"El Araceli" Non-destructive Test from the "Misterio de Elche" Play

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Abstract. In the city of Elche, every year, on August 14 and 15, it is celebrated a sacred musical drama of the death, the passage into heaven (known as the Assumption) and the crowning of the Virgin Mary. This event, known as "Misterio de Elche" play is unique in Europe. Since the mid-fifteenth century it has been performed in the Basilica of Saint Mary and in the streets of the old city of Elche, situated in the region of Valencia. The stage has two levels: the horizontal "terrestrial" stage and the vertical "celestial" stage, characteristic of the medieval mystery play. Ancient aerial machinery is used to enhance the spectacle by means of special effects. From the upper level, several aerial devices are raised and lowered in a controlled manner. These devices are called "La Mangrana", "El Araceli" and "La Santísima Trinidad". To give context to the reader, it is important to highlight that "El Araceli" is a device prepared to support five people situated in a special layout. The original supporting structure of this apparatus was made up of forged steel, wood and hemp ropes, but with the passage of time, some successive renovations were required. In 2010, wear was detected in some parts by the technical department that could cause security problems. Due to this circumstance, it was ordered a deep study. This paper analyzes a non-destructive test that was carried out on "El Araceli". A data acquisition system customized to the device was used to verify that the apparatus was suitable for the loads for which it was designed.

Keywords: Non-destructive · "El Araceli" · "Misterio de Elche" · Heritage

1 Introduction

In the town of Elche, during the 14th and 15th August, and without significant interruption since the last third of the XVth century, festivities are held in honour of its patron saint, the Virgin of the Assumption. The representation of the final days, death, assumption into heaven and coronation of the Virgin Mary, is the highlight of the performance that takes place inside the temple of the Basilica of Saint Mary [1–4].

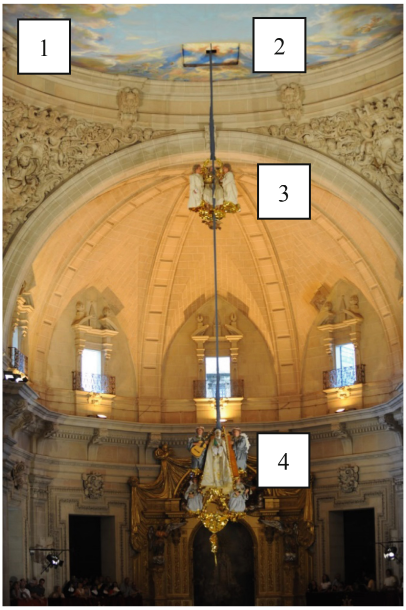
This theatrical work has outlived others of its kind that were celebrated in the Christian world centuries ago, despite the clauses established by the Council of Trent that banned them inside temples. It was protected by a papal decree granted in 1632 by Pope Urban VII [5]. This act has remained unchanged for five centuries and has only been

M. Ceccarelli and R. López-García (Eds.): HMM 2022, HMMS 40, pp. 160–172, 2022.
https://doi.org/10.1007/978-3-030-98499-1_14

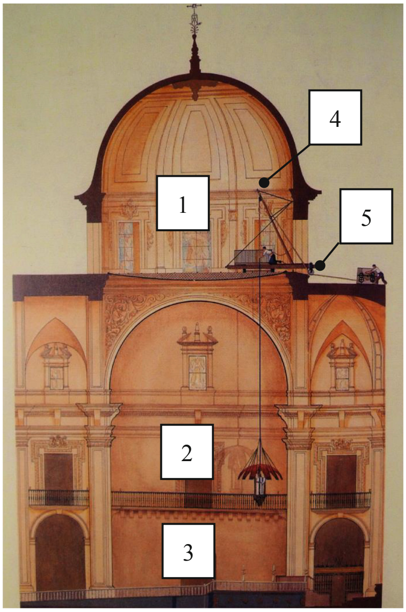
interrupted by cases of force majeure, such as wars or epidemics like the one we are currently experiencing.

In this work, unique in the world and a UNESCO World Heritage Site, the inside of the temple is transformed into a huge stage. Its aerial rigging system is equipped with a double hoist that allows the aerial artefacts to be lowered and raised to a height of 27 m.

Figure 1 (a) shows 2 of the artefacts suspended by the same rope. Traditionally, a maximum weight of 6000 N has been allowed [6].



