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Original article

RESTORATION STRATEGY FOR DISMANTLE AND RECONSTRUCT STONE WALL RUIN AT DEDAN SITE, KING SAUD UNIVERSITY EXCAVATIONS, AL-'ULA, SAUDI ARABIA: A CASE STUDY

Saleh, M.
Conservation dept., Faculty of Archaeology, Cairo Univ., Cairo, Egypt

E-mail: *mohsensaleh_22@yahoo.com*

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Abstract
Different archaeological ruins (walls, floors, and architectural details) have been discovered at Dedan site "Al-Khraibeh" through king Saud University excavation in 2008. Most of these ruins suffer from deterioration factors. Leanings of Dedan walls have been observed toward the west direction, one of these walls was in critical case. Therefore the restoration process should be immediately carried out to save this archaeological wall from collapsing. Documentation, investigation, analysis and diagnosis were carried out in order to determine the wall condition and conservation strategy. To diagnose the current status of the leaning wall same examination and analysis methods were used, optical microscope (OM), polarized microscope (PM), scanning electron microscope (SEM) equipped with (EDS), x-ray diffraction (XRD), and soil classification. Deterioration aspects e.g. flaking, separation and fragmentation have been noticed,clay mortar was used to cement the stone blocks. Dedan soil was classified as silty clay soil (CL-ML). a correct diagnosis always depends on data and correct results, which is the first step of conservation strategy. This paper deal with the restoration and conservation methodology for dismantle and reconstruct the leaning stone wall.

Keywords: *Excavation, Diagnosis, Conservation Strategy, Dismantle and Reconstruct*

1. Introduction

Dedan is the ancient name of Al-'Ula oasis, situated in the northwest of the kingdom of Saudi Arabia 26º 39' Longitude, and 37º 54' latitude, fig. (1-a, b). The ruins at the site are concentrated 4 km north of the town of Al-'Ula, known by the natives as 'Al-Khurayba' ('ruin hillock'). Based on written and archaeological records, we can say that as of the beginning of the 1st millennium BC the town was obviously closely associated with the influential role of the kingdom of Dedan and its central role in the civilization and trade in northwest Arabia, and in other regions of the ancient Middle East. The substantial increase in power and influence exercised by the Lihyanite tribes, and their dominance over the region at the end of the 6th century BC, led to the decline of the historical and cultural role of the kingdom of Dedan as it submitted to the rule of the new Lihyanite rulers. The ruins at the archaeological site extend over a rectangular area with a length of 2 km and a width of 500 m. This area, in the center of which lies the ancient temple, was often subjected to destructive activities, for example by the old railway lines, crossing the site from the north to the south, or by the removal of stone from the site to build houses in the modern town of Al-'Ula [1,2]. The principal feature in the center of the Dedan ruins before beginning excavating was an enormous stone basin, with a diameter of 375 cm, a depth of 215 cm and a volume of around 6,000 gallons (24,000 L), hewn from the rock in one piece. Three steps hewn from a single stone block are located inside the basin to aid descent [3]. The precision of the basin curvature represents a geometrical masterpiece, in which symmetry and harmony melt into one. The basin probably served as a water basin for ritual cleansing ceremonies performed close to Dedan principal temple. The excavations in Dedan uncovered the walls and numerous details of the temple, which was dedicated to the deity DhuGhaiba ('The Absentee'), the predominant deity during Lihyanite rule in the kingdom of Lihyan. In addition to the religious rooms within the temple, which was built using the sandstones prevalent in the surrounding mountains. The archaeological excavations of the King Saud University at the Dedan site were discovered stone ruins such as: lentils, columns, stone pillars, and different materials of archaeological artifacts; stone, pottery, glass, wood and metal [4]. The Dedan site is subjecting to different destructive factors, such as: earthquakes, torrents, rain, wind, storms, human sabotage [5].

