# WITTENBERG'S CASTLE CHURCH TOWER
## CLASSIC EXAMPLE FOR SUCCESSFUL MONUMENT RESTORATION

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## 1 INTRODUCTION

The destruction of building materials by environmental influences has increased rapidly in recent years. Our public buildings, made of natural stone, are especially vulnerable in this respect. Destruction may be due to the nature of the building material and its binder on the one hand, and on the other to the age of the structure and, often, its exposed position. Many years ago appeals were made to the population as well as to industry to take measures against the growing decay of monuments and buildings. Products have been developed in recent years for the protection and conservation of stone, which are being used with great success. The purpose of this paper is to show the successful use of silicon organic products for the restoration and conservation of a famous monument, the tower of Wittenberg's castle church. Before details of this work are presented, a short description of the most important damaging processes is given.

## 2 MECHANISMS OF STONE DESTRUCTION

The breakdown of natural stone is caused by many different factors. First of all, it is necessary to consider the type of natural stone involved. Porous, limebased sandstone, for example, weathers in totally different way compared with dense, pure limestones such as marble. Eruptive stones, on the other hand, have such excellent weathering resistance that stone destructionis unlikely to be a major problem.

Weathering processes are initiated and influenced by the absorption of water and harmful substances. Three types of weathering can be distinguished: mechanical, chemicall and biological corrosion. The destruction of porous, lime-based natural stone through chemical corrosion is a special problem at the present time. Here, breakdown of the stone is caused by the action of acid waste gases, mainly sulphur oxides, on the lime binder, which is transformed into gypsum which is carried to the surface of the stone by the migration of water. The binder is thus chemically changed and at the same time removed from the stone. Besides this, weathering processes are largely initiated by the absorption and formation of salts resulting in the mechanical breakdown of the material. Here a summary of destructive processes:

*Mechanical corrosion*

- frost damage
- salt damage
  - through crystallisation
  - through hydration
  - through hygroscopicity
- road salt damage

*Chemical corrosion*

- loss of binder through chemical change into salt

| | | | |
|---|---|---|---|
| $CaCO_3$ | $+ H_2SO_4$ | $\rightarrow CaSO_4$ | $+ H_2O + CO_2$ |
| lime | + acid rain | → gypsum, | + carbonic acid |
| insoluble | | soluble | |
| binder | | salt | |

- migration of binder as cause of natural encrustation

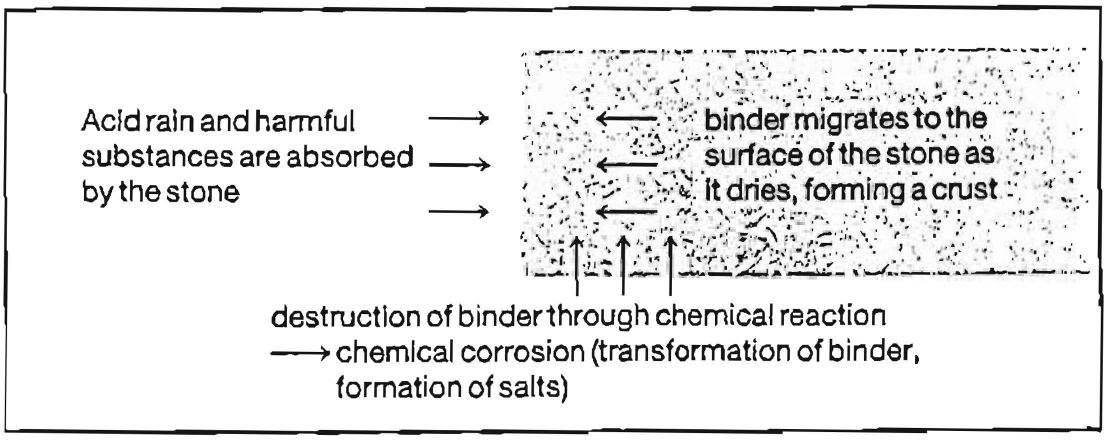
| | | | |
|---|---|---|---|
| $CaCO_3$ | $+ H_2O + CO_2$ | $\rightleftharpoons$ | $Ca(HCO_3)_2$ |
| lime | rainwater | drying | calcium bicarbonate, |
| insoluble | | | water soluble |

The calcium carbonate binder which is converted into calcium bicarbonate inside the stone is carried to the surface as the stone dries, where it is deposited once more in the form of calcium carbonate.

