Impacts of Weathering Processes on Kousa Pasha Fort, Alexandria, Egypt – A Study in Applied Geomorphology

Impacts of Weathering Processes on Kousa Pasha Fort, Alexandria, Egypt – A Study in Applied Geomorphology

Ahmed.F.H .Elsayed[1]
Kawther.S.M .Abo Elreesh[2]

Abstract:

Weathering is one of the challenges which threaten most Egyptian monuments. It plays a role in destroying the mineral components of monumental buildings. It is also considered one of the most dangerous natural problems facing monumental buildings of different kinds. Weathering is no less influential in terms of its devastation from the other natural dangers. However, it has a slow effect that takes long years and increases over time and based on the frequency of its cycle inside the pores of the building stones.

Kousa Pasha Fort has been exposed to damage as a result of being influenced by various and interlocking weathering operations. The rate of weathering varies according to the materials of construction. That is, weathering is the product of an interaction between the internal structure of the stones and their mineral components and the prevalent ecological conditions.

The present study aims to investigate the geomorphological effects of weathering processes on Kousa Pasha Fort. This is to explain the reality which the fort experiences. Therefore, appropriate and urgent decisions can be made, based on such evaluation, as regards the restoration and maintenance of the fort.

Key words: Egyptian monuments, Kousa pasha fort, weathering processes, Geomorphological Effects.

1. Geography Department, Faculty of Arts, Damanhour Univ., Egypt
Email : ahmed.farahat@dmu.edu.eg.com

2. Ph. D in Physical Geography.
Email : kawther.sobhy@yahoo.com

1-Introduction:

Kousa Pasha Fort is located in Abu Qir region behind Abu Qir Water Company and close to Abu Qir maritime port. The coordinates (31° 19' 27.95" to the north and 30° 3' 51.62" to the east) account for the central point of the location of the fort. (Fig.1).

Figure 1: Location of the study area.

The fort was built in the age of Mohamed Ali Pasha in 1822 as part of the defensive line of Alexandria from the eastern side. It was erected on the coast of the Mediterranean Sea and retained most of its architectural elements. Only were the neglected parts destroyed. The fort has a pentagonal shape of five sides constituting the external boundaries of the fort. The design of the fort follows a semi-crescent planning. (Gomma, 2007). (Fig.2).

The fort is a rectangular construction that is not on one level as the north and southern towers stand out. The fort consists of two floors. The ground floor is of the same level as the trench surrounding the fort. It is 8 cm deep.

Figure 2: The internal yard of Kousa Pasha Fort.

It consists of four tunnels. The upper floor which stands on the trench extends on the same level of the ground of the surrounding road. It consists of two storehouses leading to two towers: northern and southern. The fort has a truss roof. The two towers are rectangular in design. They were used to support the external façades of the fort. The two towers have two identical façades with a rectangular window that ends in a semi-circular necklace. The entrances of the towers open from the western profile of the fort which overlooks the yard of the internal fort. (Abo Elreesh, 2018). (Fig.3).

Figure .3 : Scheme of the Kousa Pasha Fort , Meaning of numbers that : (1) Fortress walls (2) Northern Tower (3) Southern Tower (4) Storehouses (5) Internal fort (6) Northern tunnels (7) Southern tunnels (8) Yard (9) Trench (10) Entrance of the fort .

The fort was damaged as a result of being affected by multiple weathering processes. Besides, the weathering rate varies according to the surrounding environmental conditions and the type of building material. This is because the weathering process is the result of the interaction between the internal structure of the stones, their mineral components and the prevailing environmental conditions. (Delalieux F, et al, 2001). [3]. (Ruiz-Agudo, et al, 2007). (Fig.4).

Figure 4: Remains of Kousa Pasha fort.

The construction materials, being thermally expanded as a result of the direct exposure to the sun rays, vary in laboratories. The expansion rate of the external layers of the exposed surfaces differs from that of the internal layers of such materials because of the difference in the temperature of the surrounding medium. (Winkler, 1966).

Therefore, the size of the construction materials increases by expansion when exposed to high temperatures. However, it diminishes by contraction when exposed to low temperatures. This is due to the temporal tardiness of the internal layers which is directly correlated with the thermal resistance of the materials and the thickness of the walls (Sousa et al, 2005).

High temperature plays an important role in the activity of saline weathering. It causes the fast evaporation of the liquids which hold salts. Therefore, such salts are crystallized in different parts of the walls, the surfaces of stones, or immediately under the surfaces, not to mention the role of crystallization in the transformation of some of the stone materials. This encompasses the transformation of gypsum into anhydrate as a result of the loss of the water molecule that is united with the gypsum mineral (Al- Gohary, 2000).

Low temperatures during winter and night are tantamount to the growth of water molecules and salts inside the pores of the stones via hydrolysis. Thus, their size changes, and the poral structure of the stones is damaged. The area under study is an appropriate environment for the occurrence of saline weathering (Kamh, 2011).

It is consistent with the climatic conditions in terms of high temperature during daytime, relative high humidity, high rates of evaporation and the role of the northern and the northwestern winds, which dominate the area most times of the year, in pushing the sea water spray toward the fort. Such conditions help with the formation of salts on the external surfaces of the fort, not to mention the proliferation of salts in the carbonic limestones which form the fort. The water leaks and evaporates, leaving the salt atoms inside joints. Consequently, they crystallize, grow in size and contract on the walls so that some of their components are decomposed. (Rodriguez-Navarro et al, 1999).

The study area is an appropriate environment for the occurrence of weathering processes. The climatic conditions there are suitable in terms of high temperature during daylight hours, high relative humidity, high evaporation rates, and the role of the northern and north western winds that prevail most of the year and push sea water spray towards the fort. These conditions cause the formation of salts on the external surfaces of the fort.

In addition to the abundance of salts in carbonaceous limestones that form the fort, the water leaks and evaporates leaving the salt particles inside the joints. Thus, they crystallize and grow in size, causing pressure on the walls that separates some of their components.

Winds carry the sea spray which holds salts to the surfaces of the fort. They leave the salts inside the pores of the construction stones and their surfaces as a result of drought and of being exposed to consecutive cycles of saturation with spray holding salts. With the repetition of salt growth inside the construction stones, some salt pressure is generated on such pores, which causes weathering on their texture. (Goudie, et al, 1997).

Besides, winds play a role in the motivation of the biological weathering factors as they help with the transmission of seeds and pollens and their precipitation in joints and faults that permeate the construction materials. Such seeds grow in suitable conditions to form plants and bushes that increase the width of joints and faults.

Moisture also significantly contributes to the weathering of forts. Water drops gather on the external surfaces of forts because of the properties of the construction materials, including porosity that allows water to pass to the inside so that soluble salts can dissolve in water. With the rise of temperature in daytime, such water rises in the construction materials bearing with it salts that crystallize, in turn, on the external surfaces of the construction stones where flowers grow. As the process recurs, intensive pressures on the peripheral layers of the construction stones happen, leading in the end to their fragmentation and collapse. (Winkler, 1973) (Fig 5).

Figure 5: The effects of Moisture on the northern profile of the northern tower of Kousa Pasha Fort.

When water gathers below the surface around the foundations of buildings, it rises in the walls by virtue of capillarity to distances that typically rely on the porosity and permeability of the construction materials and their ability to absorb water. (Abd-Elhady, 1997). [17].

They also draw on the difference in temperature and humidity rates in the surrounding medium as well as the quantity of the gathering water around the foundations. Therefore, the materials, connecting the mass granules of stones and concrete, move, making such walls over time fragile and incohesive bodies that can readily decline by other factors of weathering (Wellman, et al, 1965).