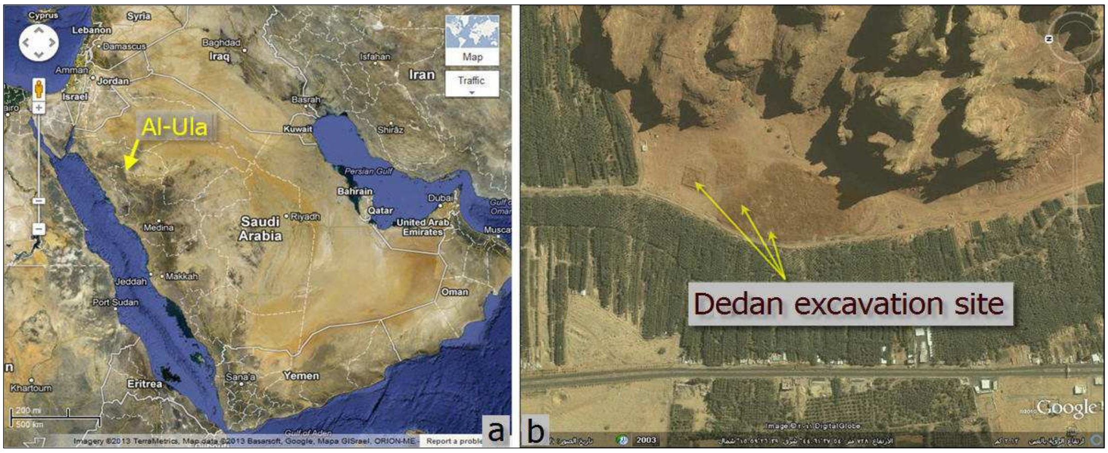

Figure (1) Shows **a**. the location of Al-'Ula, **b**. Dedan archaeological site, excavation area.

2. Materials and Methods

Dedan stone walls were investigated and analyzed with field observations (documentation of visible damages aspects). Optical Microscopy (OM - with a Smart-Eye USB digital microscope at various magnifications, from a maximum of 170x fixed magnification), in order to characterize the morphological features as attested previously by some scientists [6,7], superficial shape and the grain size of the stones and mortars. Polarized Microscopy (PM – with a MT 9000 Series MEJI Co. LTD Japan) used to determine the mineralogical composition and the grain features [8,9]. Scanning Electron Microscope (SEM) JEOL/EO, JSM-6380 device, equipped with an EDS detector operating up to an accelerating voltage of 25 kV and a working distance of 9mm used to investigate the morphology of the surfaces [10] and to detect the distribution of the chemical elements. X-ray diffraction method (XRD) performed with an Ultima IV, multipurpose X-ray diffraction system, equipped with a copper anticathode. The measuring conditions were set as follows: Cu target, 40 kV accelerating voltage, 40 mA current, the scanning range of 2θ was from 4 to 70° and the scanning speed was 2°/min used to identify the chemical compositions [11,12]. Dedan soil samples were analyzed with scientific techniques to identify granular classification and physical properties.

3. Results

3.1. *Field observations*

Through field observations of Dedan site it can be observed the stone structures are characterizes by the following features: *Majority of stone walls ruins are tending towards west direction, fig. (2-a). *Mortar is fragile, and mainly consists of clay. *Double faced wall is the main construction method in Dedan wall [13,14], fig. (2-b). *Ashlars sandstone used in the oldest periods but rubble sandstone used in the newer periods.

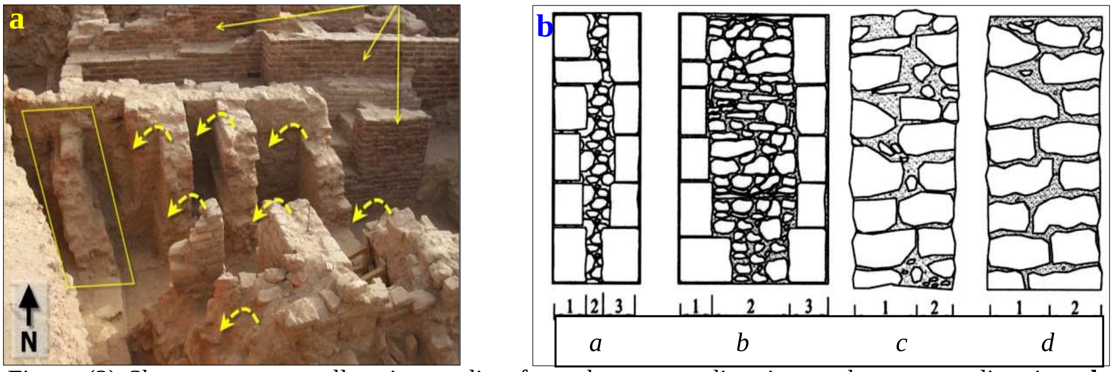

Figure (2) Shows **a**. stone walls ruins tending from the eastern direction to the western direction., **b**. double faced wall, *a*, three layers thin wall, *b*, three layers thick wall, *c*, weakly connected, and *d*, fairly connected

