Journal of Construction in Developing Countries, Vol. 15(1), 93–113, 2010

Treatment of Salt Attack and Rising Damp in Heritage Buildings in Penang, Malaysia

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Abstract: Of the common building defects that occur in heritage buildings in Penang, Malaysia, salt attack and rising damp are considered the most challenging, particularly for building conservation. Both problems of salt attack and rising damp are closely associated. Moisture from the rising damp makes the building's existing salts soluble, or ground water that contains salt finds its way through the building wall. This moisture then evaporates on or just below the wall's surface, leaving salt residue behind. High salt concentrations in masonry walls cause extensive fretting and crumbling of the lower parts of walls. These are formations gradually contribute to building dilapidation and reduce the building's aesthetic value. Sodium chloride and calcium sulphate are commonly found in masonry walls, apart from other forms of salts. The sources of these salts may be natural or manmade. This paper is based on research into the problems of salt attack and rising damp in heritage masonry buildings in Penang, Malaysia. Based on a case study of five buildings in Penang, the research findings showed that these buildings faced several common building defects, including salt attack and rising damp. Treatment guidelines for salt attack and rising damp are proposed within the Malaysian context of architectural heritage and climatic conditions.

Keywords: Conservation, Building defects, Salt attack, Rising damp, Desalination

INTRODUCTION

Heritage buildings are susceptible to deterioration due to several factors including climatic conditions, dampness and structural failures. Of the common building defects that occur in heritage buildings in Penang, Malaysia, salt attack and rising damp are considered the most challenging, especially for building conservation. Both problems of salt attack rising damp are closely related. Moisture from rising damp can dissolve the existing salts in the building material; in addition, ground water that may sometimes contain salt can find its way through the building walls. The Moisture then evaporates on or just below the surface of the wall, leaving salt residue and deposits behind. These formations gradually contribute to the dilapidation of the building, consequently affecting the building's aesthetic value.

This paper is based on research examining the problems of salt attack and rising damp in heritage

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masonry buildings in Penang, Malaysia. Five buildings in Penang were selected as case studies. This paper also discusses treatment guidelines for salt attack and rising damp that are appropriate in the Malaysian context of architectural heritage and climatic conditions.

SALT ATTACK

Various types of soluble salts are known to cause damages to building masonry, including sodium chloride, carbonates, nitrates and sulphates of calcium, magnesium, potassium, sodium sulphate and magnesium chloride (City of Adelaide, Department of Environment and Natural Resources, 1997) (see Table 1).

Table 1. Various Types of Salts in Heritage Buildings

Sodium chloride	$NaCl$
Sodium sulphate	Na_2SO_4
Hydrated sodium sulphate	$Na_2SO_4.10H_2O$
Hydrated calcium sulphate	$CaSO_4.2H_2O$
Hydrated calcium carbonate	$CaCO_3$
Hydrated magnesium sulphate	$MgSO_4.6H_2O$
Hydrated magnesium sulphate	$MgSO_4.7H_2O$
Sodium nitrate	$NaNO_3$
Hydrated sodium sulphate nitrate imdroxide	$Na_3(NO_3)SO_4.H_2O$
Hydrated sodium magnesium sulphate	$Na_2Mg(SO_4).4H_2O$

Salt attack is caused by moisture containing salts rising up through the capillaries of the brickwork from the ground below. These salts build up in the plaster and on brick surfaces over a period of time and attract airborne moisture. It is the expansion and contraction of such salts that causes the familiar rising damp symptoms of eroding and blistering paint and plaster. Common causes of salt attack include:

i. Windborne salt spray, if the building is located near a sea or river. Airborne salt (meteoric).

ii. Pollution from nearby factories.

iii. Biological factors such as bird droppings, fallen leaves remaining in blocked gutters, and sewer leakage.

iv. Brick clay puddling (salts used in the process leach into the soil).

v. Unsuitable chemicals used for cleaning.

vi. Urine (toilet) and animal blood/butchering (from fish or meat markets).

There are two types of salt attack that will depend on which building area the salt penetrates. When salt penetrates the surface and white powder is formed, this phenomenon is known as efflorescence and is harmless to the masonry (apart from creating an unsightly visual appearance). Salt may also attack by penetrating from below the surface; this is a more serious condition as the salt will become crystallised, a phenomenon known as subflorescence. Pressure from the growth of the crystallisation process will cause building materials to crumble, resulting in serious damage to the buildings (see Figure 1).

Salt-induced weathering is due to three factors, namely geographical location, type of sandstone (building materials) and cleaning regime (maintenance of the building). Environmental factors also contribute to accelerating the process of decay (Pombo Fernandez, 1999). Salt weathering occurs most often during the hot season (the summer months of November to April in the southern hemisphere) due to lower relative humidity and stronger sunlight. Large temperature changes and increasing rates of evaporation trigger more upward water movement in the building walls, resulting in the process of salt crystallisation (Arayanark, 2002).