*Biological corrosion*

- building materials are attacked by microorganisms such as algae, lichens, mosses and bacteria
- formation of salts by products of metabolism

As pointed out later, the tower of Wittenberg's castle church consists mainly of porous sandstones. These stones usually weather from the inside outwards, forming crusts and reducing the surface to a thin shell:



# 3 STONE PRESERVATION

As shown above, the destruction of stone through weathering is mainly due to loss of binder caused by its transformation and migration to the stone's surface. The purpose of stone conservation is to restore the stone substance by replacing lost binder, and at the same time to protect the stone against weathering in the future. Modem stone preservatives must have the following characteristics:

- Formation of a new, weathering-resistant binder - preferably mineral in nature.
- Deep penetration into natural stone, at least through to the undamaged core of the stone.
- No formation of salt by-products that would cause damage to the structure.
- No change or impairment of the important physical characteristics of the stone, especially its water-vapour permeability, thermal and hygric behaviour.
- Reduction of the stone's absorption of water and other harmful substances.

The best stone-reinforcing agents known to date for meeting these requirements are those based on silicic acid esters.
These products react according to the following equation:

$$Si(OR)_4 + 4\,H_2O \xrightarrow{\text{catalyst}} SiO_2 \cdot x\,H_2O + 4\,ROH$$

where $ROH$ = alcohol
$SiO_2 \cdot x\,H_2O$ = silica gel

This reacton deposits a mineral silica gel as a new binder in the pore system of the stone. The binder destroyed by weathering is replaced by the silica gel. The concentration of the active constituents determines the amount of silica gel formed. For many types of stone, an active concentration of about 75 % - corresponding to about 350 g silica gel per kilogram of consolidating agent - has been found particularly suitable.
With extremely porous stones, an excellent penetration depth of 10 to 20 cm can be achieved because of the low viscosity and low molecular weight. Stone conservation agents based on silicic acid esters, therefore, deposit the silica gel binder deep within the stone, just where it is needed.
Since the quantity of binder formed is proportional to the concentration of the active ingredient, it is impossible to fill the pores completely. After the consoli-

dating treatment, the pore system remains permeable to water vapour and gas.

The best-known stone reinforcing agent worldwide is **WACKER Stone Strengthener OH** which has been marketed by Wacker-Chemie for almost 30 years. The product is a mixture of monomeric and oligomeric silicic acid esters. A metal-organic catalyst enables fast curing to a solid, tack-free silica gel.
WACKER Stone Strengthener OH, however, does not significantly reduce the capillary absorption of water and dissolved harmful substances. To achieve both strengthening and water repellency, Wacker-Chemie has developed a product called **WACKER Stone Strengthener H** which is also based on silicic acid esters but contains also water repellent organo-silicon components, such as silanes or siloxanes.

Due to its better strengthening performance, optimal stone conservation is in a first step to do strengthening with WACKER Stonestrengthener OH and in a second step to do the water repellent treatment.
Wacker-Chernie offers a wide range of water repellent products. All are based on alkoxy functional silanes and siloxanes. The most important products are **WACKER 290, WACKER SMK® 1311** and **WACKER BS 1001.** All three are highly effective on a great variety of natural stones as well as on most artificial mineral substrates, eg concrete, bricks, plasters etc. Table I summarizes the products characteristics and shows their differences:

TABLE 1
Comparison of some water repellent products

| *product* | *composition* | *active ingredient content [%]* | *diluent* |
|---|---|---|---|
| WACKER 290 | silane/siloxane mixture | 100 | organic solvents |
| WACKER SMK® 1311 | silicone microemulsion concentrate | 100 | water |
| WACKER BS 1001 | silan/siloxane emulsion | 50 | water |