3.2. *The leaning wall*

Field observation notes tending of stone walls ruins to the west direction, inclination rate have varied from wall to another according to stones quality and walls thickness. Through documentation process of 9H square great tending of one wall has been noticed. Therefore diagonal and horizontal reinforcement began as fast as possible, fig. (3- a, b). Internal fillers layers is heterogeneous materials consists of clay, different sandstones fragments, and organic remains, fig. (4-a, b, c) [15]. Deterioration map of the tending wall was sketched. Sandstone of Dedan site are varied in color between red, yellow and grey to white [16].

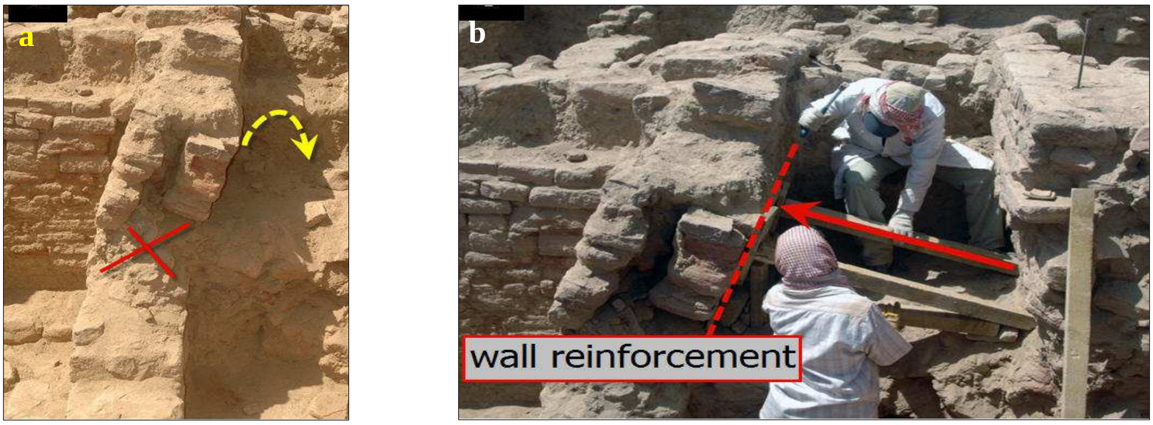

Figure (3) Shows **a**. tending wall after discovering, **b**. diagonal and horizontal reinforcement

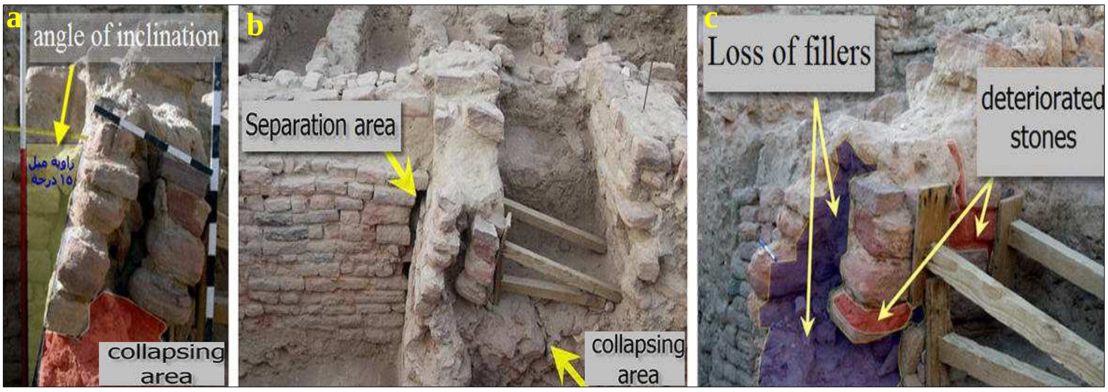

Figure (4) Shows **a**. inclination angle of the wall, **b**. separation and collapsing areas, **c**. loss of internal fillers and stone deterioration

3.3. *Optical microscope (OM)*

Undoubtedly using optical micro-scope helps a lot to know some properties of Dedan building materials, also serve as a guide to which kind of analysis must be followed [17]. OM results of stone samples showed three types of sandstone. First, laminated yellow sandstone has fine quartz grains with sharp edges. Second red sandstone, quartz grains vary in sizes, shapes and distribution. Third white to gray sandstone has spherical shape of quartz grains that different in sizes, fig. (5- a, b, c).

