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HAMMAM AL-SARAH AN APPLIED STUDY

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This study aims to rehabilitate Hammam al-Sarah, a unique bath complex located in the northeast of Jordan, built in the first half of the eighth-century. The importance of this article stems from the fact that all studies conducted so far were limited to the description of the monument ignoring the intrinsic value of its restoration.
In this research, the authors visited the monument to investigate the constructional techniques and materials used in the building. The study team explored the procedures to restore the building and present it to the visitors. To that end, stone and mortar samples were analyzed in order to preserve the monument and its cultural values. The analyses used in this study provide guidelines for the conservation of this neglected monument. Results show that it is extremely important to use materials, i.e., stones and mortar similar to those used in the original building.

KEYWORDS: *Mortar, Stone, arches, cupola, Pendentives.*

INTRODUCTION

Hammam Al-Sarah is considered one of the important monuments, built in Bilad Al Sham (Great Syria) during the early Islamic era; it brings out most of the Islamic building features used in that period.

Most of architectural information about this building was provided by Butler and Creswell in the first half of twentieth century [1]. Unfortunately this information was not taken into consideration when the Department of Antiquities of Jordan carried out limited clearance and restoration work in the 1970's. This work was done in an artisanal manner without proper documentation and supervision. Furthermore, concrete cement was used extensively thus jeopardizing the long-term durability of the building.

This article sheds light on the constructional techniques, architectural forms, and materials used in the original building. It provides a brief description of the current state of preservation of the monument. It also provides few recommendations for future restoration works. The study consists of two parts; the first describes the various constituent element of the monument, while the second part deals with the analyses of the stone and mortar used in the original building.

LOCATION AND HISTORY

Hammam al-Sarah is located (55) km to the northeast of the capital city Amman and about (2) km to the southeast of Qasr al-Hallabat, a Roman fort completely rebuilt in the Umayyad period (661-750) and provided with elaborate decorations in mosaic, carved stucco and fresco painting [2]. Identification of this monument was made possible by the Princeton Archaeological expedition to Syria headed by H.C. Butler who visited the site in the winter of 1905, drew plan and sections with adequate photographs [3].

Butler attributed the bath to the caliphate of al-Walid bin Abed al-Malik (705-715) on analogy with the bath complex of Qusayr Amra [4] the little palace of Amra) shown in **(Fig: 1)**.

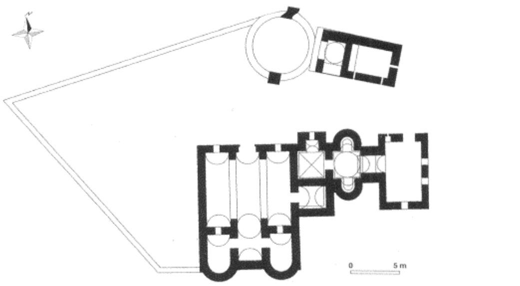

Fig (1): Qusayr 'Amra after (Almagaro, 1975, 4)

Which was then thought to belong to the same caliph. The plan, roofing system and constructional techniques were so similar that both must belong to same period, thought Butler. In 1926 K.A.C Creswell visited Hammam al-Sarah and noted it's similarity to Qusayr Amra; he also noted that the arches in the former building were more perceptibly pointed than those in the latter and concluded that al-Sarah was slightly later in date belonging to the years between (725-30) [5].

Until Butler and Creswell 's visits Hammam al-Sarah was still in a fairly good state of preservation; since then, however, especially in the early 1950's the building was subjected to a systematic pilfering for its stone which left only the rubble cores of exposed walls standing. In the 1970's the Department of Antiquities of Jordan carried out clearance and partial restoration works; the latter was done in an artisenal manner without proper technical supervision. These restorations included the reconstruction of the spherical cupola above the hot chamber (Calidarium) and the facade of the tunnel-vault of the passage, which overlies the furnace [6].