(a) Snapshot of the performance with 2 devices in the air. Canvas in sky (1), the doors (2), "The Coronation" (3) and "El Araceli" (4)



(b) Longitudinal section of the temple with the arrangement of the main parts of the aerial rigging. (1) High rigging, (2) "La Mangrana", (3) Lower rigging, (4) Hoist, (5) Terrace

Fig. 1. Site of the performance. The Basilica of Saint Mary.

The lifting machines installed have undergone modification over time. The last modification, carried out in 1760, was undertaken by the architect, Marcos Evangelio, and, except for maintenance operations, these devices remain in their original state. Despite their "primitive" technology, these machines achieve a high degree of precision and efficiency.

1.1 The Aerial Rigging

Figure 1 (b) shows the set, which is made up of two different parts: one at ground level, known as the lower rigging, and another aerial rig, known as the upper rigging or sky in the dome. The upper devices are operated with the help of a hoist that facilitates the lowering and raising of the apparatus. The 3 main aerial artefacts involved in the performance are called: “La Mangrana”, “El Araceli” and “La Santísima Trinidad” [7–12].

1.2 Manoeuvres in the Upper Rigging

The aerial stage, shown in the upper part of Fig. 1(a), is formed by a large circular canvas that covers the base of the dome. This canvas is decorated with paintings depicting the sky with musical angels. Slightly offset from the circular perimeter of the dome and aligned with the longitudinal axis of the temple, there is a square opening covered with two sliding doors, which open to allow the passage of the aerial apparatus.

Figure 1 (b) shows the general operation, where the rope starts from a reel and, by means of a series of pulleys, changes its trajectory until the rope is in a vertical position. The apparatus is attached under the upper pulley and on the platform. In this position, the actors are given access and exit to the aerial artefacts. At the moment that the apparatus enters the scene, the doors of sky open and allow it to be lowered down. The winch unwinds or collects the rope from its reel and the apparatus is lowered or raised [13].

2 “El Araceli”

The structure of “El Araceli”–shown in Fig. 3 – is the aerial apparatus where two of the most important scenes of “la Festa” take place. On the one hand, the assumption of Mary into the sky and, on the other hand, “La Coronación” (The Coronation) by “La Santísima Trinidad” (The Holy Trinity) [6, 7, 13].

Figure 2 shows the artefact in operation in 2 of its interventions during the performance. The lateral ends are occupied by angels carrying stringed instruments, who remain kneeling, throughout their intervention, on ledges arranged in each house. The two lower positions are occupied by two children who pretend to play a guitar without strings. The two upper positions are occupied by two adults. The central location may be represented by the High Angel, played by a priest, or the Virgin of the Assumption, depending on the act of the play.

2.1 Structure of “El Araceli”

The whole structure consists of a frame that is roughly symmetrical in its vertical axis, built with rectangular steel profiles, as shown in Fig. 3. These profiles are shaped in the form of a parabola and made up of sections of two superimposed profiles: two forming an arch and two more for each of the branches. The ends of the branches are joined by a crossbar (lower part).

At its upper vertex, it has an eyebolt, which can be seen at mark 1 of Fig. 3, for coupling the apparatus to the rest of the system. This ring is attached to the outer arc of the parabola by means of a single rivet. The apparatus has a second reinforcement, parallel to the crossbar that closes three quarters of the vertex, where the central platform (mark 6, Fig. 3) rests. From the central ledge and downwards, two struts (mark 8, Fig. 3) extend, and upwards, four columns which, fastened together with two parabolic arches, form the harness of the central ledge.

(a) "El Araceli" with the High Angel. Descent (b) "El Araceli" with the High Angel. Ascent (c) "El Araceli". The Assumption of Mary (d) "El Araceli". "The Coronation"

Fig. 2. "El Araceli" in its two interventions during the performance.

The exterior of the frame has four side ledges: two lower ones, where the whole structure is closed, and two located at mid-height. Each exterior platform has an articulated bar which, together with a leather belt, as a preventive element to tie the occupant of the ledge to the frame. Each support is reinforced at the bottom with a strut (Fig. 3).

As for the main dimensions of "El Araceli", it is 2475 mm high, 1510 mm long and 600 mm wide. The free space of the lower side platforms limits the height of the actors to 1.170 m and is therefore intended for use by children. The central and upper side ledges situated at mid-height are intended for use by adult actors as they are not limited by their upper part.