The present study aims to investigate the geomorphological effects of weathering processes on Kousa Pasha Fort. This is to explain the reality which the fort experiences. Therefore, appropriate and urgent decisions can be made, based on such evaluation, as regards the restoration and maintenance of the fort.

2-Sampling and Methodology:

The construction materials are the stage on which weathering in its different forms happen. They also play a significant role in the specification of the mechanism of the different processes of weathering they are exposed to. Technologies and non-destructive methods are recommended for their examination.

Kousa Pasha Fort was built of Oolitic limestones. twelve weathered samples were collected from different positions of the fort for examination. (Fig6).

Figure 6: The entrance of the northern tower, consisting of oolitic limestone.

The **laboratorial work** was performed through three primary parts: petrographical results, hydrochemical analysis and petrophysical results. Such results are discussed for the achievement of the aims of the study.

The petrographical examination for the identification of the stone texture and its internal appearance draws on three techniques:

A. **Thin section for polarized microscope** is utilized to determine the system of granule order inside the texture of the stone as well as the degree of their integration and cohesion (1 sample is used).

B. **Scanning Electron Microscope (SEM)** is used to study the internal shape of the construction materials and the identification of how far they are influenced by weathering processes and to highlight their products on the internal texture of such materials. (4 samples are used).

C. **X-ray Diffraction (XRD)** is used to identify the mineral structure of the stones employed in the construction since weathering rates dwell on the ability of the mineral components to resist the different weathering factors. (1 sample is used).

Field investigations of features resulting from weathering processes in the Kousa Pasha Fort contribute to the assessment of the current status of the fort. Therefore, appropriate decisions can be taken regarding the restoration and maintenance of the fort according to a field survey.

Hydrochemical Analysis is conducted to identify the type and concentration of salts in the collected samples of the stones and to specify the total dissolved salts and the values of electrical conduction using the Electrical Conductivity Meter.

Five weathered samples were collected from different positions of the fort for examination, following the method of (Rhoades , 1982).

Petrophysical properties : The physical parameters (Porosity and water absorption) have been examined for five weathered building materials samples (using mercury porosimeter and manual laboratory work using the immersion method). (Dawn, 2001). Ultrasonic wave velocity (Cp) and the rock's internal friction (QC) were measured using a magneto astrictive Ultrasonic, (Kapranos et al, 1981).

3-Results and Discussion:

[3-1] Petrographical Results:

The Petrographical examination of the construction materials contributes to the identification of the stone texture and its internal appearance, not to mention the specification of the system of granule ordering and the degree of their integration and cohesion. Besides, it identifies how Far the stone texture is affected by the processes of weathering and the physiochemical change it experienced as a result of the interaction of the construction materials with the different factors of weathering (Al-Omari, et al, 2015).

Thin section shows that such stones belong to Oolitic limestones. The essential component of such stones is calcite that differs in the degree of its crystallization from fine to medium to coarse. The pores are medium-sized and connected to each other.

The Oolitic granules appear closely connected and pervaded by sparite and microspar. The Oolitic granules in the texture tend to be disc-shaped. Such a feature indicates that the stone porosity reaches its highest value in the texture of disc and semi-disc granules.

The texture of sample is a packed stone. The Oolitic granules appear closely connected and pervaded by sparite and microspar according to Denham classification. (Awad, et al, 2007). (Fig .7).

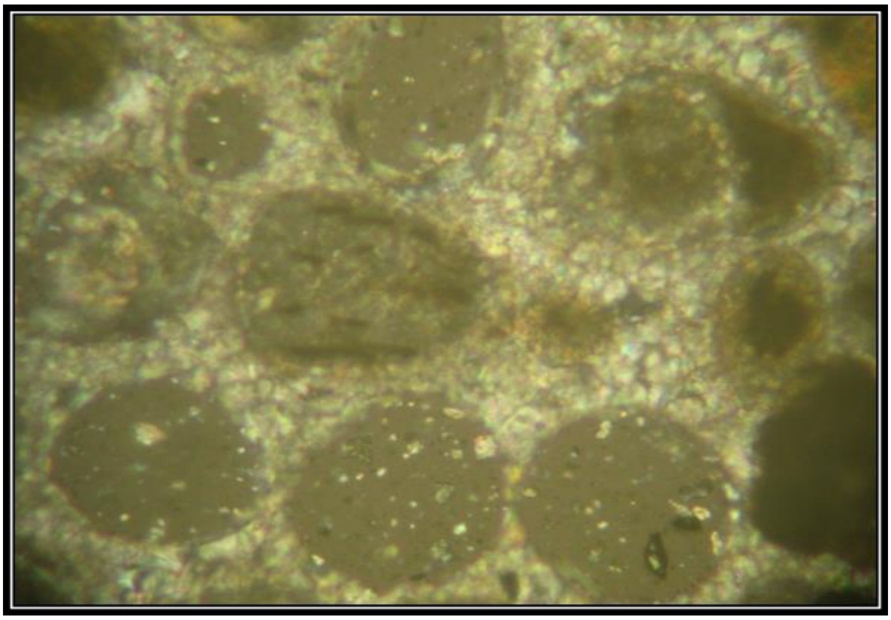


Figure 7: Thin section of stone sample collected from Kousa pasha fort, the texture is a packed stone. The Oolitic granules appear closely connected and pervaded by sparite and microspar according to Denham classification.

Scanning electron microscopic (Viles, 1996). Results of the SEM indicate that salt weathering is the principal controller of the fragmentation of the internal texture of the construction materials of Kousa Pasha Fort. This is because they are influenced by the common maritime effects in the site of the fort and exposed to consecutive cycles of weathering. (Smith, et al, 1983). (Fig.8, 9).

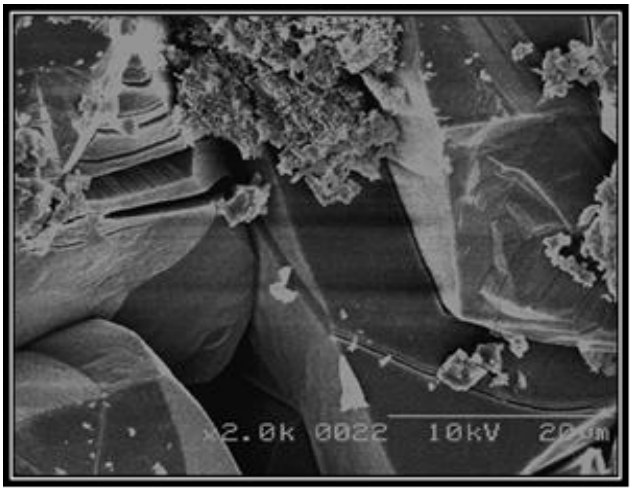


Figure 8: Scanning electron photo-micrograph of stone sample collected from kousa pasha fort presenting well crystallized calcite, effected by Parallel cracks appeared across the dissociation levels of the crystals.

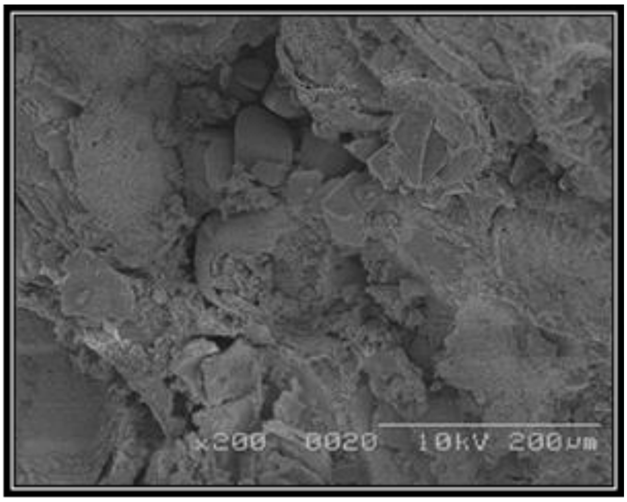


Figure 9: Scanning electron photo-micrograph of stone sample collected from kousa pasha fort presenting the hygroscope was affected by weathering, and the surfaces of limestone grains crumbled.