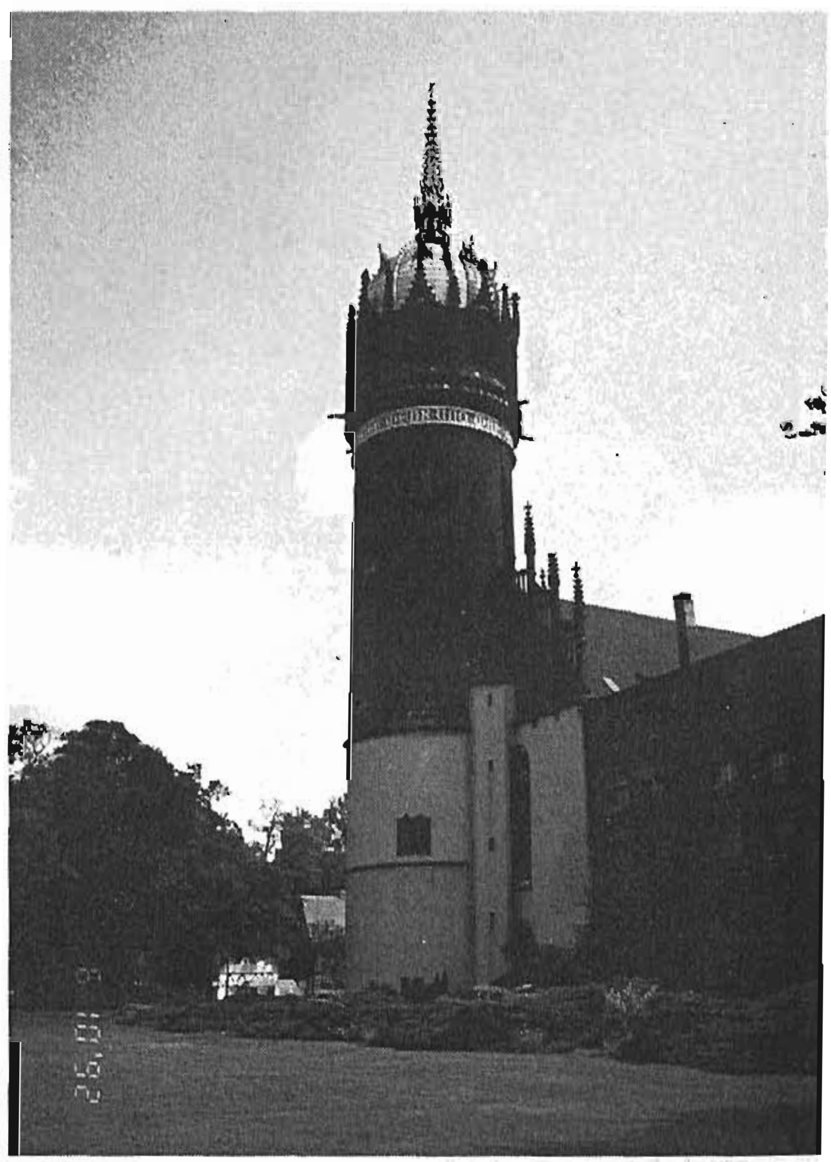
WACKER 290 is well established for approximately 20 years. However, as solvents are being increasingly branded as harmful, water borne systems have become more and more important.

WACKER SMK® technology is a very extraordinary approach to transfer silicones into water. Silicone microemulsion concentrates based on WACKER SMK® are 100 % silicone products which form spontaneously silicone microemulsions when poured into water. Details about this technology can be read in the literature (H. Mayer; *Tenside Surf. Det.,* **30** (1990) pp 90 - 94).

WACKER BS 1001 is the most recent development of Wacker-Chemie. In contrast to WACKER SMK® 1311 , dilutions of WACKER BS I00I in water are storage stable. Therefore, the product can be prediluted, whilst WACKER SMK® 1311 has to be diluted on the same day when it is used.