Its unladen mass is 130 kg and its maximum theoretical load weight assigned on stage is 6000 N. It should be noted that its maximum weight in service is currently 4550 N.

2.2 Restoration of "El Araceli" in 2010

In July 2010, and during the assembly of the high rigging, certain problems were detected in "El Araceli". In the lower part of the gospel's side, signs of decomposition were observed. On the terrace of the temple itself, the action required was taken to guarantee its correct operation in safe conditions for the tests planned. After the analysis, the notch-tenon-wedge joints were perfected. Figure 5 (a) shows the previous design of the wedges that hold the tenons. Figure 5 (b) shows the redesign made, which consisted of opening the wedge at its end, which ensured that it was attached in the right position.

After the site tests were completed, the event organisers commissioned a major review. The apparatus was transferred to a suitably equipped workshop, where photographs, detailed sketches, functionalities of its parts, etc., were recorded in order to study it in detail.

From this situation, the need to perform a series of tests arose, which gave rise to the study presented here.

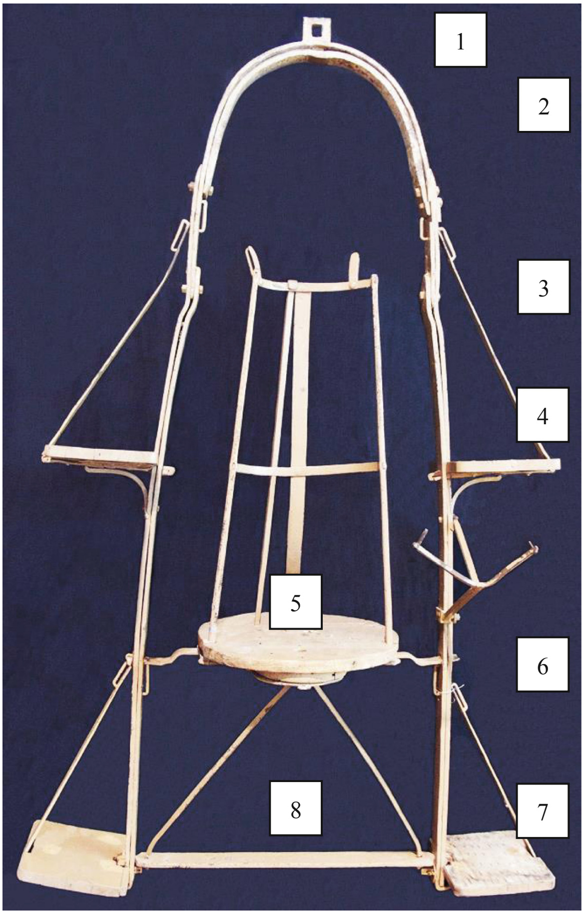


Fig. 3. Structure of the main elements. (1) Eyebolt, (2) Parabolic arches, (3) Branch, (4) Upper side ledge, (5) Central ledge, (6) Crossbar, (7) Lower side ledge, (8) Lower struts.

(a) Front view

(b) Rear view

Fig. 4. Close-up of the eyebolt fastening rivet located at the upper vertex

(a) Traditional wedge (b) Redesigned wedge

Fig. 5. Notch/tenon/wedge fastening system belonging to the device's locking crossbar.

3 "El Araceli" Test

These days, any machine or mechanism is subject to compliance with strict regulation in terms of safety, use and periodic maintenance. These regulations are even stricter in the case of apparatus for lifting persons, which are designed with redundant safety systems and with significantly high design safety coefficients.

To put this in context for the reader, we believe it necessary to mention that the elements that form part of the "Misterio de Elche" are exempt from the application of current regulations [14, 15], due to the fact that it is a device for transporting actors during artistic performances and because it is an artefact made up of parts that are more than 550 years old. The conservation of these elements was one of the values that led to "la Festa" being proclaimed a World Heritage Asset by UNESCO.

Historically, the inspection protocol for machines and apparatus used in the performance of this type of event was limited to a visual inspection [16]. In 2010, the possibility of performing non-destructive tests on the most critical elements that could affect the safety of people, was raised. Information is available on non-destructive or semi-destructive heritage assets [17, 18]. Most of the structures studied are made of wood although not much information exists about structures similar to those analysed in this paper.