Sulfates and chlorides are the most widespread salts in the stones constructing Kousa Pasha Fort. The sulfates are crystallized in their acicular shapes (Fig.10), and chlorides in their fluid shapes. (Wellman, et al, 1965). (Fig.11).

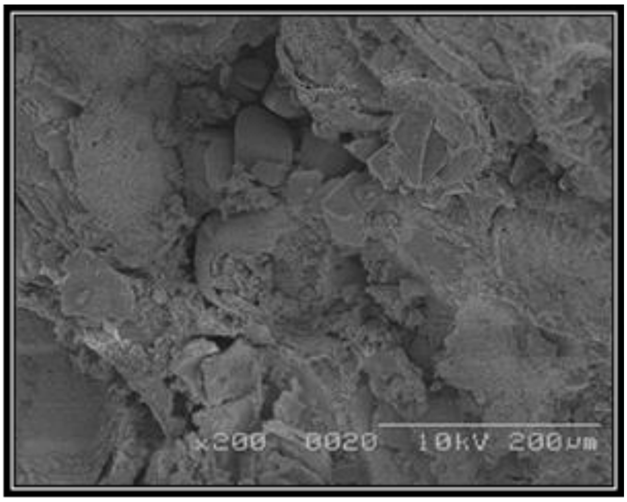


Figure10: Scanning electron photo micrograph of stone sample collected from kousa pasha fort presenting sulfate salts appear crystallized in needle form.

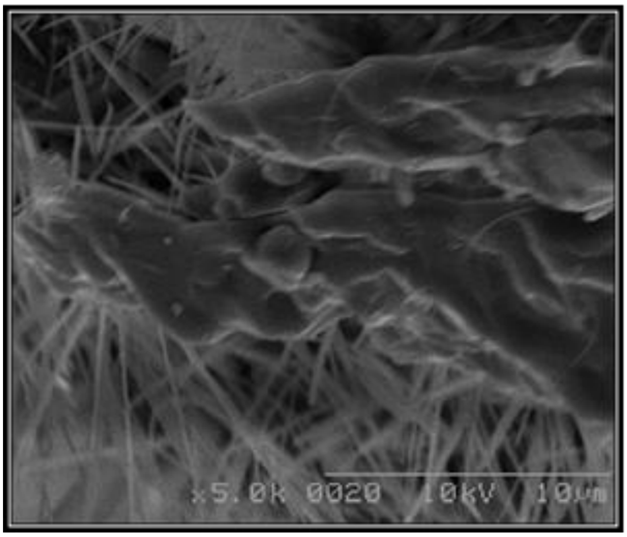


Figure11: Scanning electron photo-micrograph of stone sample collected from kousa pasha fort presenting chlorides salts appear crystallized in fluidized form.

X-ray diffraction has been carried out to identify the mineralogical composition of construction materials of Kousa Pasha Fort. Weathering rates for the building stones depend on the ability of the mineral components of the stones to resist various weathering factors.

They also draw on the homogeneity of the minerals and the nature, as well as the physiochemical characteristics, of the construction materials exposed to such factors.

Sample is essentially formed of calcite along with secondary minerals such as dolomite, Aragonite and quartz. The stones are of the dolomite limestone type as a result of the existence of dolomite in the samples. (Fig.12).

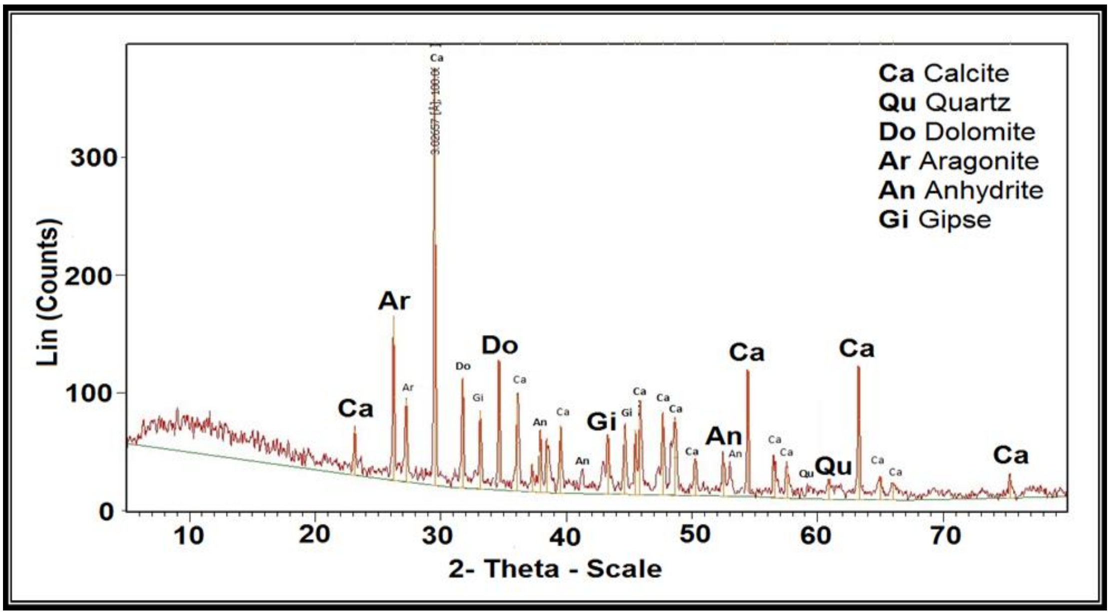


Figure 12: X-ray diffraction chart of The Mineral Structure of Limestone sample collected from construction stone of kousa pasha fort.

Aragonite often turns calcite under the influence of pressure and high temperature. Based on the field study and the laboratorial examination of the stone samples, the quartz mixed with limestone granules is shown to be a secondary mineral that has been precipitated around the original stones. This weakens the stones and makes it more likely to be weathered and fragmented. (Awad, 2002).

The existence of gypsum in the sample ensues from its presence as a natural impurity in the stones. It can also be the result of chemical weathering of the limestones. (Charola, et al, 2007).

Sometimes calcium sulfates are transformed into gypsum (hydrous calcium sulfates) through hydrolysis that activates an increase in the size of salts. Therefore, it is easy for the stones containing the salts to be fragmented and, thus, influenced by chemical weathering. (Mahsoub, et al,1989).

The anhydrate is found in the sample as a consequence of the transformation of gypsum to the anhydrate mineral since gypsum loses the two water molecules which are chemically united with its molecules. Therefore, it is transformed from the dehydrate phase to the anhydrate one due to its exposure to high temperatures and dehydration (Al-Mahary, 2006).

[3-2] Hydrochemical Results:

The construction materials in Kousa Pasha Fort are affected by the consecutive cycles of saline weathering due to the frequent growth of salts inside the constructing stones. This leads to topical pressures inside the pores which are tantamount to the damage of the internal texture of the stones (Cultrone, et al, 2008).

The examination of the hydrochemical analysis is performed in five samples of the construction materials collected from the weathered parts of the fort to identify the source and mechanism of the salts.

The total dissolved salts and the values of electrical conduction therein by using the Electrical Conductivity Meter. The extracted solutions has been prepared following the method of (Rhoades, 1982).