# 4 CONDITION OF WITTENBERG CASTLE CHURCH TOWER

Before work can be started on the restoration of a monument, the extent of structural damage must be determined and its causes analysed.The photograph below shows the tower in its original condition:



The lower section of the tower consists of plastered masonry. The plaster, which contains cement, was renewed only a few years ago. The upper section consists of sandstone squares and sandstone ornaments. The surfaces are badly soiled and in the rain-protected areas in particular there are thick, black crusts of dirt as shown by the next photograph.

Many stone samples were taken in the form of drill cores to determine the causes of the damage observed. These samples were analysed to determine their salt content (chloride, sulphate, nitrate) and their water-absorption capacity (capillary and hygroscopic).
The results showed that the building consists of two types of sandstone which can both be classified as *Elbe sandstones* (sandstones from the region of the river Elbe). The materials were analysed for the purpose of more detailed characterisation, and the results are shown in table 2.

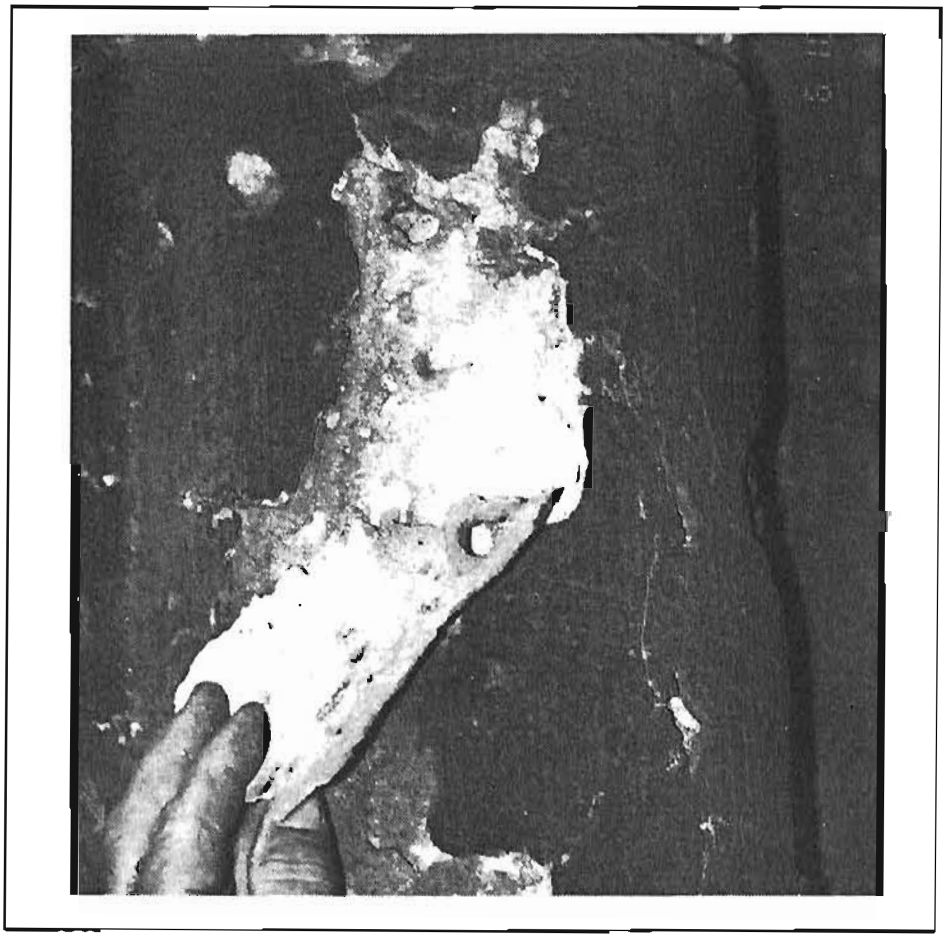


TABLE 2
Characteristic data of the Elbe sandstones types A and B

| | *Sandstone A* | *Sandstone B* |
|---|---|---|
| Colour | white | yellow |
| Grain size | medium | medium |
| $H_2O$-soluble components | 0.25 % | 0.38 % |
| HCl-soluble components | 0.5 % | 0.81 % |
| Water absorption coefficient | 10 $kg/m^2h^{0.5}$ | 5.5 $kg/m^2h^{0.5}$ |
| Pore volume | 15.95 % | 16.38 % |
| Pore filling ration | 10.72 % | 6.47 % |
| Clay mineral content | very low | average |
| Iron content | 0.02 % | 0.19 % |

Both sandstones contain a silicate binder. The low clay mineral and iron content of type A points to its being a *Postaer Sandstone.*
Sandstone B contains rather more clay minerals and iron and its colour is therefore more intense. Its appearance seems to be that of a *Kottaer Sandstone.*

Low salt concentrations are present in the interior of the sandstones, as expected, but these concentrations increase considerably towards the exterior. The pollutant content is especially high on the sandstone surfaces and in the crusts. The sulphate concentration, for instance, reaches top levels of up to 15 % by weight (only relating to the anion), and the nitrate concentra~ tion goes up to 1.5 %. The chloride content, on the other hand, is very low at <0.1 %.

