in today's society and it affects every public or private property independently of its architectural/cultural/historical importance. Owing to lack of funds, some rehabilitation works (concerning embedded piping for example) are very poorly patched up with very unpleasing aesthetic results.

RECOMMENDATIONS

For each arena, a set of recommendations was made concerning the elimination of the causes of each type of anomaly detected, whenever possible, and the rehabilitation of the anomaly itself, when deemed necessary. A summation of these recommendations in terms of type of anomaly is presented next.

Structural or construction pathologies

As seen in Table 1, most of the major structural problems detected (anomalies 1, 5, 8, 10, 12 and 16) concerned the brick and/or stone masonry structure, made of walls, arches and vaults. In a couple of cases, the urgency and potential danger involved were such that the arenas were temporarily closed down, either in localised sectors or as a whole. The following measures were proposed

- cracking of the arches and vaults and on the connection between them and vertical walls, as well as open joints between bricks/stones, are to be injected with a lime and cement mortar; measuring devices bridging both sides of the most important cracks (for example mid-span cracks that may lead to mechanisms) are to be monitored; if they show relative displacements, indicating live cracks (not to be expected in the arenas assessed), strengthening must be specifically designed for each case (for example active or passive ties, concrete encasing, metallic plates, carbon or other fibre composites and so on); in the meantime, access to seats over the potential mechanisms should be restricted;
- cracking of walls is treated similarly; if cracking resumes, the foundations of the walls need to be strengthened in order to stop further settlement;
- loose or missing bricks and stones from the arches or vaults are to be repositioned using adequate mortar; at least in one of the arenas, in some of the vaults the matrix of the bricks is degraded beyond recovery and they should all be replaced;
- in one of the arenas, severe scaling of the schist beams justified a dimensional survey and an assessment of the beams supports, a structural safety design and strengthening of the unsafe beams (metallic profiles or a new concrete mid-span supporting frame); in areas with widespread structural insufficiency, global replacement has to be considered; heavily delaminated non-structural stone (for example in seats) needs to be replaced;

- arches that have been partially eliminated need to be reconstructed using materials similar to the originals ones, in order to restore the initial structural functioning;
- over-deformation of the walls were particularly sensitive situations and had to be dealt with urgently; access to the seats over the walls affected was restricted and monitoring of their movement and cracking was implemented; depending on the results, the cracks are to be injected similarly to the situations described above or a strengthening of the foundations is needed followed by a reposition of the structural functioning of the walls that may include metallic bracing and, if necessary, concrete encasing;
- as most of these problems are either caused or made worse by water infiltrations through the benches, that problem must be dealt with, as described below, and elements must be left to dry before the less urgent structural rehabilitation takes place.

Most of the remaining structural problems (anomalies 4, 11, 13 and 15 in Table 1) concern the relatively recent additions of concrete structures to the arenas and are dealt with as follows:

- Cracking of concrete elements was in every case accompanied by corrosion of their reinforcement (anomaly 7 in Table 2) and often by spalling of the concrete cover; the standard treatment in these cases is the removal of any loose/delaminated concrete, sandblasting of the rebars to remove rust, elimination of concrete loose powder using compressed air, replacement/lap splicing of the heavily corroded rebars and concreting with shrinkage-free mortar; the use of a protective coating such as paint was recommended; some very thin slabs with serious corrosion and spalling problems (for example in the bulls' pen areas) may have to be replaced altogether;
- porous concrete is to be injected with an epoxy shrinkage-free mortar after removal of all loose particles; in a couple of cases of beams and columns, the quality of the concrete is too low (inadequate materials and poor workmanship) to guarantee structural safety and the elements affected should be demolished and rebuilt, as strengthening is more costly and the conservation of these modern concrete additions is not important;
- leaning columns, even though usually a serious problem, did not pose in this case a serious problem and no structural measures were proposed;
- gaping expansion joints are to be subject to standard procedures, which include removal of all degraded materials, remaking of concrete edges, replacement of sealants and drainage design.

Corroded metallic elements (anomaly 2 in Table 1) are to be sandblasted to remove rust and subject to a proper corrosion and fire prevention treatment, whenever they are liable to rehabilitation, or replaced with a similar solution or another with other less degradable materials when they are too weakened to allow rehabilitation. In one of the arenas, a metallic structure supporting wooden seats, both beyond recovery, must be removed. Degraded timber elements (anomaly 7) are almost always to be replaced as they are beyond repair (for example in staircases, benches and at the supports of roofing structures) and other materials easier to maintain and more durable ought to be considered. Deteriorated roofing (anomaly 3) is usually dealt with by replacing the damaged tiles, corrugated sheets or their connections, besides rehabilitating their metallic or timber support elements as described above; when in concrete, it needs a waterproofing membrane conveniently protected against ultraviolet radiation and eventual mechanical actions. As for cracking of non-structural hollow brick walls (anomaly 14), it is a minor problem solved by removing the mortar next to the cracks, removing loose particles,

injecting the cracks, placing a glass fibre grid over them and replacing the mortar and paint removed. All these anomalies are common to other much more common types of construction and their rehabilitation is therefore standard.

Finally, the two structural problems concerning the benches are to be solved by injecting the cracks at the supports with an elastomeric mortar (anomaly 6 in Table 1) and replacing the excessively flexible pre-fabricated elements (anomaly 9), when necessary, or levelling the seats over deformed vaults. Where the benches were made of hollow bricks, sometimes even with an inserted steel bar, the deteriorated bricks or rebars are to be replaced.