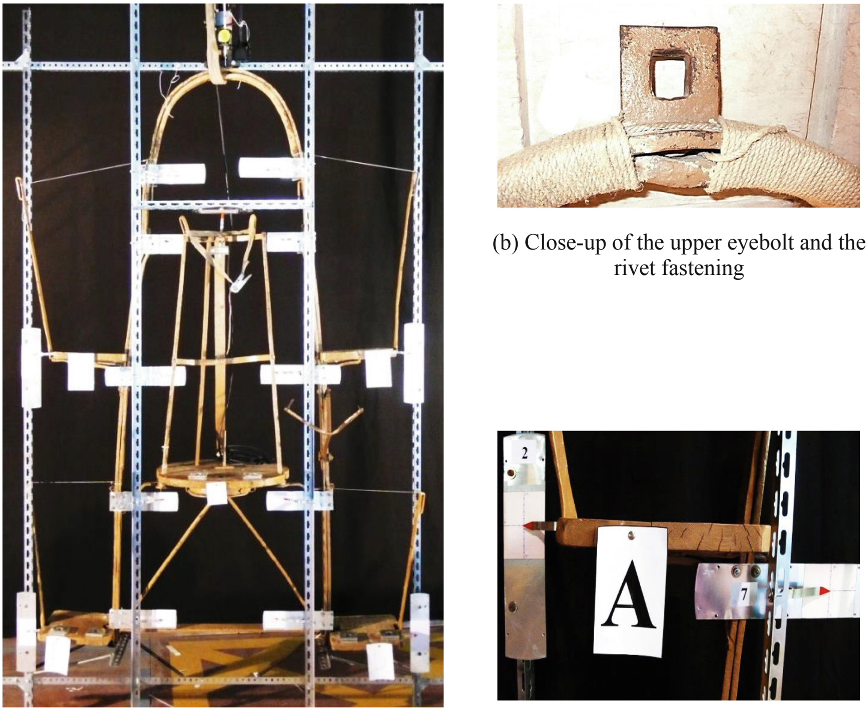
3.1 Justification of the Test and Types of Load Applied

Although the current regulations on types of apparatus do not apply, the "Misterio de Elche" technical team studied the possibility of performing a non-destructive test. It was decided that it should be of the non-destructive type and its main objective was the integrity of the device and people. This course of action was well received by the trustee, who is responsible for its proper conservation.

It was determined that it would be advisable to subject the mechanism to a non-destructive, loading the apparatus to roughly 1.5 times the maximum load mass allowed.

The test was performed in conditions similar to real life. Figure 6 shows the apparatus attached to a frame by the upper eyebolt. This was fitted with analogue dials, on which deformations in the x and y axes, according to the load conditions, were recorded. As a safety measure, the support point was secured with a brace in the event of a hypothetical failure of the eyebolt rivet, as shown in Fig. 7.

The test performed was of the static traction type [19]. On the one hand, the apparatus was pulled by its own weight and the loads superimposed. On the other hand, it could be assumed to be static since the operating speed of the apparatus is roughly 0.35 m/min, a speed which, for the purposes of the test, was deemed not to be significant. Traditionally, this speed was used to eliminate possible adverse effects of uncontrolled inertia. It is worth mentioning that this particularity also exempts it from regulations relating to lifting apparatus [16].



(a) Structure of "El Araceli" and reference frame

(b) Close-up of the upper eyebolt and the rivet fastening

(c) Close-up of the analogue dial

Fig. 6. Notch-tenon-wedge fastening system belonging to the device's locking crossbar.

Regarding the load for the test, it should be noted that the device was originally designed with 5 places: for two children and three adults, but no weight limit either in total or per actor had been established. It was only recommended that a certain symmetry in weight and volume be maintained to ensure the balance and aesthetics of the staging. Thanks to data from previous experiences, the maximum masses of the actors were set: 42 kg for a child and 80 kg for an adult. Taking into account the proposed safety coefficient (1.5), the total value of the load on the device should not be less than 4770 N.

To carry out the test, concrete parallelepipeds or load units (hereinafter referred to as l.u.). These parts fitted into the dimensions of the ledges and had a unit weight of 162 N. The weight of the l.u. was quite illustrative as 3 l.u. added up to 486 N (slightly more than the weight of a child) and 5 l.u. added 810 N (roughly the weight of an adult). From these data, it can be deduced that, in order to ensure the load conditions expected, the ledges reserved for the children had to be loaded to 4 l.u. and those for the adults to 8 l.u. All this is shown in Table 1.