The high nitrate content in particular points to the fact that these surfaces, i.e. crusts, retain large quantities of moisture in conditions of high humidity and thus promote further damage within the stone. Corrosion of masonry namely cannot occur without the absorption of moisture, whether this be rainwater or hygroscopic absorption of water vapour from the air. The crusts of dirt found in this case cannot by any stretch of the imagination be described as patina, but must be regarded as pollutive waste within the facade.

# 5 RESTORATION AND CONSERVATION

The conservation procedure generally encompasses the following stages:

- cleaning
- first conservation
- stone repair
- issure sanitation
- second conservation
- colour adjustment
- stone protection

## CLEANING

Three cleaning methods were tested on the church tower of the castle: hot water pressure cleaning, powder/water eddy pressure cleaning and powder pressure cleaning.
The pure water cleaning method did not lead to any visible success on the dirtiest parts of the masonry. The cleaning effect was more obvious following powder/water eddy pressure cleaning, but the surfaces cleaned looked uneven after treatment. Only powder pressure cleaning resulted a relatively even, light surface.

In the final analysis, however, it was decided against use of the powder pressure cleaning method. The masonry was cleaned with water and the loose crusts of dirt removed in order to retain the darker appearance of the tower.

## CONSERVATION

As already described under point 4, the Elbe sandstones have a considerable absorptive capacity, so that impregnation with conservation agents should pose no problems from the building physics point of view.
Conservation tests were carried out on both types of sandstone (type A = Postaer Sandstone, type B = Kottaer Sandstone) in order to test this theory. First of all, absorption of the conservation agent and penetration of the pure strengthening agent WACKER Stone Strengthener OH were determined and changes in the strengthening profile were evaluated by means of tensile strength measurements using the *Herion* device. Tests to determine water repellency were then carried out both on the pre-strengthened and the original, non-strengthened sandstones.
A solvent-dilutable silane/siloxane product (WACKER 290) and a water-soluble alternative (WACKER SMK® 1311) were used. Both products were tested in a 10 % dilution. Table 3 shows the results on sandstone A (Postaer Sandstone), table 4 those on sandstone B (Kottaer Sandstone).