DESCRIPTION OF THE BUILDING

The plan of Hammam al-Sarah shown in **(Fig: 2)** consists of three principal elements: A) The audience – hall. B) The bath proper. C) The hydraulic structures.

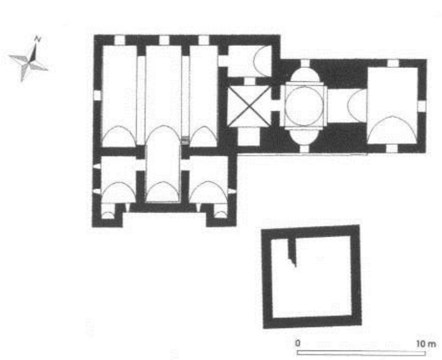

Fig (2): Hammam al- Sarah, after (Bisheh, 2000, 127)

The building was entered through a door 2.08 m wide opened in the center of the south wall of the audience-hall .The blocks which made the door –jambs are still laying on the ground as they had fallen. These blocks which gave a height of about 2.00 m to the entrance-door were regularly dressed and carved with altar-like motifs .The entrance was spanned by a single monolithic lintel 2.23 m long, which was found broken into three pieces. This lintel is carved with a *tabula ansata* and two knotted wreaths.

The audience-hall was roofed with three tunnel-vaults resting on the side walls and two intermediate transverse arches which sprang from low engaged piers 0.95 m high topped by quarter-round stone brackets. The central longitudinal axis and the sides nearest the walls (between the engaged piers) were paved with long marble slabs .The rest of the floor was paved with hard square tiles .The northeastern corner of the audience-hall was occupied by a fountain pool originally lined with marble as indicated by the numerous fragments still preserved in situ .At the back of the central aisle of the audience-hall is an alcove (the throne alcove) which was originally paved with marble slabs as the impressions on the mortar bedding indicate .Two doorways (each 0.92 m wide) on the right and left sides of the alcove opened into lateral rooms of the same depth as the alcove .The two rooms were paved with colored mosaics small portions of which were preserved .In the right (south) room the preserved section shows intersecting diagonal rows of dark brown tesserae forming indented squares, each enclosing a diamond pattern .At the back of the side rooms ,in the outer corners, are two small rectangular recesses which form salients on the east wall. These recesses, whose floors are 0.20 m, above the mosaic pavement served as latrines [7].

A door (1.63 x 0.80 m) in the northwestern corner of the audience-hall leads into the tunnel-vaulted undressing (Apodyterium) chamber; against the eastern wall of this chamber is a plastered bench 2.45 m long, 0.80 m wide, and 0.40 m high. A large section of the roofing vault had collapsed, but the preserved section still retains its plastered surface with faint traces of paint. The vault was built of longitudinal courses of thin **(plat: 1)**, wedge-shaped voussoirs of roughly hewn limestones, and on the outside it was covered with water- proof cement.

In the center of the eastern wall opens a door (1.70m. high and 0.87 m. wide), which leads into the cross-vaulted warm chamber (Tepidarium) **(plat: 2)**.
On the far side of the room, opposite the entrance, is a nearly square recess (1.55 x 1.50 m) covered by a tunnel-vault; at its floor level opens a hole to drain the water out into a crudely built channel. In the upper part of the south wall, at a height of 2.4 5m from the original floor, there are three vertical grooves which extend through the roof to the outside; these grooves were intended to receive pottery pipes which served as chimney-flues. At each corner of the room was a square-sectioned clay pipe which did not extend to the roof but stopped at the point where the upper parts of the sidewalls overhung. These corner pipes were obviously intended to heat the walls. The cross-vault was built of thin, wedge-shaped voussoirs and covered by water-proof cement.