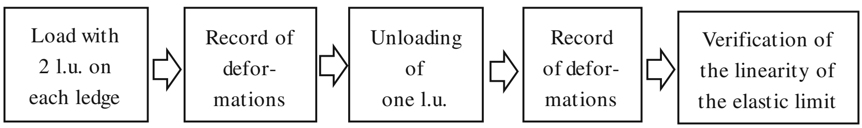
At the top of the apparatus, the upper eyebolt was fitted with a touch probe with a scale division of 0.01 mm and a dynamometer to record the load exerted.

Table 1. Test loads and load units.

Position	Maximum nominal mass	Maximum nominal weight	Equivalent load units	Minimum test load (× 1.5)	Load units	Load on apparatus
Type of load	(kg)	(N)	(l.u.)	(N)	(l.u.)	(N)
Central figure	80	785	5	1178	8	1296
Adult left	80	785	5	1178	8	1296
Adult right	80	785	5	1178	8	1296
Child left	42	412	3	618	4	648
Child right	42	412	3	618	4	648
Total	324	3179	21	4770	32	5184

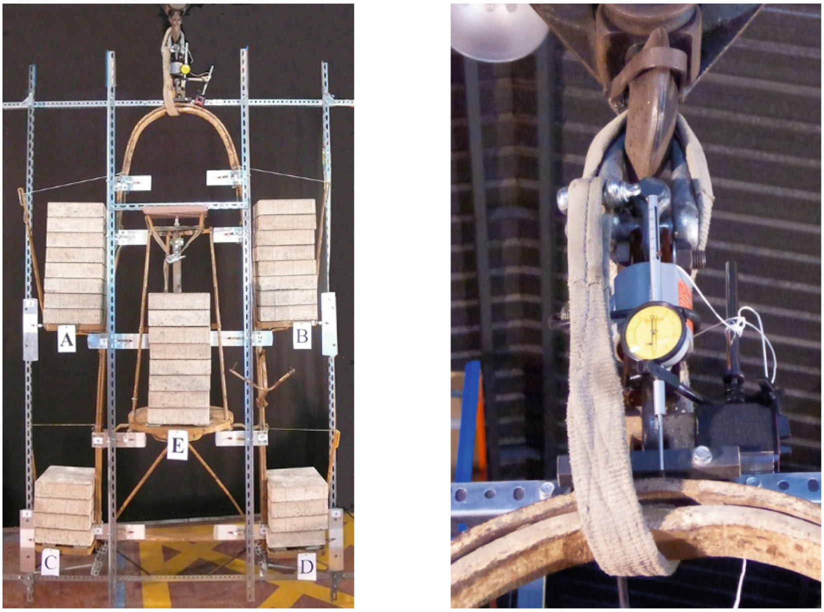
3.2 Test Procedure and Measurement on Control Points

The test was conducted rigorously in order to ensure the integrity of the apparatus. A loading system was devised so that the test could be stopped as soon as permanent deformation was detected. "El Araceli" was loaded progressively according to the following diagram:



Before loading the apparatus, the dials on the control points of interest were set to zero. These dials had a scale division of 0.5 mm.

The acquisition of the data of greatest interest, due to the apparent deformation, were the ends of the upper and lower side ledges and the central seat, points 1, 2, 3, 4 and 11. Other unremarkable displacements were also recorded in the recesses of the side ledges and around the arch and branches. The deformation in the fastening rivet of the upper eyebolt was obtained by means of a touch probe with a scale division of 0.01 mm as shown in Fig. 7.



(a) Apparatus subjected to maximum test load

(b) Close-up of the eyebolt fastening, touch probe and safety system

Fig. 7. Notch/tenon/wedge fastening system belonging to the device's locking crossbar.

4 Results

Table 2 shows the displacements of the points of greatest interest as a function of the load conditions applied. Once the maximum load has been reached, according to the procedure detailed in the previous point, the apparatus was unloaded in reverse order until it was no longer under load.

The fastening rivet of the eyebolt that supports "El Araceli", reached an acceptable safety coefficient of $Cs = 1.45$. The touch probe fitted to the eyebolt recorded a deformation of barely 0.02 mm at maximum load, returning to zero when the apparatus was unloaded. We concluded that it did not make sense to load the apparatus further to verify a higher safety coefficient for the rivet. Loading the apparatus further could lead to the deterioration of other parts. To ensure the resistance at this point, the apparatus was reinforced with bolted braces by way of a bracket and re-secured with four 10 mm lengths of hemp rope tied to the arches of the parabola, bridging the eyebolt. All this is shown in Fig. 6 (b).