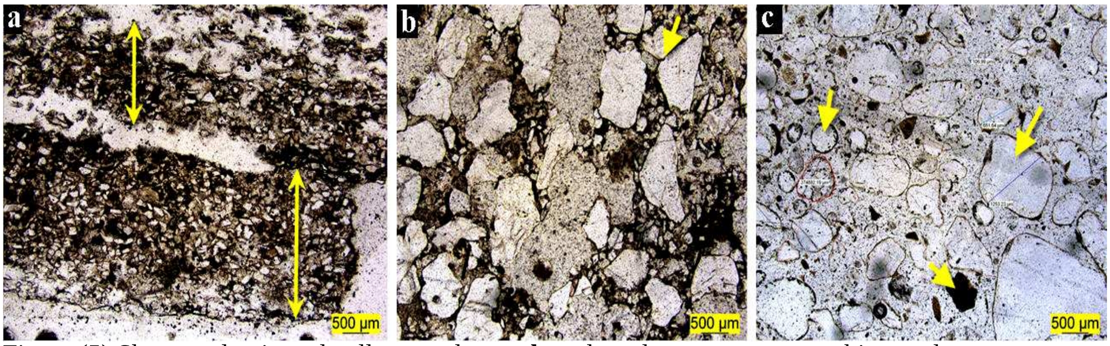

Figure (5) Shows **a**. laminated yellow sandstone, **b**. red sandstone, **c**. gray to white sandstone

3.4. *Polarized microscope (PM)*

Polarizing microscope "PM" is used to identify the crystal texture, grain size, grain shape and the type of cementing material of the stone [18]. Laminated yellow sandstone has mic-roscopic texture, of quartz in background of iron oxides and clay minerals mixture [19,20]. Red sandstone samples are composite of quartz varied in size, shape, in rich ground of iron oxides. The white to gray sandstone consists of quartz grains in rich ground of calcite and iron oxides mixture, fig. (6- a, b, c).

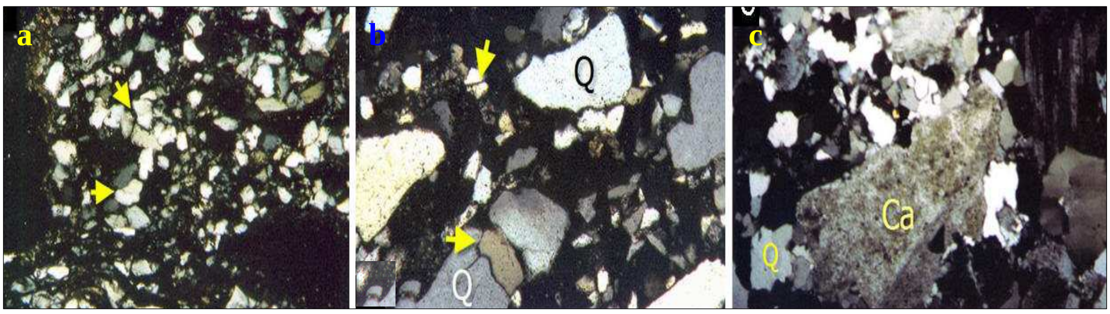

Figure (6) Shows **a**. laminated yellow sandstone (C.N.) X100, **b**. red sandstone (C.N.) X50, **c**. white to gray to white sandstone (C.N.) X50

3.5. *SEM*

SEM-EDS results showed that the laminated yellow sandstone cementing materials are iron oxides and tiny amount of clay minerals. The red sandstone cementing materials are calcium carbonate, iron oxides and tiny amount of clay minerals. White to gray sandstone have calcium carbonate and tiny amount of clay minerals as cementing materials of quartz grains [8], fig. (7-a, b). The results of the EDS analysis carried out on the three sandstone samples are shown in tab. (1).