The results are listed in [Table.1]. It is noted that electrical conduction values of the samples of the construction materials range between 1544-18800 microsiemens/cm, while the total dissolved salts range between 1034.5-12596 ppm.

Incidentally, the electrical conduction of water is related to the salts dissolved therein. The more concentrated salts are in water, the more conductible of electricity water is. From the observation of the relation between the values of electrical conduction and the total dissolved salts in all of the tested samples with their types — whether limestones or concrete added to the construction paint. It is found that it is a strong direct correlation. Besides, values of electrical conduction went up with the rise of the total dissolved salts, (Fig, 13).

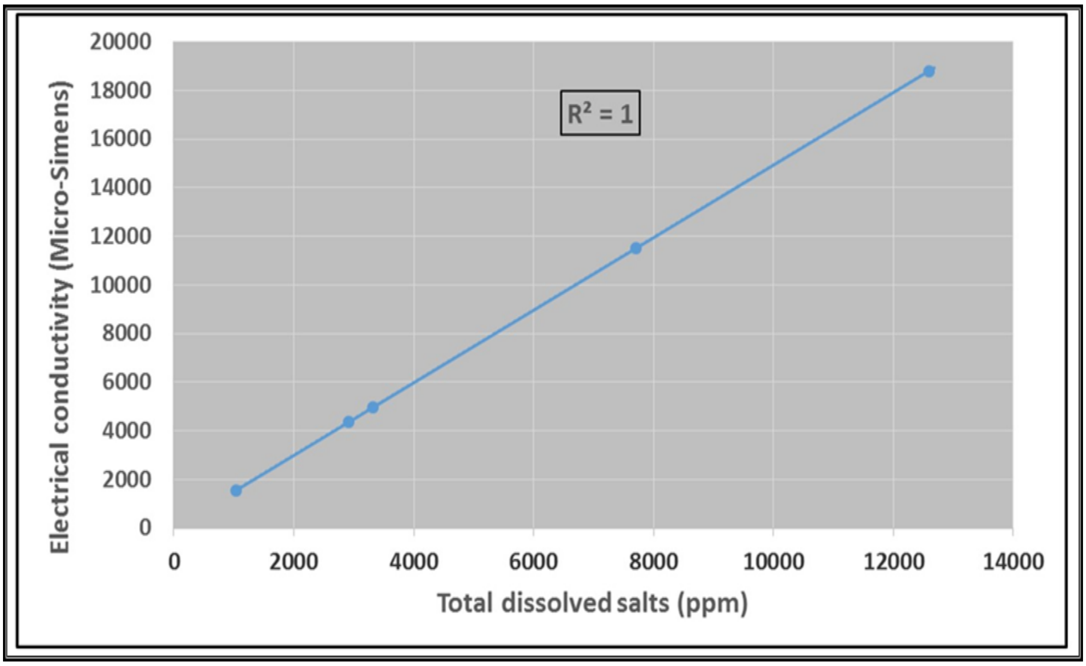


Figure.13: the Relation between electrical conduction and the dissolved salts in the samples of the construction materials.

Table 1: Results of the hydrochemical analysis of the stone samples are construction materials samples collected from kousa pasha fort.

Sample code	Sample type	Electrical conductivity (Micro-Simens)	Total dissolved salts (ppm)	Percentage of hypothetical dissolved salts							Chlorides salts	Sulfates salts
				KCl	NaCl	CaCl	CaSO4	MgSO4	MgCO3	Mg(HCO3)2		
KT – 1	White limestone	4360	2921.2	5.3	38.6	3.1	39.5	5.5	5.5	2.1	47	45
KT – 2	Grey limestone	11500	7705	2.8	45.8	2.4	31.9	12.1	2.5	2.5	51	44
KT– 3	Yellow limestone	18800	12596	4.7	47.1	1.2	29.8	14.2	0	2.2	53	44
KT– 4	Mortar	4950	3316.5	3.8	38.8	10.4	25	19	2.4	0.5	53	44
KT – 5	paint	1544	1034.5	3.3	43.5	5.2	36.9	8.1	1.5	1.4	52	45

Table source: Laboratory measurements.

Results of the hydrochemical analysis of the sample of the construction materials of Kousa Pasha Fort show that chlorides (accounting for an average of 47% of the total dissolved salts) and sulfates (accounting 45% of the total dissolved salts) are the most prevalent salts in the samples. There is also a small proportion of carbonates.

Sodium Chloride (Halite) is one of the most important salts observed. It is characterized by its high capacity of thermal conduction. The temperature of such a salt is usually higher than the surrounding construction materials. This causes a malfunction in the thermal balance between the precipitated salt and the construction materials. Such a malfunction is generated by the heat produced by the internal friction of the salt crystals with the granules of such materials, not to mention their absorbability of water molecules from the air at low relative humidity, which makes the stones constantly humid (Fabry, et al, 2008).

The salts observed in the samples are hygroscopic, especially the chlorides which are capable of withdrawing humidity. In that sense, they can change from an anhydrous form to a hydrous one. Thus, they can take part in chemical interactions in the presence of water, which leads to the weathering of the stones containing them (Fantle & Tipper, 2014).

[3-3] Petrophysical Results:

Turkington and Smith, 2000 indicated that the stone petrophysical properties (in particular porosity and water absorption) are characteristic for stone susceptibility to weathering factors and weathering intensity. To identify the petrophysical properties of the construction materials used in Kousa Pasha Fort, five samples from different positions in the fort are collected for analysis, three weathered limestone samples and two mortar samples.

The results are listed in [**Table.2**]: It is noted that the porosity in white limestone is 14.8%, gray limestone is 18.7%, and yellow limestone is 17.1%, the porosity in mortar and paint samples are 32.3 % and 44.0 % respectively. While is noted that water absorption in white limestone is 10.3% , gray limestone is 13.6% , and yellow limestone is 12.4% , water absorption in mortar and paint samples are 20.8 % and 28.6 % respectively.

Porosity is one of the most important properties of the construction materials. It helps the pores in the construction materials to facilitate weathering and control the possibility of making the salt-laden water reach the walls of the building. With the increase of temperature, water evaporates and the salts inside the pores crystallize. The increase in the size of the salt crystals causes the walls of the pores to crack, and new gaps with different dimensions are formed. This eventually leads to the fragmentation of the internal structure of the stones (Al-Humosani, 2007).

The proportion of water absorption represents the ability of the stone to absorb water and other hydrous solvents. Besides, there is a close relation between the porosity of stones and the proportion of its absorption of water. Stones with high porosity can absorb a great amount of water in a short time. Such stones are not commensurate with construction or restoration because the absorption of water means that the dissolved salts have permeated the pores. With the recurrence of the process, saline weathering occurs (El-badri, 2008).

Ultrasonic technique has been reported to be a nondestructive technique (Weimann. w et al, 1995). and used for examine weathering degree of different rock types through the ultrasonic velocity within the rock under investigation (Kamh, 2003).

The results are listed in [Table.2]: The results indicate, that Weathering rates directly influence the velocity of ultrasonic waves and the values of the internal friction of the waves in the construction materials. The velocity of ultrasonic waves in the samples ranges from 1.42 to 2.11 km / sec. None the less, the values of internal friction range from 6.37 to 9.4 because of the damage of the internal texture of the construction materials since it is badly affected by weathering processes. (Maria, et al, 2000). (Fig.14).