Ground water contains chlorides and nitrates, which are hygroscopic. Both soluble salts can cause visual signs of dampness and decorative spoiling on the wall when present in large amounts. Chlorides can also often be

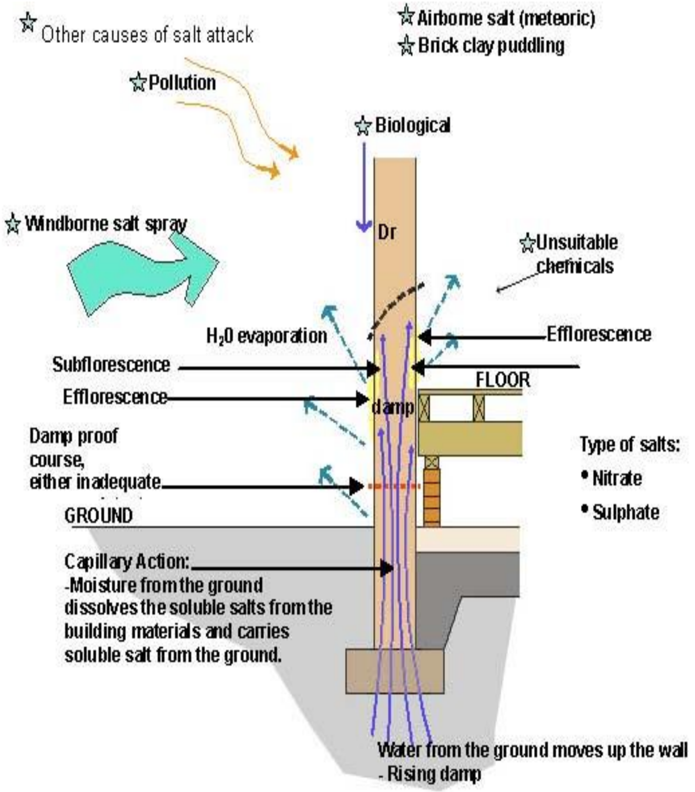

Figure 1. Causes of Salt Attack in Buildings

found in coastal areas, where they originate from salt water in the atmosphere. Gypsum plaster contains high levels of calcium sulphate, and efflorescence can be seen on wall surfaces where water is passing through and evaporating, resulting in sodium sulphate deposits. Cement-based products contaminated with sulphates result in the formation of calcium alumino-sulphate (ettringite) under conditions of dampness and high alkalinity, which causes the cement to expand more than 200%, leading to serious disintegration (Woolfitt, 2001)

Typically, walls infested with salt attack are also affected by rising damp. In such cases, rising damp occurs at the lower levels of the ground floor walls, where salt contamination can be seen. This is a serious problem as it could affect the strength of the existing load-bearing walls. A moisture meter can be used to measure the moisture content in the wall in order to determine the level of rising damp affecting the lower walls. Problems related to both salt attack and rising damp need to be tackled effectively and resolved by experts.

RISING DAMP

The problem of rising damp is common in buildings around the world. It contributes to decay in masonry buildings, especially with regard to load-bearing walls constructed of brick and mortar. All masonry materials are porous, including bricks. Bricks consist of voids or pores due to the nature of brick-making techniques. Bricks are permeable; water can pass through the pores via capillary action or a wicking effect.

Ground water is a common source of water that contributes to rising damp problems in the masonry wall. The higher the ground water table, the more severe the rising damp problem. The water table differs from one place to another depending on the geographical locations of buildings and type of soils.

The height to which water rises in a wall is determined by the rate of water evaporation from the wall surface (City of Adelaide, Department of Environment and Natural Resources, 1997). The rate of evaporation on the external wall is related to the nature of wall surfaces, climate, orientation and location. As moisture evaporates from both sides of the wall, more water is drawn from the ground and a continuous upward flow of water occurs. The rate of flow depends on the ground water table in a particular location. Rising damp may cause staining on the internal walls, especially if they have decorative wall coverings. In severe cases, rising damp causes plaster to crumble and paint to peel off. Musty smells are common in poorly ventilated rooms.

On the external walls, signs of rising damp can usually be seen at the base of the masonry walls, where crumbling plaster and peeling paint are evident. Severely affected masonry exhibits extensive decay, and powdery salt residue can clearly be seen at the base of the wall. If the latter occurs, the building requires extensive and costly repairs.