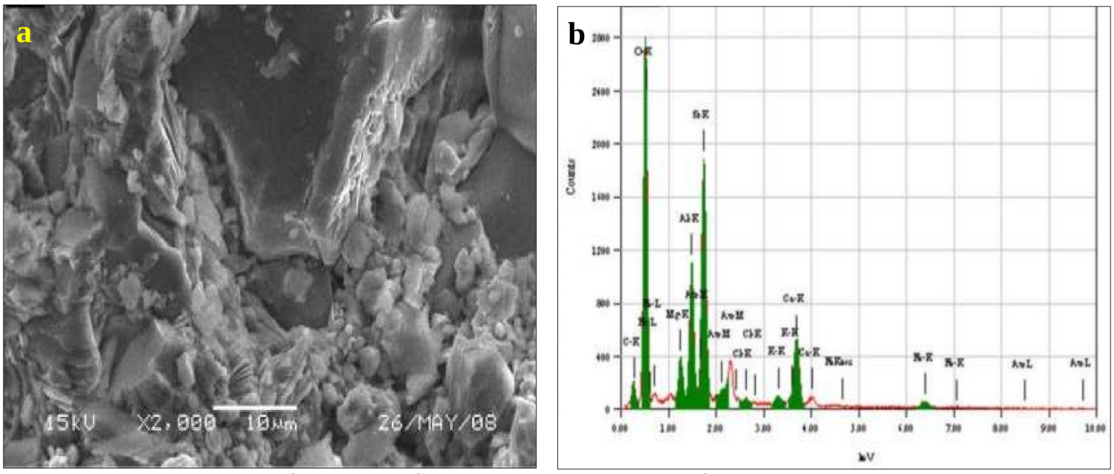

Figure (7) Shows **a**. the deformation of quartz, **b**. EDS analysis of red sandstone

Table (1) Elemental composition (wt. %) of the studied stones samples.

Sample	Elemental composition (wt. %)									
	C	***O***	***Mg***	***Al***	***Si***	***S***	***Cl***	***K***	***Ca***	***Fe***
Yellow sandstone	05.26	47.94	-	21.55	25.25	-	-	-	-	-
Red sandstone	05.09	34.63	03.55	12.41	23.91	-	01.74	01.51	14.13	03.81
White sandstone	02.95	41.87	-	14.43	38.41	0.08	-	-	02.27	-

3.6. *X-Ray diffraction (XRD)*

Sandstone and mortar samples were selected and prepared to be tested with powder method [21], The XRD analysis results were showed in tab. (2).

Table (2)Identified minerals of the stones and mortar samples by XRD.

Samples	**Minerals**	**Formula**	**Index No.**
Laminated Yellow Sandstone	Chamosite, Iron II	Fe-Mg-Al-Si-Al-O-OH	07-339
	Quartz	SiO_2	05-0490
	Kaolinite	$Al_2Si_2O_5(OH)_4$	01-0527
	Silicon Oxide	SiO_2	14-0260
	Iron Oxide	Fe_2O_3	16-653
Red Sandstone	Quartz	SiO_2	05-0490
	Goethite	α-FeOOH	17-0536
Mortar	Quartz	SiO_2	05-0490
	Kaolinite	$Al_2Si_2O_5(OH)_4$	01-0527
	Goethite	α - FeOOH	17-0536
	Calcite	$CaCO_3$	05-0586
	Orthoclase	$KAlSi_3O_8$	09-0462
	Halite	NaCl	05-0628

3.7. *Dedan soil classification*

The investigation results carried out according to Jain 2005 [22] on Dedan soil samples are shown in tab. (3-a, b) and fig. (8-a, b)

Table (3) **a**. Grain size analysis test, **b**. Physical properties of Dedan soil

Sieve No.	Diam. (mm)	Wt. ret.	Retained %	Passing %
	12.5	0	0.0	100.0
	9.500	0	0.0	100.0
# 4	4.760	0.83	0.7	99.3
# 10	2.000	2.22	1.8	98.2
# 16		3.5	2.8	97.2
# 20	0.850	4.88	4.0	96.0
# 40	0.425	16.02	13.0	87.0
# 60	0.250	32.56	26.4	73.6
# 100	0.150	43.83	35.5	64.5
# 200	0.075	50.09	40.6	59.4

Dedan Soil Properties	Result
Liquid Limit , LL , %	26.400
Plastic Limit , PL , %	21.700
Plasticity Index , PI , %	04.700
Specific Gravity , Gs	02.711
Gravel , %	00.700
Sand , %	39.900
Silt , %	37.400
Clay , %	22.000
% Passing # 200	59.400
Soil classification :	CL-ML
CL-ML = **Silty Clay**	