In Table 2, it is worth noting the last row, which shows the value of the residual displacements when the apparatus was unloaded. The value (0.0) in all the records indicates that there was no permanent deformation and, in no case, was the elastic limit exceeded.

Table 2. Test loads and displacements at points of interest.

	Total Weight Increase	*Point 1. C*			*Point 2. A*			*Point 3. B*		
Order	*(N)*	*q1*	*x*	*y*	*q2*	*x*	*y*	*q3*	*x*	*y*
0	0	0	0	0	0	0	0	0	0	0
1	810	16.2	0	-1	16.2	0	-1	16.2	0	0.4
2	1620	32.4	0	-2	32.4	0	-2	32.4	1	-7
3	2430	48.6	0	-4	48.6	0	-4.5	48.6	1	-10
4	2916	48.6	0	-3.5	64.8	0	-6.5	64.8	1	-12
5	3402	48.6	0	-4	81	0	-8	81	1	-15
6	3888	48.6	-1	-4	97.2	0	-10	97.2	1	-16
7	4692	64.8	-1	-5	113.4	0	-11	113.4	1.5	-18
8	5178	64.8	-1.5	-6.5	129.6	0	-12	129.6	1.5	-18
0	0	0	0	0	0	0	0	0	0	0

	Total Weight Increase	*Point 4. D*			*Point 11. E*		
Order	*(N)*	*q4*	*x*	*y*	*q5*	*x*	*y*
0	0	0	0	0	0	0	0
1	810	16.2	0	-1	16.2	0	0
2	1620	32.4	0	-2	32.4	0.5	0
3	2430	48.6	1	-3	48.6	0.5	0
4	2916	48.6	1	-3.5	64.8	1	0
5	3402	48.6	1	-4	81	1	-1
6	3888	48.6	1	-4	97.2	1	-4
7	4692	64.8	1	-4	113.4	1	-4
8	5178	64.8	2	-4	129.6	1	-4
0	0	0	0	0	0	0	0

The graphical results of the displacements as a function of the load applied, experienced by the side ends of points 1, 2, 3, 4 and 11 corresponding to the ledges A, B, C, D and E, are shown below.

