# Practical and Analytical Methods for Evaluating Deterioration in Brick Walls

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## 1. Abstract

Salt deterioration in the brick walls of the historically valuable 18th century fortress of Suomenlinna near Helsinki, Finland, has been the topic of intense investigation over the past few years. The methods used have proved very suitable for in situ investigations. Previous analyses and test cycles carried out in the test room of the Tenaille von Fersen (TvF) building, one of the sites of investigation and the subject of an EU Heritage laboratory project, have provided new and vital clues to the causes and mechanisms underlying brick deterioration. This report gives a brief outline of the methods and equipment used for evaluating the deterioration process of brick walls in situ. The results, obtained from changing the climatic conditions of the test room and within the walls, will be used to formulate concrete directives for optimising the temperature and humidity of the Great Hall of the building. In this way it is hoped to minimise deterioration while ensuring comfort for visitors. The European Heritage project is due to end in autumn 2002.

## 2. Introduction

The phenomenon of deterioration of natural stone surfaces, fired brick stones, mural paintings and sculptures of various materials has been the subject of intense study over the past 10-20 years, but mainly through laboratory experiments or small-scale measurements on site. The first such studies began in 1980 in Finland and focused on two objects: a fortress in Hämeenlinna (built and rebuilt in the 13th–15th centuries) NW of Helsinki with an inland climate, and the fortress of Suomenlinna on an island just outside Helsinki. The fortress of Suomenlinna was built in the mid-1700s. UNESCO added the island to its World Heritage list in 1991.

Today the problem of salt deterioration in the brick walls and floor tiles of old brick buildings is especially important to solve, because their use has changed, the climatic conditions have changed, and laboratory experiments no longer suffice to find workable solutions for limiting the deterioration.

These buildings were both left unheated for years, but today the Hämeenlinna fortress is used as a museum. The Tenaille von Fersen (TvF) building on Suomenlinna will soon boast an exhibition room, a café and a beautifully vaulted Great Hall which already serves as a favourite venue for weddings, concerts and other performances. The hall was once a granary located above a horse-driven pump room.

*FIGURE 1 Tenaille von Fersen, the Great Hall set out for a dinner*

In order to study the deterioration process in the TvF building and develop specific directives for optimally regulating the temperature and humidity, the (TvF) Deterioration Mechanisms Study was launched in 1999 under the auspices of the European Commission's European Heritage Project. The programme is based on an earlier series of laboratory tests performed between 1979 and 1985 in the TvF building [1-3] and current tests in situ in which the temperature and humidity are regulated in a test room and in the Great Hall during use.

This report briefly outlines the method used for evaluating the deterioration process of brick walls. The results of measurements to date from the test room and Great Hall are reported in the International Journal for Restoration of Buildings and Monuments 2002 (in print) /4/ .

## 3. Salt and moisture in the construction

Many analyses performed 20 years ago on samples of deteriorated and intact bricks from Hämeenlinna and Suomenlinna revealed the main factors involved in deterioration. Some 30 brick samples, drilled from the 2 – 3.5 m thick walls at different depths and in different places, were collected as dry brick powder and analysed quantitatively and qualitatively. In general the salt content of samples from inside the building was 1 – 5% by weight in the surface of the wall and 0.2 – 3% at a depth of 0.5m.

It is known that water-soluble salts have a specific equilibrium relative humidity ($RH_{eq}$). As long as the relative humidity of the immediate surroundings is above $RH_{eq}$ the salt remains in solution in the pores of the brick surface, i.e. $RH > RH_{eq}$. If enough moisture evaporates to lower the RH below this threshold, the salt solution becomes saturated and precipitates, depositing crystals on the brick surface, i.e. $RH < RH_{eq}$. In the literature the $RH_{eq}$ of several salts are listed and a thermodynamic model for calculating aqueous salt solutions in porous materials is reported by C. Price /5/. The calculation or measurement of $RH_{eq}$ for double-triple salt solutions in a very inhomogeneous brick wall with different salt combinations is far more complex.

The previous laboratory tests showed that salts change shape as they move between different humidity levels [2, 3]. This is true both of salts binding hydrates (sodium sulphate and sodium carbonate) and of those not binding hydrates at any moisture level (halite, nitratine). These changes in volume in relation to the surrounding moisture of the brick surface are one important factor influencing deterioration.