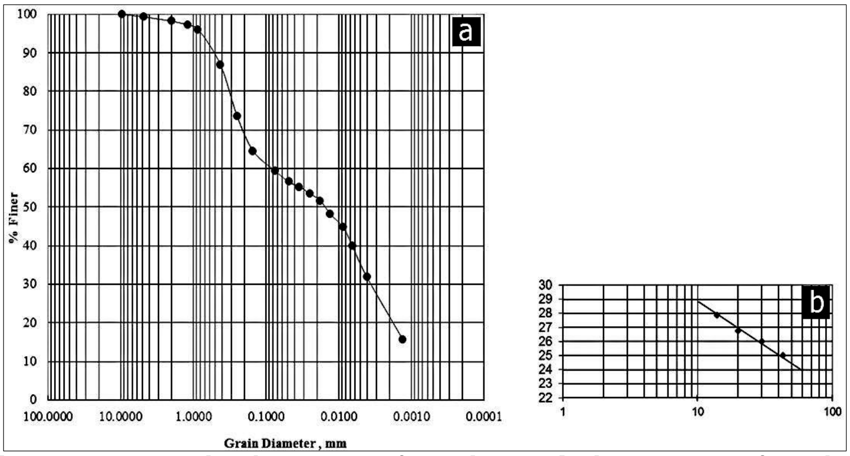

Figure (8) Shows **a**. grain size distribution curve for Dedan site, **b**. determination of Atterberg limits of soil

4. Plan of Conservation

After studying the previous results a restoration plan of the stone wall summed up in the mechanical cleaning, punctuation, loosening courses stones then sorted and the exclusion of the damaged ones in order to replace with suitable stones then reconstruction with the same old traditional method [23]

4.1. *Stone wall punctuation*

To identify the stone location, the wall punctuate as follows: * Mechanical cleaning of the stone wall surface. * Use crayons for punctuation process. * Punctuation start from top courses to bottom courses, fig. (9). * Register each stone with number in a detailed sketch of the wall. * Each stone has number and card, fixed with the stone after loosening [24].

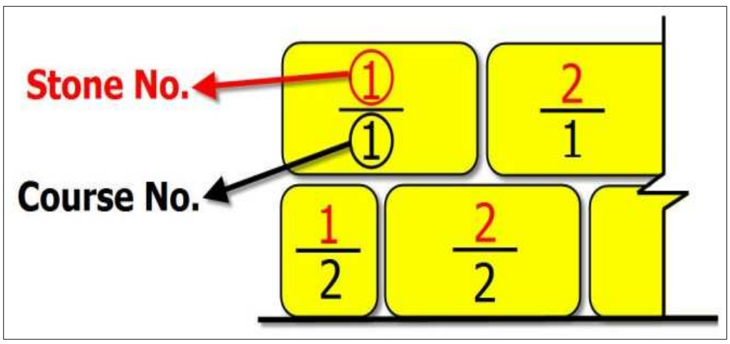

Figure (9) Shows method of stones punctuation of Dedan wall

4.2. *Reconstruction*

Traditional mud mortar was used to rebuild the loosening wall, bearing in mind the principles and rules of ancient construction technique, as well as small sandstone fragments were fixed on the filling layer surface to distinguish the reconstructed part [25,26], fig. (10-a, b), fig. (11-a, b), fig. (12-a, b, c, d, e, f, g) show Dedan stone wall conservation stages.