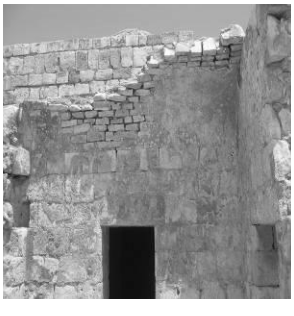

Plate (1) Apodyterium

Plate (2) Cross-vaulted at Tepidarium

The floor of the tepidarium had long since caved in. It was carried on 25 columns built of circular bricks (0.22m. in diameter) which rested on square tile plinths, 0.30m. to the side **(plate: 3)**.

The columns were arranged in five rows, and above each column was placed two square tiles; two additional tiles were placed in a slanted position along the side edges of each column so as to form a sort of gable between each pair of columns. The space between the columns was bridged by large tiles over which a thin layer of mortar was laid. The floor of the room was 0.50m. higher than that of the square recess. It is likely, therefore, that the recess was fitted out as a bath tub in which bathers could splashthemselves with water.

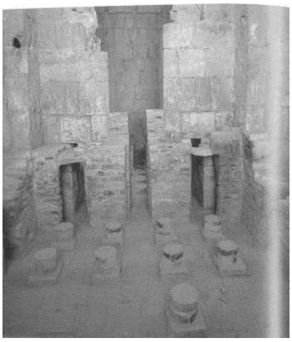

Plate (3) Calidarium the hypocaust after (Bisheh, 2000, p.128)

A door in the center of the east walls leads into the hot-chamber (Calidarium), a square room measuring 3.70m. to the side. To the left and right are two semi-circular recesses topped by semi-domes constructed with voussoirs which radiate from a saddle-like block placed above the summit of the window arch [8]. The walls of the recesses are pitted with small holes to allow for attaching a marble facing. The Calidarium was roofed by a dome resting on spherical-triangular pendentives of four courses of stone **(plat: 4)**.

The dome has long since collapsed, but originally it was built with 19 projecting ribs composed of long, thin, wedge-shaped pieces of shale. The dome was pierced by small circular windows some of which had already become large holes when Creswell visited the building in 1926[9].

Plate (4) Calidarium the dome

On the north side of the calidarium is a tunnel-vaulted passage (3.15 x 2.60 m) and at the far end of the passage is the stoke-hole. The vaulted passage opened onto unroofed walled enclosure which served as the service and storage area for the fuel .It was left open to allow the wind to blow and induce the hot air into circulating to the hot and warm chambers.

To the east of the bath proper are the hydraulic structures, which consist of three main elements:

1) A raised square water tank measuring internally 4.30m. to the side.
2) A well about 24.00m. deep and 5.00m. in diameter constructed of coursed masonry.
3) A rounded structure built of roughly shaped stones and rubble .It served as the space where the beast of burden walked round to drive the water pumping mechanism (sãqiyah) and to lift water from the well into the tank.

MATERIALS AND METHODS

In 2006, the authors visited Hammam al-Sarah, which is located the northeast of the capital city Amman in Jordan. They found that the main problem in the building was in the restoration work, which was done on the dome and the arch in the Calidarium by the Department of Antiquities of Jordan in the 1970's, due to using modern materials such as concrete cement extensively. This caused jeopardizing the long-term durability of the building. The authors investigated the building and summarized the damages of the building in the following observations:

1- Ceiling collapsed; Walls are preserved to few courses. In the apodyterium only a small section of the tunnel-vaulted roof is preserved.
2- Lime stones were in a deteriorating state, specially the lower courses on which salts are accumulating on their surface; the accumulation of soils on surfaces of building stones helped in the transformation of their color from white to yellowish – brown.
3- Some cracks occurred in different standing walls of the building such as the northern wall of the Audience- hall and the eastern wall of the tepidarium.
4- The disappearance of many circular bricks, which were carrying the floors of the calidarium and tepidarium.
5- Disappearance of all floors of the complex, except for the small parts, which are still present in the corners of the calidarium and tepidarium.
6- In the course of reconstruction the dome of the calidarium acquired a weird conical shape instead of being spherical.