Rising damp can also occur because of defective ground and surface drainage in a building. A defective drainage system and/or plumbing system leakage can cause water to accumulate in the foundation and create a reservoir that can aggravate rising damp problems. The combined factors of a high water table, drainage system failure and lack of drainage slopes around buildings make rising damp problems even more critical.

Dampness on masonry walls may also occur if there is condensation within a room or an area. This usually happens when warm moisture in the air cools against a cold surface. This can be the main cause of dampness at the base of the walls rather than rising damp alone. This problem can be controlled, to some extent, by allowing for natural ventilation inside the room or area.

The combination of salt attack and rising damp has caused substantial damage to older buildings due to a lack of Damp-Proof Course (DPC). Installation of DPC was not common during construction work in the early 1900s. Lack of DPC installation allows soluble salts in the ground water to soak upward (via capillary action) in the masonry walls, dissolving soluble salts from the building material itself in the process and creating harmful salt residues on the wall that cause damage to the masonry (City of Adelaide, Department of Environment and Natural Resources, 1997). It is unfortunate that many buildings were constructed before people became aware of this problem. A lack of understanding of building maintenance is also to blame for the decay.

REVIEW OF RELATED STUDIES

Studies on salt attack and rising damp have been carried out extensively in Europe and Australia. Studies in Europe have often been conducted in Venice, Italy due to the location of the city, which is surrounded by sea. In Australia, salt studies have been carried out in cities or areas close to the sea including Sydney and Tasmania. Studies on salt attack have also been conducted in Thailand.

Deposits of water-soluble salts in the pores of historic masonry have been found to be the major cause of deterioration of these surfaces. Gauri et al., (1986) reported that soluble salts are inherent in brick, concrete and natural stone. Boyer (1986) revealed that polluted drain water, roof salts, de-icing salts and adjacent materials are sources of salt deposition. Ashurst (1994) asserted that careless cleaning with improper chemicals can deposit salts, causing masonry walls to deteriorate.

A report by The National Training Centre for Stone & Masonry Trades (1998) stated that the crystallisation of soluble salts in historic masonry can cause severe deterioration of the substrate, a phenomenon known as sub-florescence. Grimmer (1984) defined sub-florescence as a build-up of soluble salts, i.e., salt crystals, deposited under the masonry surface as moisture in the wall evaporates.

Problems associated with sub-florescence can be diagnosed by visual clues such as spalling and rising damp. Proper diagnosis of sub-florescence can be confirmed through laboratory testing. Several methods can be applied to remove the build-up of salts including water washing, surface rendering and poulticing. Once these salts are successfully removed, it is important to prevent reoccurrence. Preventative applications include installation of damp-proof barriers, chemical injection and coating the masonry with a sealer or impregnator.

In a study of damage to historic buildings and monuments in Venice, Italy, Collepardi et al., (2000) found that these damages were strongly related to the capillary rise of seawater. Acid rain due to SO_3 emission from nearby industrial areas was also found to contribute to the deterioration of historical buildings in Venice. The study showed the extent of the damage related to salt weathering producing efflorescence and sub-florescence as well as the formation of ettringite or thaumasite accompanying the salt crystallisation.

Buchwald and Kaps (2000) also revealed the existence and movement of water and damaging salts as the origin of numerous types of decay observed in masonry. They found that salt migration can be subdivided into at least two processes, based on different mechanisms. Ions of dissolved salts can be transported by the migrating water. In the case of long-term problems with moisture penetration, evaporation at the edge of the damp area leads to a distinctive tide mark as a result of salt deposition (Hutton, 2003). When this occurs at the base of a wall, the tide mark is often taken as a typical diagnostic feature of rising damp.

Fremantle (2000) cautioned that the rising damp phenomenon that occurs in buildings as a result of salt crystallisation in the brick pores, will, in turn, damage the brick itself. Fassina's study (2000) revealed that as more soluble chlorides and nitrates penetrate the building wall due to rising damp, the less soluble sulphates will usually concentrate at the lower part of the building wall. A definitive diagnosis is essential to evaluate the cause of dampness. This diagnosis requires data on the distribution of water within the building materials in order to determine whether there is an actual source of water ingress (free moisture) or whether the dampness has other related causes (Coleman, 2000).

A study by Bucea et al., (2005) observed deterioration due to salt crystallisation on both concrete exposed to sulphate solution and mortar exposed either to sulphate solution or chloride solution. Crystallisation deterioration was either due to sodium sulphate or a combination of sodium and magnesium sulphates or sodium chloride. The study found that chemical attack due to exposure to sulphate took place on both the concrete and mortar.

These previous studies on salt attack and rising damp have paved the way for the current study to examine similar problems in heritage buildings in Penang, Malaysia.