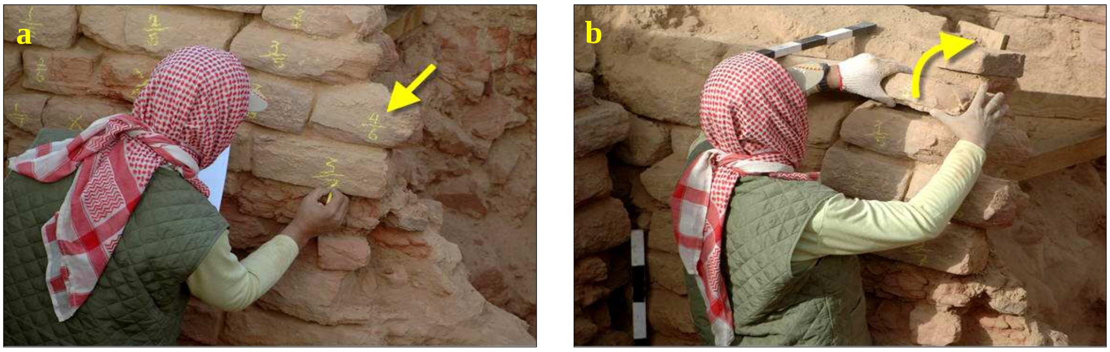

Figure (10) Shows **a**. stones numbering, **b**. beginning of the manual loosening processes

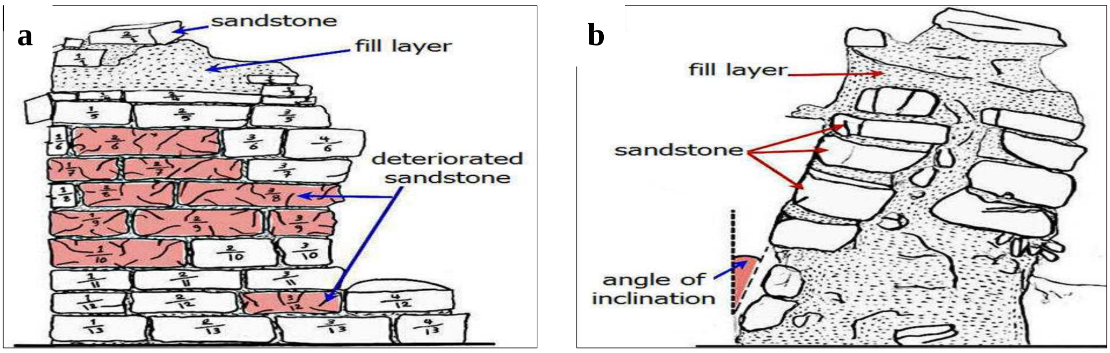

Figure (11) Shows **a**. identify deteriorated stones in the eastern direction, **b**. detailed drawing shows the stone wall condition from the northern direction

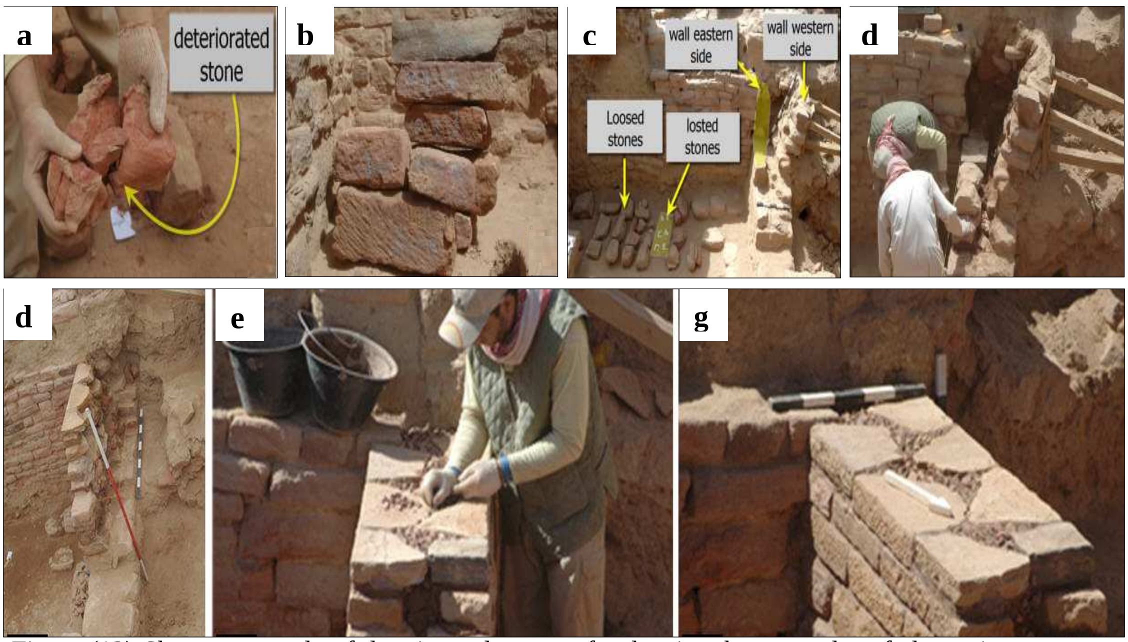

Figure (12) Shows a. sample of deteriorated stones after loosing, b. examples of alternative stones, c. removing the tending part of the western side, d. the beginning of rebuild, e. removing the tending part of the western side, f. small gravels were fixed on the filling layer surface to distinguish restored part, g. Dedan wall after conservation