To rehabilitate the building, the authors took samples of plaster and stones of the building materials, and test them in the laboratory. Structural analyses were performed to make sure that the rehabilitation is feasible.

RESULTS AND DISCUSSION

Studying the constructional materials

All the test samples, which were taken from the site, were tested in the labs in Summer 2006. The tests were conducted according to the ASTM specifications [10].

Plaster

Two samples of plaster were taken for purposes of testing and analysis. The first sample was taken from above the floor level of the northern corner of the Calidarium, while the second sample was taken from the surface of the northern wall of the apodyterium from a height of 0.45 m. above the floor level.

By means of laboratory testing of plaster samples, it became clear that they were compressed of unslacked lime and Calcium Carbons mixed with hay remains which are clear to evident before the naked eye. It is well known that the use of those components is capable of giving positive attributes to the construction. They contribute to more adhesiveness to the built wall. Also, it gives the surface of walls and floors almost perfect smoothness and polish. Away from that, plaster is porn–to–crack material, which needs a long time to become dry due to the fact that it holds same permanent humidity within it.

Stones

Limestones, which are abundantly available in the region, were, used; four samples were taken from the stones used in the building for purposes of experiments testing. The first sample was taken from the second course of the tepidarium from a height of 0.60 meters above the floor. The second was taken from the first course of the external wall of the Audience hall, whereas, the third sample was taken from the third course of the apodyterium from a height of 0.95 m.

The fourth sample was taken from the floor of the Calidarium. The compressive strength absorption and the specific gravity of the four specimens were found according to the ASTM C170 and C97 and listed in
the Table below.

Table 1: Properties of building stones

Serial No.	Type of Stone	Apparent specific gravity (Gsa)	Bulk specific gravity (Gsb)	Absorption Abb%	Compression strength Kg/cm^2
1	1 2 3 4	2.54 2.53 2.46 2.54	2.2 2.26 2.03 2.16	6.3 4.8 9 7	356
2	1 2 3	2.6 2.6 2.6	2.3 2.2 2.2	5.2 7.6 6.7	270
3	1 2 3 4	2.6 2.61 2.6 2.62	1.86 1.85 1.86 1.86	15.1 15.2 15.1 15.3	210
4	1 2 3 4	2.6 2.8 2.6 2.6	2.2 2.4 2.4 2.2	6.1 6.3 6.0 6.3	450
					$\sigma_{average}$=321.5k/cm^2 =32.15MPa

2. STRUCTURAL ANALYSIS

All the arches in Hammam Al-Sarah are semi-circular arches with geometry showing in **(Fig: 3)**, the arch span (L) equals 2.64 m, while the rise, (F) equals 1.32 m. The arch width is 600 mm. Assuming the arch is subjected to uniformly distributed load (q) then the vertical reactions at support A and B (V_A and V_B) equals $ql/2$ while the horizontal reactions (thrust) at supports A and B (H_A and H_B) are given by $\left[{ql^2}/{8f} \right]$[11].

To study the stresses at any section Kforces, as well as the bending moment Shown in **Fig: 4**, the normal and shear forces, as well as the bending moment are found at section K.