RESEARCH METHODOLOGY

The research methodology involved collecting primary and secondary data from various sources. Secondary data included reports, maps from the Geology and Mineral Department of Malaysia, and statistics from the (now-defunct) Museum and Antiquities Department of Malaysia, as well as other bodies involved in building conservation. These secondary data sources helped determine the location of the selected building, its proximity to bodies of water, orientation to the sun and other surrounding features/elements, as well as the building's history and the construction methods used. Information gathered from the Geology and Mineral Department was used to ascertain the type of soil and the level of water table on which the selected buildings stand.

Primary data collection involved site visits, interviews and samples taken at the five selected heritage buildings in Penang. Samples were stratified according to the spatial locations of the buildings and specifically their distance from nearby seas or rivers. Based on map references and previous reports, it was deduced that lowland areas had different salt content from highland areas due to climate differences, ground water and soil type. Highland areas were predicted to exhibit slower evaporation (due to cooler weather) and fewer salt attack problems than lowland areas. Moreover, buildings located near the sea and/or river might be more susceptible to salt attack due to the existence of sea spray and higher ground water levels. Overall, five masonry buildings located in George Town, Penang were selected for this research based on date of construction, size, location and orientation.

Salt samples taken from the selected heritage buildings were sent to the laboratory for ion chromatography tests. The ion chromatography test is a form of liquid chromatography that uses ion-exchange resin to separate atomic or molecular ions based on their interaction with the resin. Its greatest utility is for analysis of anions for which there are no other rapid analytical methods available on the market. For this study, ion chromatography tests were used to determine the ion compositions of the samples by specifying the percentage of soluble salts in the samples. The tests used conductivity detectors to analyse the samples taken from the buildings (in aqueous form) in parts-per-million (ppm) quantities of common anions such as fluoride, chloride, nitrite, nitrate and sulphate as well as other common cations, including lithium, sodium, ammonium and potassium.

Based on the findings, appropriate and suitable methods of treatment for preventing further salt attack and rising damp problems in each building were discussed.

BUILDING CASE STUDIES

This research utilises five case studies of prominent heritage buildings in George Town, Penang. These buildings are:

(1) The Old City Hall. Built in 1903 in Neo-classical style, the Old City Hall houses the Council Chamber and is part of the Penang Municipal Council's departments. The two-storey masonry building features several building elements made from timber.

(2) The Old Town Hall. This is the oldest building owned by the Penang Municipal Council. Its foundation was first laid in 1879 by Lt. Governor Sir Archibald Edward Harbord Anson and was officiated by Frederick Weld, the Governor of the Straits Settlement in 1880. The building has been extended several times in its history (in 1890, 1903, 1938, 1958 and 1991) to accommodate demands for more internal space.

(3) The Old Penang High Court. Construction on this building started in 1901 and was completed in 1905. The Old High Court Building was declared a National Monument in 2001 under the (now-defunct) Antiquities Act of 1976. Its architectural style is similar to the nearby Old Town Hall and Old City Hall, with British Palladian architecture featuring classical columns, balconies, a symmetrical layout and a front portico.

(4) Noordin Mausoleum. Located at no. 167, Chulia Street, Penang, this is a small site comprising two buildings and a graveyard. The Noordin Mausoleum is a single-storey building, while the other two buildings comprise a two-

storey school building and a single-storey street-fronting building. Mohamed Noordin, a prominent Indian Muslim trader, built these structures in the 1900s.

(5) Alimsah Waley Mosque. The Alimsah Waley Mosque and four units of shophouses in Lebuh Chulia were built on an endowment area (wakaf) administered by the Penang State Religious Council. The mosque was built in memory of the late Hadjee Abdul Cader Alim in the 1870s and rebuilt in 1952 after World War II.

RESEARCH ANALYSES

All five building samples were inspected according to the following premises:

1) Buildings located closer to the sea will have more severe salt attack problems.

2) Older buildings will have more severe salt attack problems.

The orientation and soil type of the building, as well as its surrounding features (such as large trees surrounding a particular building) will affect the evaporation rate of the rising damp, thus resulting in more severe salt attack.

The Old City Hall and the Old Town Hall are located closer to the sea than the other buildings; hence, these two buildings were more susceptible to salt attacks due to sea spray and higher ground water levels. Two other buildings – Noordin Mausoleum and Alimsah Waley Mosque – are located slightly further away from the sea and closer to the city centre, whilst the Old Penang High Court is located some distance away from the sea.