5. Discussion

Field observations of Dedan site were observed the mountains surrounding the site had many collapse and fall of some rock tombs to the eastern direction (the same direction as Dedan walls). Therefore Dedan site probably subjected to seismic waves sequential led to such inclination and collapses. The site was abandoned from the population for other reasons than earthquakes where there are no bodies or treasures during the last ten excavations seasons. According to the results of the Seismic Studies Center at King Saud University, Al-'Ula has been subjected to 149 earthquakes of intensity between 1.6 - 5.1 MAG since 641 AD - 2003 AD, fig. (13). PM analysis was revealed that the weakness point of this stone is the cementing materials which have a tiny amount clay minerals. The red sandstone is the most common stone in Dedan site prevalent in the surrounding mountains. The XRD analysis showed halite salt especially in mortar. The main source of halite at Dedan is coming from the soil with the subsoil water from the neighboring farms through water capillarity. The question is why the ancient builder used clay mortar instead of using gypsum or lime mortar? Perhaps the answer lies in; clay mortar is more flexible and absorption of seismic waves and thus makes wall buildings more resistant against earthquakes especially the north west of Saudi Arabia is one of the seismically active places. The results of the soil analysis of Dedan determined the soil classification as silty clay soil (CL-ML). Inorganic clays, symbol C, group CL. Inorganic silts and very fine sandy soils, silty or clayey fine sands, micaceous and diatomaceous soils, and elastic silts-symbol M, group ML. This type of soil is directly affected by water and moisture, whether increases or decreases affecting the physical and mechanical properties and the consequent impact on the stone walls by the movement and damage. For reconstruction traditional clay mortar was used to give the possibility to make any modification may be necessary for the wall, where clay mortar is reversible material. Also, Maravelaki-Kalaitzaki, et al. [27] take into account fixing small stone fragments to be a signal that this stone wall was reconstructed.

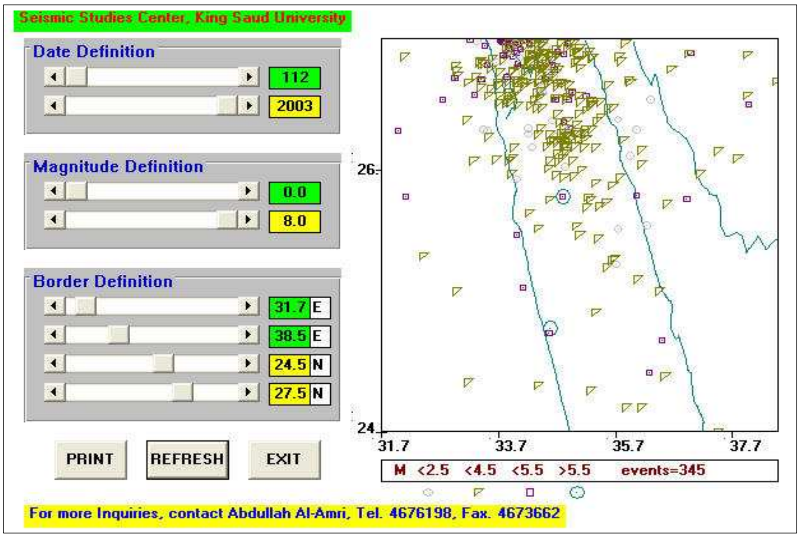

Figure (3) Shows map of earthquakes that stroked Al-'Ula site

6. Conclusion

*Through the previous study, it could be concluded the following points: * Some walls ruin of Dedan site are threatened with collapse. *Earthquakes, soil, building materials and construction methods are consider the main deterioration factors of the Dedan walls.*

**Strategy for conservation must develop for Dedan site, depends on investigation, analysis and right diagnosis. *In the case of dismantle and re-construct of stone wall, the same building materials and traditional building methods must be used, in addition to distinguish the re-constructed part.*

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