The moisture in the building varies between 30% and 80% RH and the thick brick wall is wet throughout the year, at 80-90% RH. The main salts identified in the test room were halite and trona. Smaller amounts of nitratine and thenardite were also found on walls where halite was the main salt. Overall, the type and quantity of salts vary in the building from room to room, but also within each wall. As there is no logical explanation for this vast range and variation of salts, treatment tests were begun on site instead of persisting with laboratory experiments. It is now imperative to determine what is really happening in the building itself rather than focusing exclusively on salt types.

## 4. Quality of the brick stone

The degree of deterioration generally depends on the brick quality, stage of crystallisation (drying out or getting wet), and frequency of crossing the crystallisation humidity threshold of the salt mixture in either direction. The bricks most strongly affected were weakly fired and found upon x-ray to contain clay minerals such as mica and amphibole. The firing temperature influences the quality of the brick – a higher firing temperature gives better durability, not only in terms of frost resistance but also in terms of resistance to salt deterioration. Salt deposits on such bricks are not unusual, but the brick surfaces have not deteriorated.

Other physical properties of the brick samples such as porosity, water suction, dilatation etc. were analysed to find a correlation between these properties and salt deterioration. However, the main information from these analyses is that weak bricks tend to deteriorate. An old normal brick wall has bricks of both good and poor quality, and the whole wall and vault have to be dealt with regardless of quality. The problem therefore arises of what to do with the brick walls to decrease the deterioration caused by constantly changing humidity and salts formations. All of this led us to start analysing the deterioration of brick walls in situ under real conditions while the building is in use. Tests involving changes in RH and temperature during numerous measuring cycles in an L-shaped test room in the building were carried out.

## 5. Method for evaluating the salt deterioration in brick walls

### 5.1 Treatment tests – changes in climatic conditions

Equipment needed for the treatment tests were as follows:

- Humidity and temperature sensors for continually monitoring changes in the room climate
- Humidifiers
- Air drying equipment (building air dryer) or a good ventilation system in the room

#### 5.1.1 Calibration of humidity sensor probes

Wall-mounted humidity and temperature transmitters (Vaisala transmitters) with cable probes were installed in the test room.

The probes had to be calibrated for a wide humidity range of 20-100% RH. Salts used for these calibrations were lithium chloride ($RH_{eq}$ 11%), magnesium chloride ($RH_{eq}$ 34%) and potassium sulphate ($RH_{eq}$ 98%). Because of the corrosive medium of the salts and moisture in the walls the probes need to be calibrated every 6 months.

### 5.1.2 Installation

The probes are placed in the surface of the brick and deeper inside the wall (e.g. 10 mm deep for the surface measuring sensor and 100 mm or 200 mm for the other one). One sensor is needed for measuring the humidity and temperature of the room. In our tests we drilled holes 10 mm in diameter for the probes, cleaned the holes carefully after drilling, and isolated the sensors from the surrounding air with insulation used for electrical installations.

All of the measurement data (once hourly) was collected digitally.

The effect of the humidifiers should be regulatable. With an air dryer or good ventilation system, high moisture in the room can more rapidly be reduced to normal values. This is especially important during spring and summer, when the relative moisture is generally high.

### 5.1.3 Example of a test cycle

Below we give the outline of a test cycle during which the moisture was increased stepwise at constant temperature, and the deteriorated material (debris) was collected after each change.