Three of the buildings – the Old City Hall, the Old Town Hall and the Old Penang High Court – are located on silt clay soil (closer to the sea). The other two buildings – Noordin Mausoleum and Alimsah Waley Mosque – sit on a high water table and clay sensitive soil (in an area that used to be a swamp and was reclaimed). The primary data for this research were derived from inspections of the building areas most affected by salt attack and rising damp. Two walls on the ground floor of each building were identified for laboratory tests. Each wall was drilled at depths of at 1 metre above the floor level in 3 stages, and at depths of 0–10 mm, 10–20 mm and 20–40 mm. All six drilling samples (in the form of powdery substance) were extracted from the locations, secured in plastic bags and labelled with reference codes. The samples were then sent to a laboratory in Australia, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), for ion chromatography analyses. These tests investigated the level of salt content that had accumulated in the masonry walls over the years. The results of the salt-content level would indicate the seriousness of the building problems as well as the types of treatment for salt contamination in all brick walls, particularly before the treatment of rising damp.

The results of the ion chromatography analysis of the masonry samples from each building were compared before and after undergoing salt desalination treatment. The three types of destructive soluble salts commonly found in the masonry samples of all these buildings were chlorides (Cl^-), nitrates (NO_3^-) and sulphates (SO_4^{2-}). Other types of salt found in the samples, namely calcium (Ca), potassium (K), magnesium (Mg) and sodium (Na), were not considered threats to the buildings. The results from each building are explained in the following sections.

SALT CONTENT RESULTS

Tables 2 through to 7 show the percentages of ionic concentration in the masonry samples of the selected buildings before and after salt desalination treatment. The pre-treatment readings indicate that the percentage of sulphates (SO_4^{2-}) is higher than that of chlorides (Cl^-) and nitrates (NO_3^-) in all of the masonry samples before salt desalination treatment. Readings in all samples are consistently higher at depths less than 20 mm from the masonry surface compared to that from depths of 20–40 mm.

Readings were also taken after salt desalination treatment. Data in all samples show some reduction in salt percentage in the masonry. Results from samples taken at a depth of 0–10 mm from the masonry surface show considerable reduction of the three most destructive soluble salts – chlorides (Cl^-), nitrates (NO_3^-) and sulphates (SO_4^{2-}) – which caused the most damage to the masonry. These readings indicate that the salt treatment applied was successful in reducing the percentage of salts in the masonry.

Tables 8 and 9 show the salt percentages in the masonry samples after a second application of salt desalination. The data in Tables 8 and 9 show that the second application of the salt treatment markedly reduced the salt levels in the masonry. This finding indicates that repeat treatment can further reduce the salt contents of the masonry to an acceptable level.

RESEARCH FINDINGS

The sources of salts found in the masonry walls of the buildings based on the analyses are shown in Table 10. Some sources were natural (e.g., soil and seawater), whilst others were manmade (e.g., products of the septic system).

Table 2. Percentage of Ionic Concentration in of Masonry Samples of the Old City Hall Before and After Salt Desalination Treatment (at Zone E)

Sample (Zone E)	Ca%	K%	Mg%	Na%	Cl^-%	NO_3^-%	SO_4^{2-}%	Total %
0–10 mm before	0.930	0.090	0.32	0.610	0.951	0.612	3.030	6.543
0–10 mm after	0.790	0.050	0.046	0.120	0.070	0.045	2.115	3.236
10–20 mm before	0.200	0.120	0.131	0.460	0.641	0.396	0.880	2.828
10–20 mm after	0.310	0.065	0.046	0.150	0.080	0.050	1.015	1.716
20–40 mm before	0.245	0.110	0.072	0.330	0.308	0.224	0.975	4.181
20–40 mm after	0.450	0.055	0.025	0.170	0.105	0.065	0.365	1.235
					Total % before treatment			13.552
					Total % after treatment			6.187

Table 3. Percentage of Ionic Concentration in Masonry Samples of the Old Town Hall Before and After Salt desalination Treatment (at Zone G–ZH)

Sample (Zone G–ZH)	Ca%	K%	Mg%	Na%	Cl^-%	NO_3^-%	SO_4^{2-}%	Total %
0–10 mm before	0.740	0.070	0.045	1.290	0.100	0.100	4.245	6.590
0–10 mm after	1.090	0.050	0.025	0.100	0.010	<0.005	2.720	4.000
10–20 mm before	1.865	0.065	0.040	0.365	0.050	0.065	5.270	7.720
10–20 mm after	0.660	0.050	0.025	0.100	<0.005	<0.005	1.740	2.585
20–40 mm before	0.905	0.060	0.035	0.425	0.040	0.455	2.900	4.820
20–40 mm after	0.295	0.050	0.015	0.105	<0.005	<0.005	0.880	1.355
					Total % before treatment			19.130
					Total % after treatment			7.940

Table 4. Percentage of Ionic Concentration in Masonry Samples of the Old Town Hall Before and After Salt Desalination Treatment (at Zone G–ZM)