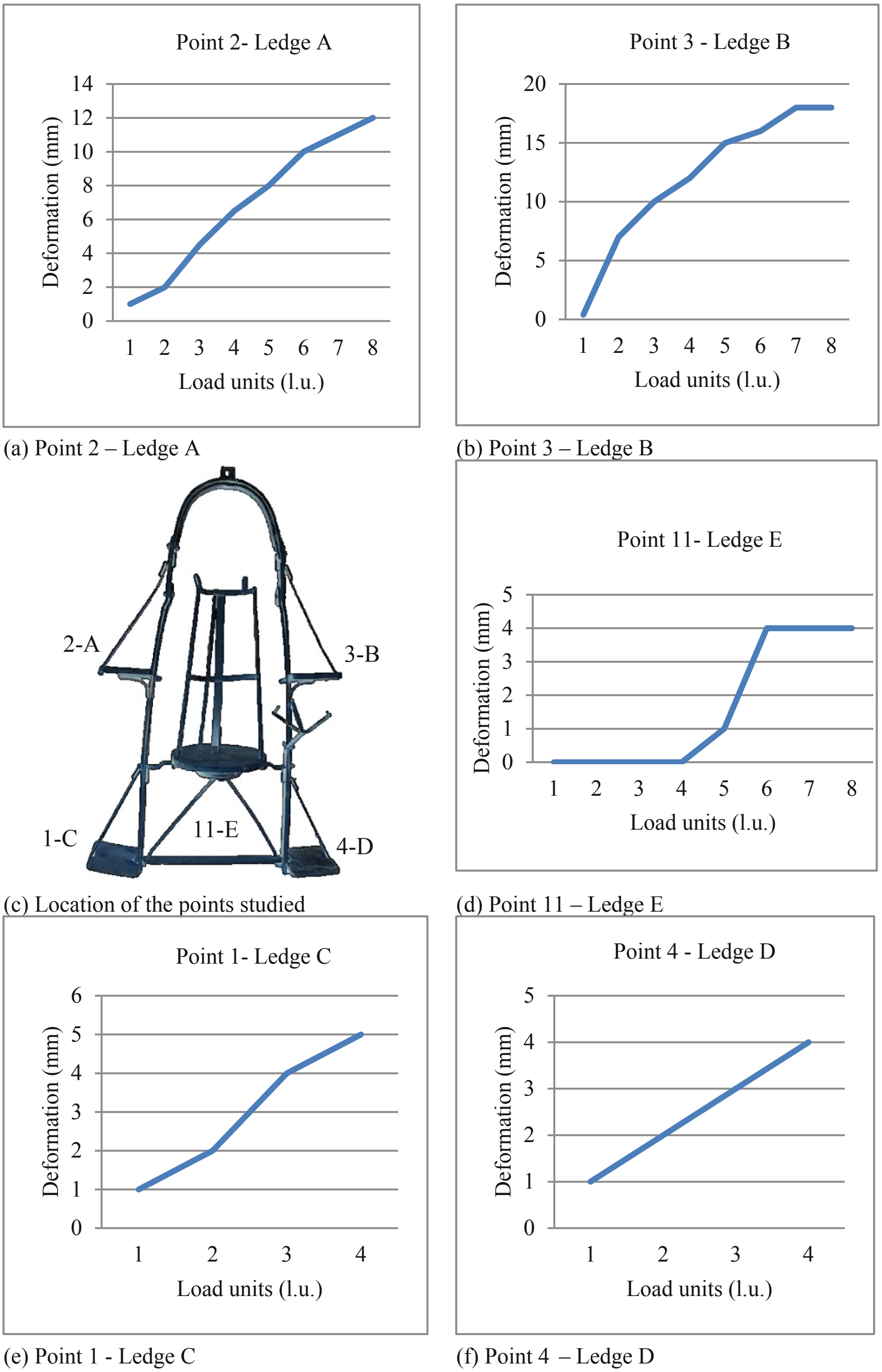


Fig. 8. Deformation/Load graphs at points 1, 2, 3, 4 and 11

As can be seen in Fig. 8, points 2, 3 and 11, intended for one adult, were loaded with 8 l.u.'s or 1296 N. The minimum safety coefficient obtained was 1.62. The weight of an adult has been assessed to be 800 N according to the Occupational Risk Prevention Act.

Points 1 and 4 shows the behaviour of the structure intended for children. These platforms were loaded with 4 load units, corresponding to 648 N. Compared to the nominal weight requirement for a singing child, 421 N, a safety coefficient of 1.57 was obtained.

5 Conclusions

It is important to note that the apparatus that is the object of this study includes parts from the XVth century. The greatness of "la Festa" is recognised for the conservation and maintenance of its elements, including the music, staging, rigging system, and artefacts.

Until 2010, the inspection of the apparatus before use was based on a visual examination. During 550 years of use, no accidents worth mentioning have been recorded. Such antiquity makes the apparatus used non-destructive relics today.

From an engineering perspective, a replica of "El Araceli" could be reproduced with better mechanical characteristics. The organisers of the Mystery of Elche deem keeping the artistic legacy alive to be very worthwhile, and therefore insist on the use and maintenance of the traditional artefacts.

Once the test results were analysed, it is concluded that:

The apparatus demonstrates sufficient rigidity and elasticity to guarantee its continued use under traditional test conditions and suitable safety conditions for people have been established.

The minimum safety coefficient achieved is 1.57, which is deemed to be a sufficient guarantee.

The eyebolt from which the apparatus is suspended was tested until a safety coefficient of 1.42 was obtained. This point was reinforced with bolted braces by way of a bracket and completed with four 10 mm lengths of hemp rope tied to the arches of the parabola. All this ensures improved mechanical resistance. The detail is shown in Fig. 6 (b).

Lower value load units could have been used to obtain better graphic resolution and to enable behaviours not picked up in this study to be appreciated. This aspect will be taken into account in future analyses.

6 Future Work

The future lines of research proposed by this study group are:

To analyse, study and improve the mechanical system for the assembly of the aerial rigging stage [20]. 5 prototypes of this system have been made, and the most suitable solution is being sought.

To study the possible restoration of the metallic parts not subject to stress by applying filler for formal reintegration.

Given the antiquity of the metallic parts that form the structure of "El Araceli", it would be interesting to characterise the steel used for future renovations.

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