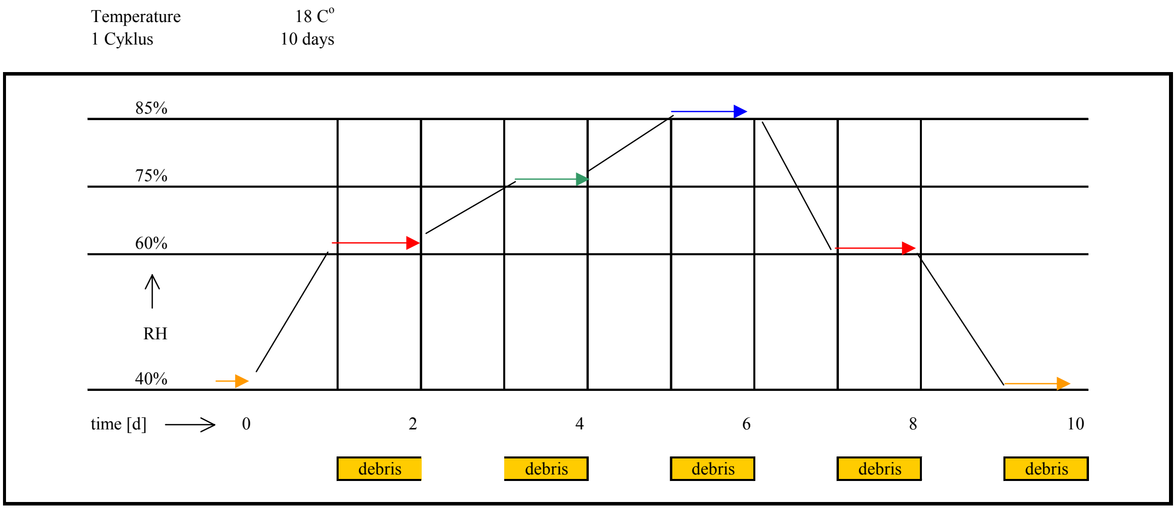


*FIGURE 2. Test programme for measuring deterioration during short (2-day) treatment periods.*

## 5.2 Analysis of deterioration

The methods used to evaluate the deterioration include the following:

- Analysis of deteriorated brick
- Analysis of the soluble salt content
- Analysis of changes to the brick wall itself

The deterioration process can be monitored fairly simply by collecting deteriorated material at given times for analysis.

### 5.2.1 Equipment

- Aluminium receptacle (100 x 100 mm, length 0.5 - 1m) for collecting debris from the wall
- Digital scale with 0.1 g accuracy.
- Oven for drying the collected material (~ 110°C).
- Strips of cloth (~60 mm x receptacle length) for hanging from the wall over the receptacle edge, especially on uneven wall surfaces, to prevent brick powder from falling behind the receptacle.

- Sieves: # 1.5 mm and # 5 mm

### 5.2.2 Procedure

Measurements must be done where there is no risk of contamination from bird droppings, cigarette butts or other waste.

Collection of brick powder and debris for analysis from each wall (part of a wall) separately is done after each treatment programme, also during especially long programmes.

The collected material is kept in the drying oven at about 110°C until dry (overnight). When cooled the material is weighed and passed through # 1.5 mm and # 5 mm sieves. Brick pieces larger than 20 mm are not included in the calculations in order to avoid extreme values, but they are registered in the laboratory manual. The amount of deteriorated material has to be calculated for each fraction.

Although salt is included in the deteriorated material, its weight can normally be considered negligible compared to that of the brick. If there is a lot of salt among the collected debris, the salt should be washed out of the sample. The salt content can be analysed as described below.

### 5.2.3 Presentation of the results

Deteriorating unit: $\frac{a}{b \times c}$ [g/m²·d]

where

a = deteriorating material (g)

b = square metre of analysed brick wall

c = time of treatment in days

*FIGURE 3. View from the TvF test room. Debris collected from receptacles.*

### 5.2.4 Analysis of soluble salt content of the brick masonry

About 50-100 g of deteriorated brick is crushed to under # 5 mm [mt] and left overnight in 250 ml distilled water. Next day the solution is filtered, and 100 ml of the filtrate is left to evaporate slowly in an oven (110°C). The precipitate is then weighed [ms].

Calculation: Soluble salt $= 250 \frac{ms}{mt}$ [% by weight of the dry brick powder]

### 5.2.5 Analysis of the brick walls

The brick walls are studied carefully to determine their condition before and after treatment. One way is to map the wall brick by brick, making it easier to follow changes to each individual brick, especially in relation to salt behaviour.

The following information is mapped with colours and symbols on a diagram of the walls.

1. Deteriorated bricks
    a. Deteriorated as a powder
    b. Deteriorated as small pieces
2. Bricks with salt deposits
    a. With whiskers
    b. With dried salt layer
    c. With fresh salt crystals
3. Bricks with brick powder on the salt deposit
4. Wet bricks

The above results can be used to monitor changes in deterioration and salt formation. Together with the moisture and temperature measurements of the walls, they provide valuable insight into the nature of the deterioration process.

## 5.3 Examples of measurements and results from the TvF test room

The changes in humidity are calculated in terms of absolute moisture [g/m³] instead of RH to give a clear picture of moisture changes. The brick deterioration as collected debris before and after each period of the test is calculated as deter.index [mg/m²d] and represented in the figures as dots.