Sample (Zone G–ZM)	Ca%	K%	Mg%	Na%	Cl^-%	NO_3^-%	SO_4^{2-}%	Total %
0–10 mm before	0.380	0.020	0.005	0.050	0.030	0.035	0.830	1.350
0–10 mm after	0.190	0.015	0.010	0.025	<0.005	<0.005	<0.005	0.650
10–20 mm before	0.105	0.020	<0.005	0.045	0.015	0.015	0.210	0.415
10–20 mm after	0.130	0.010	<0.005	0.015	<0.005	<0.005	<0.005	0.465
20–40 mm before	0.070	0.020	<0.005	0.030	0.020	0.020	0.080	0.245
20–40 mm after	0.275	0.025	0.010	0.036	<0.005	<0.005	<0.005	1.056
					Total % before treatment			2.010
					Total % after treatment			2.171

Table 5. Percentage of Ionic Concentration in Masonry Samples of the Old High Court Building Before and After Salt Desalination Treatment (Sample P1 ML/19–20)

Sample (P1 ML/19–20)	Ca%	K%	Mg%	Na%	Cl^-%	NO_3^-%	SO_4^{2-}%	Total %
0–10 mm before	0.641	0.025	na	0.070	0.632	0.049	0.122	1.539
0–10 mm after	0.207	0.051	0.009	0.022	0.016	0.017	0.284	0.606
10–20 mm before	0.192	0.024	na	na	0.104	0.011	0.079	0.410
10–20 mm after	0.251	0.013	0.009	0.010	0.004	0.003	0.108	0.398
20–40 mm before	0.121	na	na	0.010	0.002	0.040	0.031	0.204
20–40 mm after	0.111	0.017	0.007	0.034	0.008	0.006	0.100	0.283
					Total % before treatment			2.153
					Total % after treatment			1.287

Table 6. Percentage of Ionic Concentration in Masonry Samples of Noordin Mausoleum Before and After Salt Desalination Treatment (Sample AB/1–2)

Sample (AB/1–2)	Ca%	K%	Mg%	Na%	Cl^-%	NO_3^-%	SO_4^{2-}%	Total %
0–10 mm before	0.232	0.025	0.017	0.024	2.023	0.006	2.073	4.400
0–10 mm after	0.232	0.025	0.017	0.024	1.010	0.006	1.050	2.364
10–20 mm before	0.133	0.080	0.017	0.044	1.005	na	1.030	2.309
10–20 mm after	0.133	0.080	0.017	0.044	0.880	na	0.060	1.214
20–40 mm before	0.128	0.026	0.011	0.024	0.908	0.005	0.069	1.171
20–40 mm after	0.128	0.026	0.011	0.024	0.440	0.005	0.065	0.699
					Total % before treatment			7.880
					Total % after treatment			4.277

Table 7. Percentage of Ionic Concentration in Masonry Samples of Alimsah Waley Mosque Before and After Salt Desalination Treatment (Sample P1 ML/19–20)

Sample (P1 ML/19–20)	Ca%	K%	Mg%	Na%	Cl^-%	NO_3^-%	SO_4^{2-}%	Total %
0–10 mm before	0.244	0.117	na	0.655	0.160	0.046	0.536	1.758
0–10 mm after	0.245	0.056	0.004	0.211	0.036	0.009	0.165	0.726
10–20 mm before	0.279	0.071	na	0.207	0.229	0.014	0.242	1.042
10–20 mm after	0.332	0.045	0.004	0.163	0.031	0.009	0.281	0.865
20–40 mm before	0.308	0.045	na	0.098	0.016	0.008	0.187	0.662
20–40 mm after	0.279	0.036	0.004	0.125	0.025	0.007	0.183	0.659
					Total % before treatment			3.462
					Total % after treatment			2.250

Table 8. Percentage of Ionic Concentration in Masonry Samples of the Old High Court Building After Second Application of Salt Desalination Treatment (Sample P1 ML/19–20)

Sample (P1 ML/19–20)	Ca%	K%	Mg%	Na%	Cl^-%	NO_3^-%	SO_4^{2-}%	Total %
0–10 mm before	0.207	0.051	0.009	0.022	0.016	0.017	0.284	0.606
0–10 mm after	0.106	0.298	0.006	0.025	0.009	0.009	0.065	0.518
10–20 mm before	0.251	0.013	0.009	0.010	0.004	0.003	0.108	0.398
10–20 mm after	0.055	0.010	0.004	0.007	0.003	0.002	0.006	0.087
20–40 mm before	0.111	0.017	0.007	0.034	0.008	0.006	0.100	0.283
20–40 mm after	0.009	0.012	na	0.008	0.002	0.002	0.020	0.053
					Total % before treatment			1.287
					Total % after treatment			0.658