The Arches

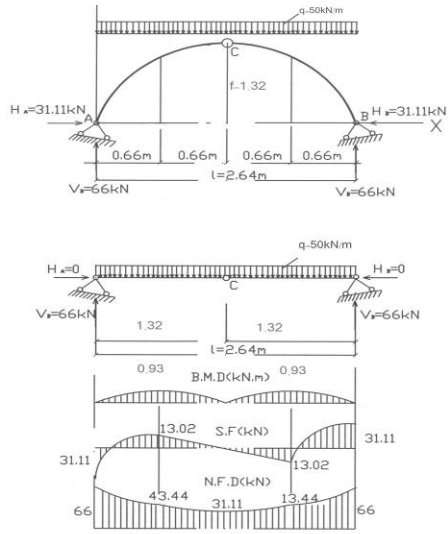

Fig. 3 Schematic diagram for a circular arch

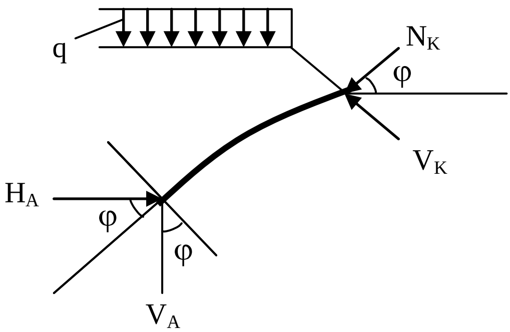

Fig. 4 Left hand section of the studied arch

The coordinate y corresponding to the abscissa x can be given by the following equation

$$y = \sqrt{R^2 - (R - \times)^2} \quad \text{.........} \quad (1)$$

The shear force at section K, V_K may be given by the following equation

$$V_K = V_A \cos\varphi - H_A \sin\varphi - q.(x).\cos\varphi \quad \ldots\ldots \quad (2)$$

Similarly, the normal forces acting at section K, N_K can be obtained from the following equation

$$N_K = H_A \cos\varphi + V_A \sin\varphi - q.(x).\text{Sin}\,\varphi \quad \ldots\ldots \quad (3)$$

Also, the bending moment at section K is given by

$$M_K = V_A, x - H_A.y \quad \ldots\ldots \quad (4)$$

The values of V_K, N_K and M_K are calculated at eight sections, with increment, ΔX = 0.33 m, the following table summarizes those values.

Table: 2 bending moment, normal and shear forces at different arch sections.

Segment number	X_k [m]	Y_k [m]	φ [degree]	V_k [KN]	N_k [KN]	M_k [KN.m]
1	0	0	90	66	-4.37	0.00
2	0.33	0.87	48.56	43.87	-27.74	-49.39
3	0.67	1.14	29.98	39.92	-23.55	-58.56
4	0.99	2.28	14.47	40.22	-58.32	-59.62
5	1.32	1.32	0.00	41	66	-54.15

The normal, shear and flexural stresses at the eight segments at points A, B and C (Fig. 5) are calculated and listed in the Table 3. Similarly, the maximum (major and minor) stresses are calculated using Mor's circle and listed in Table 3.

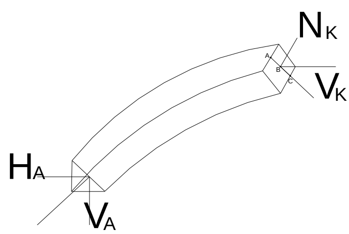

Fig. 5

Table: 3 Normal, shear and flexural stresses at section K

Stresses			Point A		Point B		Point C		Maximum and minimum at A		Maximum and minimum at B		Maximum and minimum at C	
Segment #	X_i [m]	σ axi [MPa]	σ [MPa]	τ [MPa]	σ [MPa]	τ [MPa]	σ [MPa]	τ [MPa]	σ_{min} [MPa]	σ_{max} [MPa]	σ_{min} [MPa]	σ_{max} [MPa]	σ_{min} [MPa]	σ_{max} [MPa]
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	0.024	0.024	0.00	0.036	0.549	-0.024	0.00	0.024	0.00	0.561	-0.537	-0.024	0.00
2	0.33	0.154	5.644	0.00	0.231	0.364	-5.336	0.00	5.644	0.00	5.667	-0.023	-5.336	0.00
3	0.67	0.131	6.641	0.00	0.196	0.333	-6.379	0.00	6.641	0.00	6.658	-0.0167	-6.379	0.00
4	0.99	0.324	6.944	0.00	0.486	0.336	-6.296	0.00	6.944	0.00	6.960	-0.016	-2.296	0.00
5	1.32	0.366	6.376	0.00	0.549	0.340	-5.644	0.00	6.376	0.00	6.394	-0.018	-5.644	0.00