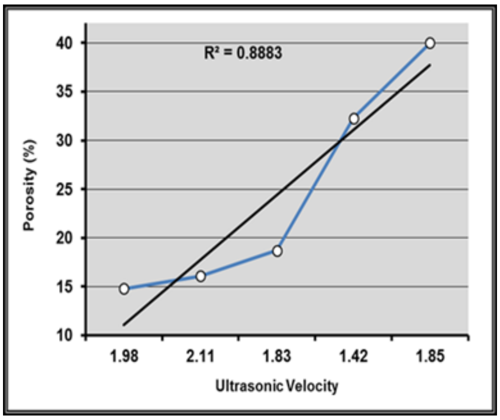
The petrophysical properties of the construction materials are highly significant since they indicate the behavior of the stones under the pressure of the salts inside the pores of the stones.

Such a property is directly correlated with stone porosity. However, the stones do not often absorb enough water that fills all of the pores in the stones due to the existence of restrained air inside the stones in the form of bubbles preventing water from occupying all of the pores in the stone sample. The reason for this may be the presence of muddy minerals in the pores that absorb water and increase in size so that they block the internal pores pores in the stones (Al-Kafafi, 2006).

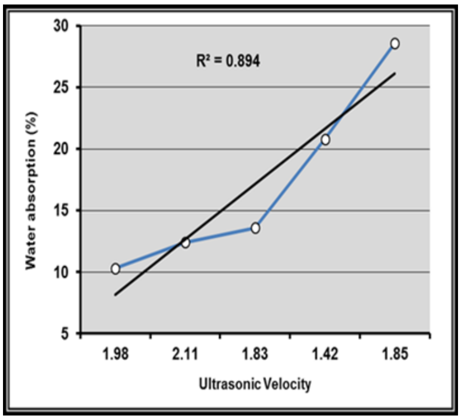
Table 2: Petrophysical properties (Porosity, water absorption and Ultrasonic wave velocity) determined on construction materials samples collected from the weathered parts of the kousa pasha fort.

Sample code	Sample type	Porosity (%)	Water absorption (%)	ultrasonic velocity	Internal friction values
KT – 1	White limestone	١٤.٨	١٠.٣	١.٩٨	٦.٥٦
KT – 2	Yellow limestone	١٧.١	١٢.٤	٢.١١	٦.٣٧
KT– 3	Grey limestone	١٨.٧	13.6	١.٨٣	٦.٦٥
KT– 4	Mortar	٣٢.٣	٢٠.٨	١.٤٢	٩.٤
KT – 5	paint	٤٠.٠	٢٨.٦	١.٨٥	٦.٥

Table source: Laboratory measurements



(a)



(b)

Figure 14 : Relationships between Ultrasonic wave velocity and (a) stone porosity , (b) coefficient of stone water absorption examined for weathered building materials samples from kousa pasha fort.

The results are listed in [**Table.3**]: The results indicate, that the pore size distributions between (0.1 - 0.5 µm) represent the largest percentage of pores by 30.46% of the total volume of pores, while pores less than (0.05 µm) represent the least percentage of the sample. (Swe, et.al, 2010), (Fig.15)&(Fig.16).

Table 3: Pore radius and Incremental pore volume (mL/g) for Oolitic limestone on construction materials sample from kousa pasha fort.

Incremental pore volume (Total Intrusion Volume) *mL/g*	(pore radius micron) / (% of pore volume)						
	less 0.05 micron	0.05 - 0.1	0.1 - 0.5	0.5 - 1	1.0 - 2.5	2.5 - 5	> 5
0.2025	4.72	8.24	30.46	5.48	17.68	25.75	7.67

Table source: Laboratory measurements.

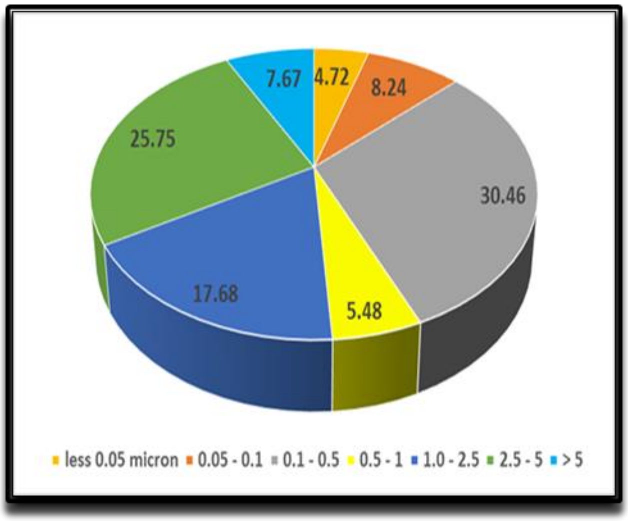


Figure 15: Graphical the pore size distributions of pore volume (%) on construction materials sample from kousa pasha fort.

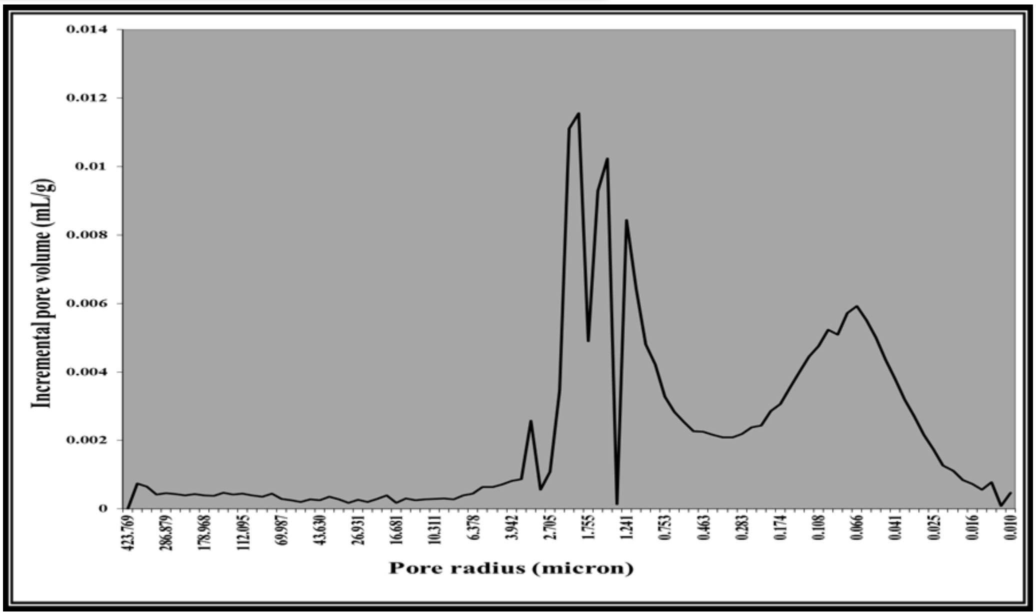


Figure 16: Graphical relationship between Pore radius and Incremental pore volume (mL/g) for Oolitic limestone on construction materials sample from kousa pasha fort.

[3-4] Field Results:

The study aims to evaluate the geomorphological effects of weathering processes in Kousa Pasha Fort in order to explain the reality which the fort experiences. Therefore, appropriate and urgent decisions, based on such evaluation, concerning the restoration and maintenance of the fort can be made.

The geomorphological effects of weathering processes, can be divide to **processes**; contain Mortar fall, Differential Weathering, Backward retraction, Lower erosion, Cavitation weathering and Salt crystallization, **features;** like Granular disintegration, Solution gaps, … etc. that were monitored from the field study in Kousa Pasha Fort are as follows:

[3 - 4 - A]: Mortar fall:

The mortar falls as a result of phasal transformations of the mineral granules which form mortar because of its thermal behavior of storing and losing thermal energy. This causes the separation of the layers of mortar from the walls in the form of crusts due to the crystallization of salts in the external layers of the surfaces of the construction materials, especially the mortar. When solvents of salts dry by evaporation, salts grow and flourish. With the recurrence of such a process, strong pressures are caused on the layers of the mortar, eventually leading to its fragmentation and fall (Mottershead, 1989). (Fig. 17).