Table 9. Percentage of Ionic Concentration in Masonry Samples of Noordin Mausoleum After Second Application of Salt Desalination Treatment (Sample AB/1–2)

Sample (AB/1–2)	Ca%	K%	Mg%	Na%	Cl^-%	NO_3^-%	SO_4^{2-}%	Total %
0–10 mm before	0.232	0.025	0.017	0.024	1.010	0.006	1.050	2.364
0–10 mm after	0.106	0.298	0.006	0.025	0.009	0.009	0.065	0.518
10–20 mm before	0.133	0.080	0.017	0.044	0.880	na	0.060	1.214
10–20 mm after	0.055	0.010	0.004	0.007	0.003	0.002	0.006	0.087
20–40 mm before	0.128	0.026	0.011	0.024	0.440	0.005	0.065	0.699
20–40 mm after	0.009	0.012	na	0.008	0.002	0.002	0.020	0.053
					Total % before Treatment			4.277
					Total % after Treatment			0.658

others were manmade (e.g., products of the septic system).

This study showed that ions of the dissolved salts were transported via migrating water, primarily due to rising damp (Buchwald and Kaps, 2000). The percentages of total ions for soluble salts of chloride (Cl^-), nitrate (NO_3^-) and sulphate (SO_4^{2-}) deposits in the brick walls were found to be above acceptable safe limits. A percentage of total ions exceeding 0.020% are considered unsafe, as it may cause serious damage to the brick walls and lime plaster.

Table 10. Sources of Salts Found in Masonry Walls

Type	Symbol	Source
Calcium	Ca	Limestone, gypsum and fluoride
Potassium	K	Soils and electrolysis of chloride and hydroxide
Magnesium	Mg	Soils
Sodium	Na	Seawater and other natural water
Chloride	Cl^-	Seawater
Nitrates	NO_3^-	Product of septic systems
Sulphates	SO_4^{2-}	Limestone

The test results indicated that the percentage of total ions for SO_4^{2-} in all drilling samples was higher compared to that of other soluble salts. The percentage of nitrates NO_3^- and chlorides Cl^- total ions in the drilling samples also showed a high percentage of total ions. Test readings showed a higher concentration of the less soluble sulphate SO_4^{2-} on the lower part of the affected wall in comparison to the percentages of nitrates NO_3^- and chloride Cl^- deposits in the area; this is due to the nature of the nitrates NO_3^- and chloride Cl^- salts, which are more soluble and thus move further upwards (Fassina, 2000). Analysis of the five case studies showed that soluble salts were found in all five buildings in different percentages of total ions.

A summary of research results (see Table 11) shows that before salt desalination treatment, the walls of the buildings located closer to the sea – the Old Town Hall and the Old City Hall – had a higher percentage of total ions of soluble salts of chloride (Cl^-), nitrate (NO_3^-) and sulphate (SO_4^{2-}) deposits in the brick walls. In comparison, other buildings located some distance away from the sea front showed a lower percentage of total ions of soluble salts. This finding supports the first research premise that buildings located closer to the sea will have more severe salt attack problems.

The oldest building in this study, the Old Town Hall, had a higher 'before-treatment' reading at 19.130% than the Old City Hall, which had a reading of 13.552%. The other three buildings, which were 'younger', also showed a lower percentage of total ions of soluble salts. Thus, this finding supports the second research criteria or premise: that older buildings will have more severe salt attack problems.

Two different readings were recorded for two different walls in the Old Town Hall building, Zones E–ZH (seafront) and E–ZM (city). The findings showed that the different walls of the building had differing levels of salt attack due to the influence of the surrounding features and orientation; the seafront wall (Zone E–ZM) had a higher percentage reading than the city wall (Zone E–ZH) due to prolonged exposure to the salt from seawater. In another case, although the Noordin Mausoleum and the Alimsah Waley Mosque buildings are located further away from the sea and nearer to the city center, the results showed a high percentage of salt content in their readings due to the high water table on site. The results indicate a lower reading for Noordin Mausoleum than Alimsah Waley Mosque due to the fact that the mosque was built some 40 years earlier. These findings support the third research criteria or premise: that a building's orientation (facing the sea or otherwise), soil type and surrounding features, including a high water table, will increase the evaporation rate of rising damp and result in more severe salt attack.