TABLE 3

Conservation of sandstone type A with stone strengthener and water repellents

| | coverage rate [l/m²] | penetration depth [mm] | water uptake [kg/m²] 10' | 30' | 60' | 24h | absorption coefficient [kg/m²h^0.5] | adhesion [N/mm²] depth [mm] 0 | 12 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|
| untreated | | | 4,9 | 9,2 | 10,4 | 10,5 | 14,0 | 1,2 | 1,2 | 1,1 |
| WACKER Steinf. OH | 7,3 | > 60 | | | | | | 1,8 | 1,4 | 1,1 |
| + WACKER 290 | 4,2 | > 60 | 0,03 | 0,05 | 0,05 | 0,11 | 0,05 | | | |
| + WACKER SMK 1311 | 4,0 | 45 | 0,02 | 0,06 | 0,09 | 0,37 | 0,09 | | | |
| WACKER 290 | 10,6 | > 60 | 0,03 | 0,03 | 0,05 | 0,10 | 0,05 | | | |
| WACKER SMK 1311 | 8,6 | 38 | 0,09 | 0,12 | 0,25 | 0,94 | 0,18 | | | |

The products penetrate the stone very well in each case. Sandstone A can be penetrated very easily (depth of penetration > 60 mm). The depth of penetration for Sandstone B is approx. 10-20 mm.

Measurements of adhesive pull strengths showed that, with both stone type A and stone type B, strength is improved considerably in the area of penetration, although the increase is not such as to give rise to fears concerning the formation of crusts.

TABLE 4

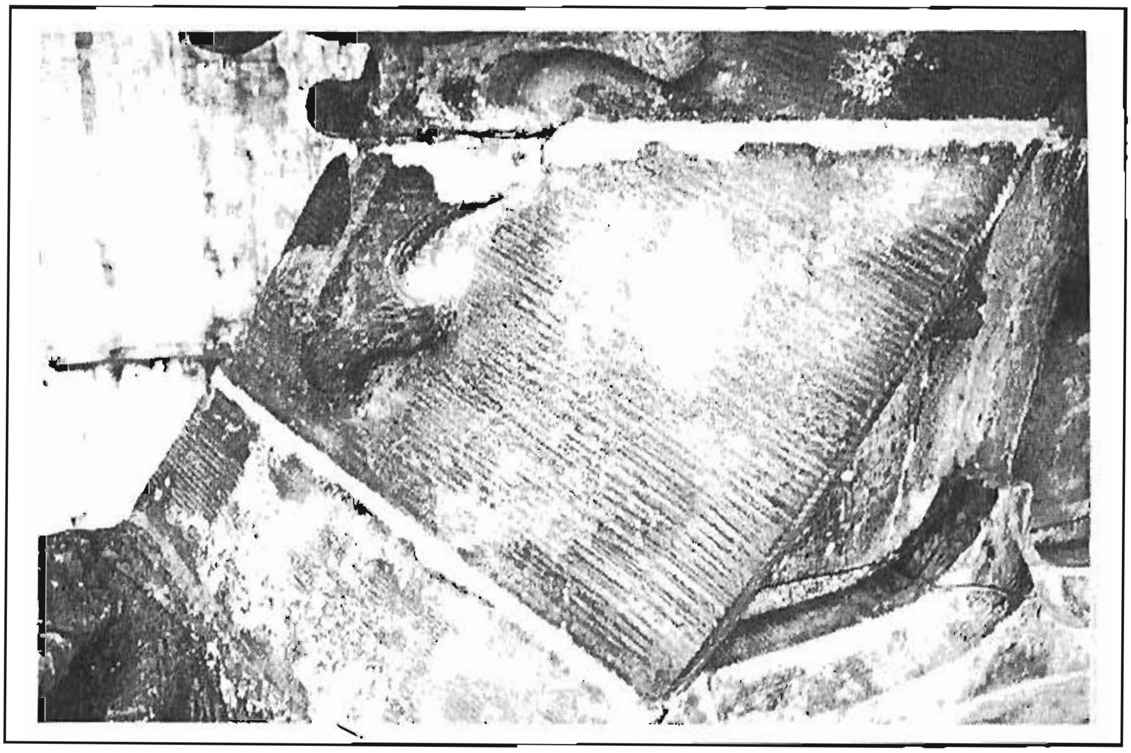
Conservation of sandstone type B with stone strengthener and water repellents