The eastern and southern façades of the buildings of Kousa Pasha Fort have the biggest share of the fall of mortar owing to the exposure to the common factors of weathering, especially the maritime effects—percentages of mortar fall range from 60% to 75 %.

Figure17: A model of mortar fall of Kousa Pasha Fort.

[3 -4 – B]: Differential Weathering:

The construction materials vary in their response to weathering processes. Some parts are highly resistant, so they remain in their positions in the form of crystals. Notwithstanding, other parts are less resistant and easily respond to weathering processes. This kind of weathering is known as differential weathering. (Abdel Wahab, 2006).

An example is the construction mortar which interacts with the different factors of weathering. In that respect, its exposure to weathering is faster than that of the building stones which remain protruding on the surface of the building. (Fig. 18).

Effects of differential weathering appear in the middle and upper parts of the external façades of Kousa Pasha Fort because of the variation in the resistance of the construction materials to weathering processes.

Besides, the upper parts of the walls receive the highest proportions of the common weathering effects in the site. The percentages of differential weathering vary from 55% to 85%, and the amount of differentiation varies from 30 to 50 cm.

Figure 18: The effect of weathering processes in the Eastern façade of the southern tunnel of Kousa Pasha Fort.

[3 – 4 – C]: Backward retraction:

Backward retraction appears as a result of a regular loss of the stone materials in a position parallel to the original surface of the stone owing to the disintegration of the construction materials. This generates the imbalance and decline of the building. (Sharp, et al, 1982).

The eastern façade of Kousa Pasha Fort has the highest share of backward retraction, the reason is that it is directly influenced by the prevalent maritime effects in the site and their exposure to consecutive cycles of weathering. Moreover, the eastern façade of the northern tunnel has the biggest share of strong backward retraction — the value of backward regression soars to 95% of the total façade. (Fig. 18).

[3 – 4 – D]: Lower erosion:

The lower parts of the buildings are exposed to lower erosion because of being influenced by the subsurface water that leaks to the construction materials and causes the salts therein, or in the soil surrounding the foundations of the buildings, to dissolve. Therefore, the salt solvents move to the exposed surfaces where they start to crystallize when the water evaporates, leading to the disintegration of such surfaces by means of the topical pressures accompanying crystallization. (Abdel Wahab, 2006).

Lower erosion appears in the lower parts of the buildings of Kousa Pasha Fort with percentages ranging from 10% to 15% of the total façade. The erosion ranges from 30cm to 80cm. (Fig.19).

Figure 19: A model of lower erosion in the northern tower of Kousa Pasha Fort.

[3 – 4 – E]: Cavitation weathering:

Weathering cavitations appear in the external façades of Kousa Pasha Fort as a result of the construction materials are influenced by saline weathering that activates salt crystallization on the surfaces or below the walls. This causes the back to back fragmentation and disintegration of the construction materials by means of the topical pressures accompanying crystallization. (Mottershead, et al , 1994).

The amalgamation of the gaps of dissolution contributes to the emergence of such cavitations. They look like small caves, (Turkington, 1998), (Fig.20).

The study of the morphometric parameters of the models of weathering cavitations in some façades of the buildings of Kousa Pasha Fort show that the dimensions of weathering cavitations (length, width, depth and circumference) are increasing in one direction. The reason is the similarity between the factors and processes of their expansion and deepening due to the constant expansion of cavitations by amalgamation and the constant deepening by decomposition and dissolution.

Figure 20: A model of the cavitation weathering on the southern tower of Kousa Pasha Fort.

It is noted from (Fig.21) the the relation between the depth and diameter of weathering cavitations and the studied façades show some deviation of the values from the straight line. This indicates the impact of the amalgamation processes between holes, not to mention dissolution and vertical decomposition, on the emergence of such cavitations.

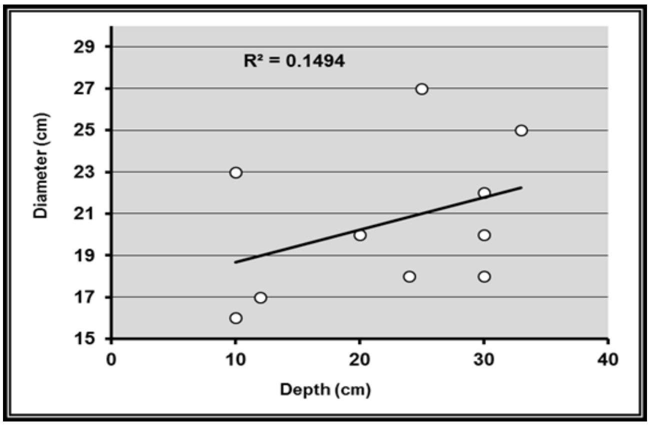


Figure 21: The relation between the depth of Weathering cavitations in the western façade of the southern tower in Kousa Pasha Fort.

[3 – 4 – F]: Salt crystallization:

Infiltration and seepage water leaks by capillarity inside the stones of construction with what they hold of salts. This causes the formation of internal paths that increase over time. Such paths reach the surface of the stones so that the water evaporates, leaving salts doubly concentrated. Besides, the salts interact with the external surfaces of the stones transforming them into powder that volatilizes or into stone crumbs that fall back to back (Sperling, et al, 1980).

The façades of Kousa Pasha Fort are influenced by the subsurface salt crystallization due to the common humid weather conditions.

Surface salt crystallization appeared evidently during the field study of Kousa Pasha Fort in the upper parts of the western façade of the northern storehouse of Kousa Pasha Fort (25% of the total façade). Its thickness ranges from 1 to 5 mm.

[3 – 4 – G]: Solution gaps:

The gaps of dissolution appear as reliefs and holes whose diameter and depth do not exceed some centimeters since some stone minerals are dissolved by water. Then, winds remove the products and leave the surface exposed with some peripheral holes and notches. (McBride, et al, 2000).

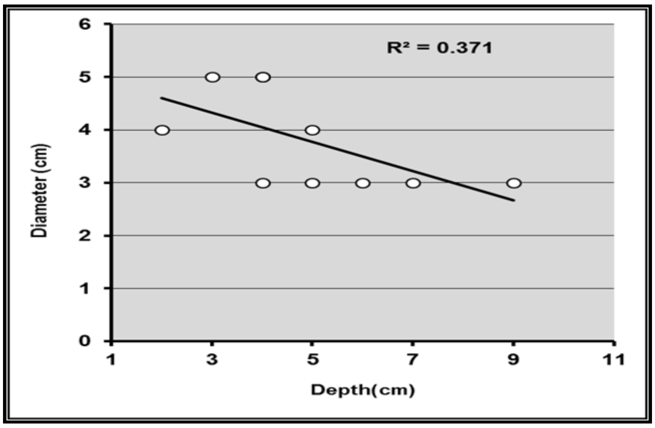
An example is the dissolution of calcium carbonates in the construction limestone materials because of the presence of carbonic acid in rain water and of air humidity. Calcium carbonates are transformed into calcium bicarbonates that dissolve in water, leaving in their positions holes and gaps characterizing limestones.

The study of the morphometric parameters of the models of the gaps of dissolution in some façades of the buildings of Kousa Pasha Fort show that the dimensions of the gaps (length, width, depth and circumference) are increasing in one direction. The reason is the similarity of the factors and processes affecting their expansion and deepening. Such factors and processes are, in turn, associated with the consistency of the nature of stones and their installation in the positions occupied by gaps. (Fig.22).