Durability pathologies

The two major durability-related problems were the lack of waterproofing membrane in benches/roofing (anomaly 3 in Table 2) and the water infiltrations from the benches (anomaly 1), mostly caused by the first one. Therefore, in all the arenas, it was proposed that some kind of waterproofing system should be introduced in the benches. The solution needs to be adapted to each case and materials of the benches, their overcoat and support. In some cases, the best that can be done is to widen all the visible cracks in the benches/overcoat and inject them with an adequate material, in others a liquid waterproofing system may be used to coat all the benches and in yet other cases the benches facing can be removed in order to apply a membrane before repositioning the facing. In concrete roofing surfaces, the latter solution was recommended. This will automatically solve the water infiltration problems, provided the drainage problems (see below) are also dealt with. Cracking of the benches overcoat (anomaly 6), independently of the waterproofing system, is dealt with by widening and injecting with an adequate material, if the number and extent of the cracks is relatively small or by global replacement otherwise. The same applies to cracking of pavements.

Problems with the external coatings of walls and soffits of arches and vaults (anomalies 2, 5 and 6 in Table 2) were detected and fall within the non-structural common rehabilitation field. Thus, degraded coatings (mostly lime mortars) need to be assessed in each case to decide between total replacement with a similar material (removing previously all peeled, loose or infected material and allowing the remaining mortar/background to dry) and local repair

- in the case of biological growth, it must be removed with an adequate product (usually a mild leaching solution);
- for localised cracks, they need to be widened and filled with shrinkage-free lime and/or cement mortars (compatible with the pre-existing mortars);
- peeled paint needs to be removed and the area repainted;
- whenever the coatings or their backgrounds are humid, they must dry before any repair is performed (for example by repairing at the end of the summer);
- regular maintenance of the coatings must be implemented, including painting or whitewashing at regular intervals, especially in the outer surfaces.

Non-structural pathologies

The main non-structural pathology, drainage system deficiencies (anomaly 1 in Table 3) needs to be dealt simultaneously with the waterproofing system of the benches, in order to prevent further occurrences of water infiltrations to the elements below. Potential ponding locations (for example over deformed benches) are to be eliminated, drains

need to be created or have their slope increased, drain pipes need to be created or widened (especially in flat or almost flat confined spaces) and connected to the public drainage system. Regular maintenance in the shape of vegetation and debris removal from the drains and pipes of the system is absolutely essential to keep it functional. The drainage of roofing surfaces needs to be checked and corrected to stop water infiltrations on top of the walls affecting the supports of the roofing structure.

Likewise, the elimination of lighting system deficiencies (anomaly 4 in Table 3), deteriorated metallic railings (anomaly 2), the results of vandalism/faulty rehabilitation works (anomaly 3) and degraded non-structural timber elements must be complemented with proper and timely maintenance. The operations involved are respectively

- the lighting system needs to be upgraded and degraded materials and components need to be repaired/replaced;
- sandblasting of the corrosion of the metallic railings and appliance of a proper corrosion treatment and painting; in some cases when the present railings are not safe, they are to be replaced with a more convenient solution or strengthened with diagonal struts;
- anaesthetic graffiti and mortar patches are to be painted over;
- doors and window timber frames deteriorated beyond repair are to be replaced with aesthetically acceptable alternatives; the others need proper treatment that may involve scouring existing paint and repainting, as well as replacement of the sealants; in some cases, a net is needed in window frames to stop birds from nesting inside the arena.

CONCLUSIONS

This paper presents the main pathologies detected during a qualitative structural condition survey campaign, based mostly on visual observation, performed on nine ancient bullfighting arenas in various regions of Portugal, whose structures and construction materials are previously described. A summary of the recommendations for rehabilitation of the arenas is also provided. Various main conclusions can be drawn from these assessments and they were organised in three groups.

In terms of structural design and materials used

- The arenas are generally circular in plan and their original structure consists of concentric walls (from two to four), radial walls or arches that support vaults or structural benches; many additions have been made throughout the years, mostly to add roofed cabins;
- materials used vary a lot, but in most cases walls, arches and vaults are made of brick and/or stone masonry, benches are stone, brick or mortar (often replacing the original timber), recent additions in reinforced/prestressed (in slabs) concrete, roofing and other secondary structures in steel or timber, pavements in cement mortars and ceramic tiles, roofing covering in ceramic tiles or metallic or asbestos-cement corrugated sheets and metallic railings.

In terms of pathologies found

- Notwithstanding the fact that these arenas are in average one century-old and there has been virtually no maintenance in at least the last few decades, the structural condition of most of them is acceptable, and in only two cases was it necessary to restrict temporarily their use;

- the most serious problems involved the over-deformation of walls (because of foundation rotation and excessive loading), critical cracking of arches and vaults (because of settlements but mostly to water infiltrations from the benches) and a serious case of scaling of structural schist;
- in terms of durability, structural materials were found to be either very durable (brick and stone masonry), not so durable (concrete, mostly because of the reinforcement within) or degradable (steel and other metals, timber and mortars); however, with proper maintenance, the performance of all these materials, even the ones from the last group, would have been totally satisfactory;
- water-related problems, namely those caused by inefficiency/non-existence of the waterproofing and drainage systems, practically monopolised the durability and non-structural pathologies.

In terms of rehabilitation recommendations

- For structures this old, it is remarkable the fact that so little strengthening was unequivocally proved to be needed; however, in most cases (for example where arches or vaults exhibited cracking that could lead to mechanisms) it was deemed necessary to monitor the behaviour of the structures before the strengthening option is abandoned;
- before any but the most urgent structural rehabilitation is performed, it is necessary to solve the waterproofing and drainage problem of the benches and roofing, which may prove to be technically difficult given the ancient solutions still in use;
- most of the remaining rehabilitation concerns the treatment of structural or non-structural cracking and the external coatings, by resorting to conventional techniques.

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