| | coverage rate [l/m²] | penetration depth [mm] | water uptake [kg/m²] 10' | 30' | 60' | 24h | absorption coefficient [kg/m²h^0.5] | adhesion [N/mm²] depth [mm] 0 | 12 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|
| untreated | | | 2,2 | 4,1 | 5,4 | 11,9 | 5,5 | 0,6 | 0,7 | 0,9 |
| WACKER Steinf. OH | 1,9 | 25 | | | | | | 1,8 | 1,40 | 0,8 |
| + WACKER 290 | 1,1 | 12 | 0,05 | 0,05 | 0,08 | 0,24 | 0,08 | | | |
| + WACKER SMK 1311 | 1,1 | 8 | 0,03 | 0,05 | 0,06 | 0,31 | 0,06 | | | |
| WACKER 290 | 1,9 | 20 | 0,04 | 0,05 | 0,06 | 0,45 | 0,06 | | | |
| WACKER SMK 1311 | 1,5 | 10 | 0,05 | 0,06 | 0,07 | 0,74 | 0,07 | | | |

The effect of the water repellents is highly pronounced. In almost every case it is possible to reduce water adsorption to w-values of $< 0.1$ kg/m$^2$h$^{0.5}$, a total reduction of over 95%. These values are obtained regardless of whether or not the stone was pre-treated with a silicon ester. It can therefore be concluded that excellent stone protection can be achieved on this object using conservation agents in the form of water repellents.

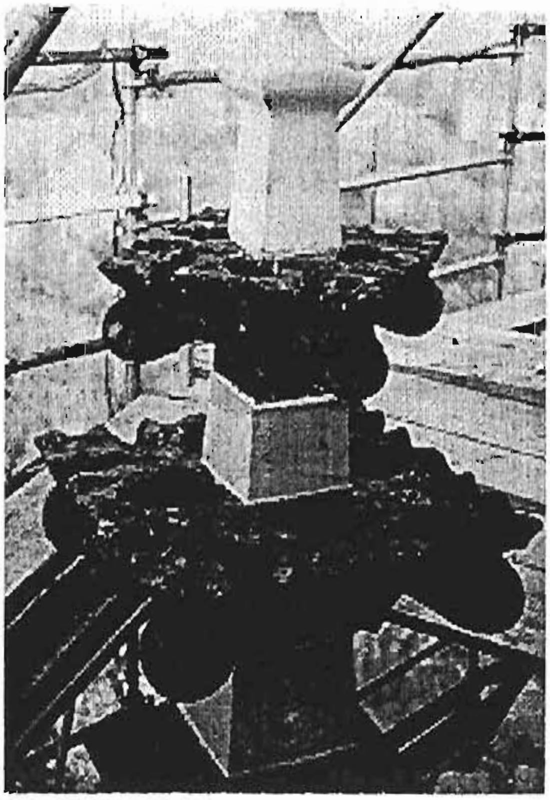
## JOINT SANITATION

The joints were exposed and refilled with mortar. The photo shows testing of two different types of joint mortar, an epoxy based ECC mortar (yellowish) and a Traß cement mortar (grey). Finally it was decided to use the ECC mortar.



## STONE REPAIR AND COLOUR ADJUSTMENT

The two photos below show an ornament restored using partly new stones, and colour-adjusted using a toned silicone resin glaze.



# 6 CONCLUSION

The Wittenberg Castle church tower is one of well over 2000 objects which are supervised by the professional expertise of BAYPLAN. Based on detailed building phsics tests, successful restoration and conservation of this monument were carried out for the pleasure of generations to come. Wacker-Chemie's silicone products have played a considerable part in this success. Suffice it to mention stone strengtheners such as WACKER Stone Strongthonor OH, water repellents such as WACKER 290 and WACKER SMK® 1311, and silicone resin binding agents in the glazes used for colour adjustment. And even now, after 30 years of active involvement in the field of silicone building protective agents, there is still no end to our creative potential. Continually increasing requirements with regard to product performance, coupled with a steep rise in the number of environmental issues make it necessary for us to develop our products further on a continuous basis. Wacker Silicones and BAYPLAN are well-equipped to meet these new challenges.