Figure 22: A model of the gaps of dissolution in the western façade of the southern tower of Kousa Pasha Fort

It is noted from (Fig.23) shows some deviation in the values from the straight line in the relation between the depth of the gaps of dissolution in the façades under study and their diameter. This indicates the constant expansion of the gaps by means of their amalgamation in addition to the constant deepening by dissolution and vertical decomposition.

Figure 23: the relation between the depth of the gaps of dissolution and their diameter in the western façade of the southern tower in Kousa Pasha Fort.



[3 – 4 – H]: Black crust:

The black crust is a combination of organic and non-organic granules as well as air dust and organisms that stick to wet surfaces. Then, they interact with the components of stones forming new minerals. They can be salts that grow by any mechanism to destroy the texture of the stones over time (Shoulikids, 1991).

High humidity contributes to the precipitation of the oxides, impurities of the stones on the surface. With the presence of air pollutants, the black crust is formed. Over time, it grows in thickness forming a solid black layer below which the stones become highly fragile and fragmented (Hijab, 2011).

Some of the external façades of the buildings of Kousa Pasha Fort are influenced by the black crust since they are directly affected by the common air pollutants in the site and the lack of direct exposure to rains, (Fig.18).

[3 – 4 – I]: Granular disintegration:

The Granular disintegration is the most significant product characterizing the act of weathering anywhere. The fundamental act of weathering is the disintegration and decomposition of stones in their positions. This happens due to the decline of the interconnection between the mineral granules constituting the external layers of the surfaces of the construction materials owing to a different thermal behavior of their mineral components with the rise or fall of the surface temperature in the surrounding medium (Hoke, et al ,2004).

The Granular disintegration appear below the exterior facades of the Kousa Pasha Fort buildings, as a result of the decomposition and disintegration of the construction materials, (Fig.24).

Figure 24: A model for Granular disintegration in the eastern facade of the northern tower, Kousa Pasha Fort.

[3 – 4 – J]: Cracks:

Kousa Pasha Fort is of the buildings with holding walls which are built to resist vertical loads only. The walls of a floor are built. Then, logs are placed on it, and the next floor is built. Thus, no momenta transmission is found between the roof and the walls. When exposed to loads of earthquakes, such walls become vertical organs supported only horizontally at the height of the roofs. When exposed to weariness as a result of the horizontal movement, whatever small it is, vertical and oblique cracks occur in the walls. (Edwards, 2004). (Fig.25).

Figure 25: A vertical crack in the southern façade of the southern tower of Kousa Pasha Fort.

Cracks appear in the fort in the upper and lower entrances and the openings of the shafts. The reason for this may be the sudden change in the sub water content of the soil below the foundations, whether upward or downward. This leads to the occurrence of cracks in the building, especially at the openings and thresholds. The impact on the buildings increases in the period of the reduction of water height and decreases in the period of its rise. (Kamh, 1994).

Some of the external façades of Kousa Pasha Fort are influenced by vertical cracks owing to the difference in the loads and weariness between the two parts of the same building. Such cracks occur in the buildings with different loads and varying heights such as the eastern and southern façades of the southern tower.

Random cracks appear in the external paint of the façades because of the rise of the humid content of the walls. High humidity contributes to the dissolution of the soluble salts in limestones. Then their solvents move to different positions of the walls.

Afterwards, such salts are borne to the exposed surfaces where they crystallize in the external layers of such surfaces when their solvents dry by evaporation. Because of the great topical pressures accompanying crystal growth of salts, peripheral and random cracks emerge in the external mortar of the walls. (Arthur, et al, 2005).

5- Conclusions:

Kousa Pasha Fort dates back to a significant historical period of the modern history of Egypt, not to mention the ingenuity of its architectural design. Some of its architectural components have been damaged due to the negligence of restoration and maintenance in the fort. It has become a shelter for families who have made some modifications to its internal architectural design.

The fort is in an urgent need for a comprehensive plan of treatment that includes principles for the prevention of the sources of damage from influencing it. However, this needs a substantial budget and the intervention of several institutions in the processes of rescue and renovation.

Results of the examination by the SEM indicate that salt weathering is the primary controller of the fragmentation of the internal texture of the construction materials of Kousa Pasha Fort. The reason is that it is influenced by the common maritime effects in the site of the fort in addition to the exposure to consecutive cycles of weathering.

The results of hydrochemical, petrographic and petrophysical analyses indicated that weathering of this fortress is highly controlled by salts, The salts monitored in the samples are hygroscopic salts, can participate in chemical reactions in the presence of water, which leads to weathering the texture stone containing them.

Furthermore, results of the hydrochemical, petrographical and petrophysical analyses indicate the high activity of weathering caused by salts. Additionally, they show that the salts observed in the samples are hygroscopic. That is, they can change from the anhydrous form to the hydrous one. Therefore, they take part in chemical interactions in the presence of water, which causes the texture stone containing them to weathering.

All weathering processes are involved in weathering and destroying the fort; none of which works in isolation from the other. Instead, they all take part in weathering and destroying the fort. The human role is no less effective and dangerous than the physical, chemical and biological factors of weathering. The condition of archaeological buildings in Egypt is currently a reflection of the impact of human activities on them. Therefore, they lost a great deal of their historical value.

The appropriate re-functionalization of monumental buildings does not only help with their development and revitalization, but also it affects the surrounding urban entities. Its impact extends also to both the economic and civilizational arenas. Hence, forts must be invested, not just to attract tourists, but to engage citizens in the utilization which guarantees its continuity.

The functionalization of forts needs intensive care since it incorporates the geometrical side to reformulate buildings properly so as to fulfill the needs of functionalization. This needs, besides renovation, the arrangement of the site and taking care of the environmental medium surrounding the area. Functionalization also requires the preparation of the urban environment surrounding the forts, including the routes leading to the buildings.

References:

1.Abd El-Hady M (1997): Scientific studies in restoration and maintenance of inorganic antiquities, Zahraa Al-Sharq Library, Cairo, pp114-121.

2.Abdel Wahab H (2006): Physical and Historical Geology, First Edition, Dar Al-Fikr Al-Arabi, Cairo, p 151. (In Arabic).

3.Abo-Elreesh K (2018): Effect of Weathering processes on the old defensive Fortresses on the Southwestern side of the Abuqir bay - a study in Applied Geomorphology, Ph.D THESIS, Faculty of Arts, El menofiua Univ., 2018. Pp 45- 95. (In Arabic).

4.Al- Gohary M (2002) : The role of some destructive factors affecting the weathering of the sandstone used in the birth house in Edfu, the book of the Fifth Conference of the