Notes:

1. The points A, B and C are shown on the bellow Fig 5.
2. σ_{axi} : The axial normal stresses at the studied point= N_k/cross-sectional area.
3. $\sigma = \frac{N_K}{A} \mp \frac{M_k y}{I}$

Where : $I = \frac{bh^3}{12}$ and $y = \frac{h}{2} = \mathbf{150mm}$

It can be observed from the tabulated maximum compressive stresses (Column 9, 11 and 13) that all the stresses are less than the test values where that was found from experiment equal (σ =32.15) MPa.

Similarly the tensile stresses listed in Table 3 (columns 10, 12 and 14) are less than $0.1\sigma_{max}$ (where the tensile stresses can be represented by ten percent of the stone compressive strength).

CONCLUSIONS

This study made apparent that Hammam al-Sarah is in need of thorough restoration in order to present this historical site in a manner attractive and comprehensible to the visitor.

Conclusions can be summarized in the following points: First, rehabilitate and restore the parts of the monument like the dome and the spherical triangular pendentives on which the dome rested. It is recommended to rehabilitate the existing the badly restored dome. Shell structure is recommended using a thickness of 0.10 cm reinforced concrete. It should be covered, internally, with long, thin, wedge- shaped pieces of unhewn shale. This constructional technique could be easily applied in the restoration of the barrel-vaults in the audience-hall and the bath's chambers.

Secondly, to reduce the humidity effect and eliminate the remnants appearing on the surface of the vault it is recommended to cover the cross-sectional vault of the tepidarium with a layer of plaster capable of the existing vault in its original shape.

Thirdly, despite that the tests of stone samples showed that they have a good compressive and tensile strengths at this time which is found to be higher than the stresses calculated for the arch structure, there is a need to solve the problem associated with salts accumulation on the surfaces of some internal stones, especially in the lower courses of the building.

It is well-known that such a salt accumulation helps in the formation of cracks which is a natural result of the wind effect on exposed and un maintained buildings. Winds carrying sand pieces are of a mechanical damaging effect on walls.

The researchers recommend the following:

1- Removing salts from stone surfaces by means of batches, then, treat the surfaces with Wacker OH, which helps eliminate sucking water out.
2- Setting up pathways around the building and connecting it with the site's main street. The pathways should be lower than the level of the bath's floor in order to prevent water leakage to walls and floor.
3- In order to restore the damaged parts, there is a need to establishing a small workshop to perform stone cut and prepare then in the same style that used in preparing the original stones
4- Restoring the clay bath floors, by using the local mud clay in the preparation of tiles for the bath's floor.

Finally, people in charge of maintenance and restoration works should conduct experimental studies before pursuing their works. Expertise and capabilities of some academic institutions, where equipments and experiences are available, should be steered to in order to perform the required analyses and performances. All that leads to synergy of efforts and translation of means of cooperation in service of these unique historical sites.

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حمام الصرح : دراسة تطبيقية

تتناول هذه الدراسة حمام الصرح في الأردن من وجهة نظر تطبيقية، وتعتمد في منهجها الأسلوب العلمي في الوصف التحليلي، وأسلوب الدراسة الميدانية للعناصر المعمارية والمواد الإنشائية المستخدمة في البناء.

كما تبين الدراسة وضع البناء في الوقت الحالي، وتقدم التوصيات التي من شأنها أن تساعد في عمليات صيانة وترميم هذا الصرح الهام، وإعادة تأهيله كمنشأة تراثية سياحية في المنطقة والتي من أهمها ما يلي :

1- إعادة معالجة الأجزاء المرممة من البناء والتي حدثت فيها أخطاء واضحة أثناء عملية الترميم السابق كالقبة والمثلثات الركنية التي تحملها.

2- استخدام الطرق العلمية الصحيحة في ترميم وصيانة البناء.