Table 11. Summary of Research Findings

Building	Year built	Close to sea	Orientation / surrounding	% salt before	% salt after
Old City Hall	1903	Yes	Sea-front wall	13.552	6.187
Old Town Hall (Zone G–ZH)	1879	Yes	Sea-front wall	19.130	7.940
Old Town Hall (Zone G–ZM)	1879	Yes	City-front wall	2.010	2.171
Old Penang High Court	1905	No	City-front wall	2.153	1.287
Noordin Mausoleum	1900s	No	City-front wall	7.880	4.277
Alimsah Waley Mosque	1870s	No	City-front wall	3.462	2.250

All test results clearly showed that the masonry walls of the buildings were highly contaminated with soluble salts. It was also confirmed that buildings with a high level of salt content, particularly sulphate (SO_4^{2-}) deposits, were at high risk. This situation results in the deterioration of not only the conditions of the existing plasterwork and mortar joints, but also the old bricks. Salt contamination problems on brick walls were resolved through the process of poulticing, whilst the problem of rising damp was treated with the injection of a chemical damp-proof course into the lower parts of the walls.

The process of poulticing, also known as the Cocoon method, involves the application of a damp-absorbent material (pharmaceutical fibre mixed with distilled water) that dries out, drawing the salts from the material. After several weeks, the poultice is removed from the wall surface, taking the salts with it. The process is repeated as often as necessary to reduce the salt concentration to an acceptable level.

The injection of a chemical damp-proof course is the cheapest and easiest way to provide barrier in masonry walls to prevent rising damp. The treatment has to be applied prior to the treatment of salt attack. Chemical injection is carried out by drilling into both sides of the affected walls. The drilling is usually carried out at intervals along the wall at about 6 inches from the floor to a particular depth (depending on wall thickness). A silicone-based chemical is then injected either by using gravity flow or pumps until it is saturated and forms a moisture barrier that later prevents any water or dampness from moving upward in the masonry walls.

Figure 2. Treatment of Salt Desalination on Wall Surfaces Through the Process of Poulticing

Figure 3. Treatment of a Course of Damp-proofing Through Chemical Injection

GUIDELINES ON TREATMENT OF SALT ATTACK AND RISING DAMP

Due to the natural destructive behaviour of salt, heritage buildings that undergo restoration work need to be treated against salt attack. In building conservation, once salt attack is detected and identified, further scientific studies need to be carried out. A proper treatment for salt attack is then proposed to overcome the problem. Preventive maintenance procedures to detect and combat salt attack problems are also required in the maintenance of heritage buildings. The following are treatment guidelines for salt attack and rising damp that are appropriate in the Malaysian context of architectural heritage and climatic conditions.

The guidelines for salt attack treatment can be summarised as follows:

i. Inspect any sign of salt attack in areas that are prone to salt attack such as toilet walls, internal and external walls, and column bases.
ii. Use a moisture meter to determine dampness in the wall and the height of the rising damp on the affected wall.
iii. Conduct scientific studies by drilling samples from the wall in order to determine the level of salt contents and types of salts present.
iv. Apply the appropriate treatment to the wall to eradicate the salt attack problem. Examples of treatments include sacrificial rendering, poulticing or chemical wash, depending on suitability.
v. Prepare another round of drilling samples for the laboratory to see whether the first treatment is successful. If not, another round of treatment should be applied until the salt content in the wall is at a safe level according to international standards.
vi. Prepare a preventive guide for salt attack for future reference.

The guidelines for rising damp treatment can be summarised as follows:

i. Look for visual indicative signs of rising damp problems. Investigate more deeply in areas that are prone to rising damp, such as shaded areas. A soil test report is necessary to determine the level of the water table at a building site.
ii. Use a moisture meter to determine the level of water presence and the height of the rising damp in the affected wall.
iii. Apply the appropriate treatment to the wall to eradicate the rising damp problem. The type of treatment should depend on the type of walls affected. Examples of treatments include chemical

injection, mortar injection, electro-osmosis and insertion of physical damp-proof course.

iv. Observe and monitor the effectiveness of the treatment.

v. Prepare a preventive guide for rising damp for future reference.

CONCLUSIONS

Salt attack and rising damp together pose a serious threat to buildings as they may cause unsightly deterioration of building exteriors and interiors as well as possible building structure failures if left untreated. Hence, it is very important to reduce the level of salts in old buildings to ensure the health and safety of the premises. Proper methods and techniques for treating salt attack and rising damp should be applied as part of restoration work. Those involved in the restoration of old buildings must be fully aware of such problems and treatments.

Scientific analyses and laboratory tests on salts should be carried out during restoration work in order to have a better understanding of how to handle the problem of salt attack on buildings. Findings from laboratory tests need to be analysed carefully to determine the severity of the rising damp and salt attack problems. A proper technical report with the results and findings should be produced for future reference, particularly during repair and maintenance works. This documentation exercise could be the basis for establishing restoration principles and guidelines for salt desalination in heritage buildings.

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