Archeology Associations between Arabs, Cairo. P143. (In Arabic).
5.Al- Humosani K (2007): Study of the problem of salts and their treatment in images and mural inscriptions in Saqqara region in application to one of the tombs chosen from the era of the old state, M.Sc Thesis, Faculty of Archeology, Cairo Univ, p155. (In Arabic).
6.Al-Mahari S (2006): a study of the impact of various damage factors on the ruins of some archaeological sites in the Kingdom of Bahrain, and proposals for restoration and maintenance in application of the archaeological ruins in SAR location, M.Sc Thesis, Faculty of Archeology, Cairo Univ. p111. (In Arabic).
7.Arthur L, Sanders A, Lawrence E, Keenan A (2005): Repair and Maintenance of Historic Marble and Limestone Structure Regular Maintenance Key to Longevity, Journal of architectural technology published by Hoffmann Architects, IncVol. 22, N 1. P 1-8.
8.Al-Omari A, Kevin B, Xavier B, Al-Mukhtar M (2015): Werathering of limestone on Al-Ziggurat walls in the ancient Al-Nimrud city (Iraq), Environ Earth Sci. 74: 609 -620.
9.Awad M (2002): Restoration of Archaeological Establishments, Dar Al-Nahda & Al-Sharq for Printing, first edition. P114. (In Arabic).
10.Awad S, Mahmoud A, (2007): An Introduction to Sedimentology, The Anglo-Egyptian Library, Cairo, p63. (In Arabic).
11.Charola A, Puhringer J, Steiger M (2007): Gypsum: a Review of its role in the deterioration of Building Materials. Environ Geol 53: 339-352.
12.Cultrone G, Sebastian E (2008): Laboratory simulation showing the influence of salt efflorescence on the weathering of composite buiding materials, Environ Geol 56: 729 – 740.
13.Dawn T (2001): Pore properties as indicators of breakdown mechanism in experimentally weathered limestones. Earth surface processes and landforms, V. 26, PP. 819 – 838.
14.Delalieux F, cardell C, Todorov V, Dekov V, Grieken R (2001): Environmental conditions controlling the chemical weathering of the Madara Horseman monument, NE Bulgaria. J. Cultural Herit. 2: 43 – 54.
15.Edwards J (2004): Cracking in historic masonry and surface finishes: Conservationapproaches and solutions, Journal of Building Appraisal, Vol. 1 No. 1, pp 20 – 33.

16.El-Badri A (2008): Acomparative study of the effect of weathering on the inscriptions of the rocky inscriptions of Eastern and Western Desert and the methods of treatment and maintenance in application to the selected sites, M.Sc Thesis, Faculty of Archeology,Cairo University. (In Arabic).
17.El-Kafafi A (2006): experimental and applied scientific studies in the treatment and maintenance of limestone in some ancient buildings in Egypt from microbiological damage, M.Sc Thesis, Faculty of Archeology, Cairo University. (In Arabic).
18.Fabry V, Seibel B, Feely R, Orr J (2008): Impacts of ocean acidification on marine fauna and ecosystem processes. ICES J Mar Sci 65: 414 – 432.
19.Fantle M, Tipper E (2014): Calcium isotopes in the global biogeo-chemical Ca cycle: implications for development of a Ca isotope proxy. Earth Sci Rev 129: 148 – 177.
20.Fitzner B, Heinrichs K, Bouchardiere D (2002): Damage index for stone monuments. Protection and Conservation of the Cultural Heritage of the Mediterranean Cities, Proceedings of the 5th Int. Symposium on the Conservation of Monuments in the Mediterranean Basin, Sevilla, Spain, April, pp 315 – 326 .
21.Gomma A (2007): Military fortify -cations in the northern coast of Egypt in the thirteenth century AH / nineteenth century, PH.D thesis, Faculty of Archeology, Cairo Univ, p 87. (In Arabic).
22.Hijab A (2011): a study of some aspects of air pollution represented by the surface layers of black (thin layers of the black - the black hard shell) on some facades of Islamic monumental buildings in the old city of Cairo (the problem and proposed solutions), published PH.D thesis, Dar Al-Kutub Egyptian, p175. (In Arabic).
23.Hoke G, Turcotte D (2004): The weathering of stones due to dissolution, Environmental Geology, International Journal of Geosciences, Springer- Verlag, pp. 1-16.
24.Kamh G (1994): The impact of geological conditions on the Islamic archaeological sites at El-Gammalia area, Cairo City, Egypt. MSc Thesis. Fac. Of Sci. Menoufiya. Univ.Egypt.
25.Kamh G (2003): Evaluation of Seven Resins as stone surface consolidants for four limestone facies using a magneto – structive Ultrasonic Technique, International Journal for Restoration of Buildings and Monuments, vol. 9, No 2, pp149-172.

26.Kamh G (2011): Salt weathering, bio-deterioration and rate of weathering of dimensional sandstone in ancient buildings of Aachen City, Germany, International Journal of Water Resources and Environmental Engineering Vol. 4(XX), P. xx.
27.Kapranos P, Al-Helaly M, Whittaker V (1981): Ultrasonic velocity measurements in 316 Austenitic Weldments. British Journal of non-destructive testing, V. 23 (6), P. 211.
28.Mahsoub M, Rady M (1989): Geomorphological Processes, Dar El Thaqafa for Publishing and Distribution, Cairo. P81. (In Arabic).
29.Maria A, Maria A, Emilio.G , Zezza. F (2000): The physical – mechanical properties and ultrasonic data as criteria for evaluation of calcareous stone decay. Proceedings of 9 th International Congress on deterioration and conservation of stone, June, Amsterdam, Elsevier, PP. 309-312.
30.Mcbride E, Picard M (2000) : Origin and development of tafoni in tunnel spring tuff crystal peak, Utah, USA, Earth surface processes and landforms, 25, pp 869- 879.
31.Mottershead D (1989): Rates and patterns of bedrock denudation by coastal salt spray weathering: a seven year record. Earth Surface Processes and Landforms 14: 383-398.
32.Mottershead D, Pye K (1994): Tafoni on coastal slopes, South Devon, UK. Earth Surface Processes and Landforms 19 (6): 543-563.
33.Rhoades J (1982): “Soluble salts”, Methods of soil analysis, Part 2: Chemical and micro-biological properties, Agronomy Monograph No. 9 (2nd ed).
34.Rodriguez – Navarro C, Doehne E (1999): Salt weathering: influence of evaporation rate, supersaturation and crystallization pattern. Earth Surf Proc Land 24: 191- 209.
35.Ruiz-Agudo E, Mees F, Jacobs P, Rodriguez-Navarro C (2007): The role of saline solution properties on porous limestone salt weathering by magnesium and sodium sulfates. Environ Geol 52:269–281.
36.Sharp A, Trudgill S, Cooke R, Price C, Crabtree R (1982): Weathering of the Balustrade on St. Paul’s Cathedral, London, (Earth surface processes and landforms, V. 7, PP. 387 – 389.
37.Shoulikids (1991): The Effect of pollution on Stone in Weathering & Air pollution, Venezia, 1991, pp 243- 272.
38.Smith B, Greevy M, (1983) Salt weathering in deserts. Proceedings. Geological Association, V. 92 (1), P. 1 – 16.

39.Sousa L, Suarez L, Calleja L, Ruiz de Argondona V, Rey A (2005): Influence of microfractures and porosity on the physico- mechanical properties and weathering of ornamental granites. Eng Geol 77:153–168.
40.SperlingC, Cooke R (1980): Salt weathering in arid environments I: Theoritical considerations, Bedford College, University of London, Papers in Geography 8.
41.Swe Y, Oguchi C (2010): Role of pore size distribution in salt uptake, damage, and predicting salt susceptibility of eight types of Japanese building stones. Engineering Geology, V. 115, 226 – 236.
42.Turkington A (1998): Cavernous weathering in sandstone: lessons to be learned from natural exposure, Q.J.E.G., V. 31, PP. 375 – 383.
43.Turkington A, Smith B (2000): Observations of three-dimensional salt distribution in building sandstone. Earth surface processes and landforms, V. 25, PP. 1317 – 1332.
44.Viles H, Moses C (1996): SEM based studies of the combined effects of salt and biological weathering on calcareous building stones (Proceedings of the 8th International congress on deterioration and conservation of stone, PP. 557 – 561.
45.Wellman H, Wilson A (1965): Salt weathering, a neglected geological erosive agent in coastal and arid environments (J. Nature, V. 205, PP. 1097 – 1098.
46.Winkler E (1966): Important agents of weathering for building and monumental stone, Eng. Geol., 1 (5), Elsevier publishing company, Amsterdam, pp 381-400.
47.Winkler E (1973): Moisture & salts in stone, stone properties duarability in man's Environment, New York, pp. 381 – 400.