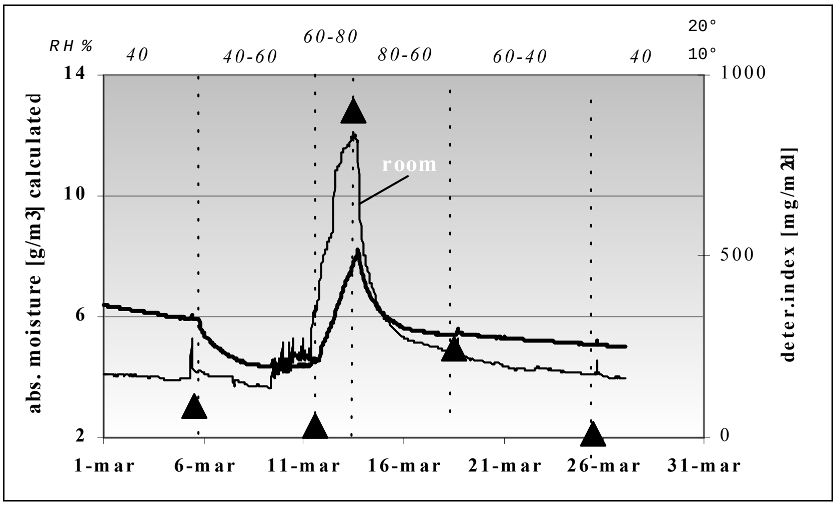


*FIGURE 4. Deterioration of one wall during changes in moisture in the test room during a 1-month test cycle. The deter.index reaches its maximum value during the period from 60-80% RH, when the moisture in the room rises above the moisture of the wall, represented by the thick line.*

Figure 5 showing amounts of collected debris from the whole test room clearly demonstrates the validity of this method for monitoring the deterioration process during moistening and drying periods. In all of these test cycles the greatest deterioration appeared during the moistening period.

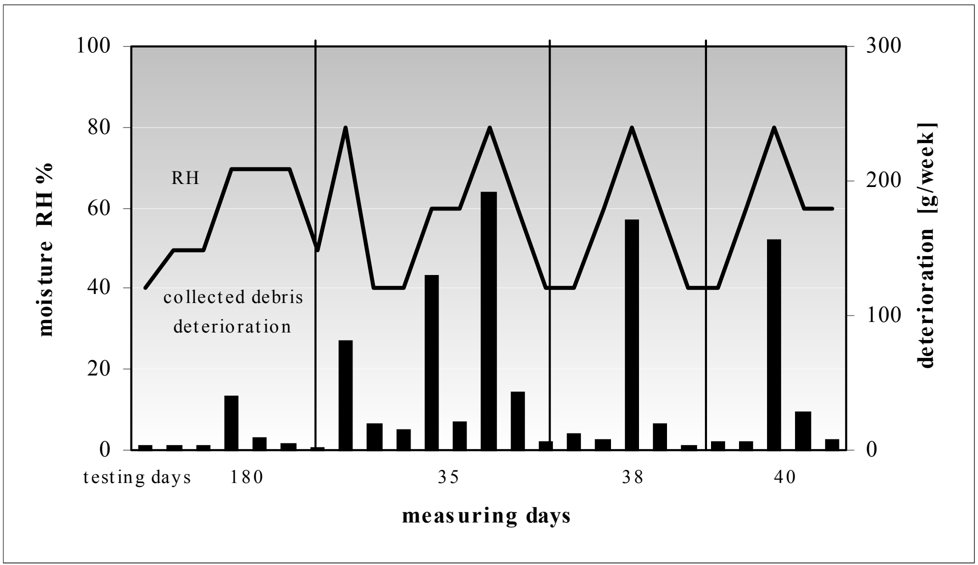


*FIGURE 5. Results of four test cycles in the test room. The line denotes the relative humidity of the room. The columns show the collected debris from all the walls. The x-axis shows the length of the test period.*

From the calculations of the in situ tests the following correlation to changes in the climate condition can be observed:

- Amount of deteriorated brick stone (as deter.index)
- Influence of salt type(s) in the wall on deterioration
- Drying/moistening of the room and surface and its influence on deterioration
- Moisture movement within the brick wall

## 6. Conclusions

Based on the encouraging results of the in situ tests in the TvF building itself, we hope to find the right directives for ventilating the building and optimally regulating the temperature and humidity of the rooms in the building. The climatic conditions must be comfortable enough for visitors and suitable for the brick walls, limiting the stress caused by salt effects during extreme periods of moisture. Some tests are still in progress, and the results from the deterioration and mapping of the walls provide further important understanding of the salt deterioration problems in the TvF building. The European Heritage project is due to end in autumn 2002.

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