Salt conversion, backfilling, and back anchoring: the securing of the painted ceiling of the Red Hall in the Neues Museum, Berlin

W. Wedekind* and J. Rüdrich†
Geoscience Centre of the University of Göttingen, Göttingen, Germany
* wwedekind@gmx.de

Abstract

In connection with the restoration of the Red Hall in the Neues Museum, located on the museums-island in Berlin (2006-2008), a procedure for salt conversion and backfilling of hollow painted plaster areas with the help of low-pressure injection technology was developed and successfully implemented. The precipitation reaction resulting from the salt conversion was assessed using electrical conductivity measurements and identification of the precipitate by x-ray diffractometric analyses (XRD). For an additional securing of the plaster areas, an extensive injection was carried out and a suspension system for the back anchoring in the hollow pot bricks was developed and implemented.

Keywords: Salt conversion, low-pressure injection technology, back anchoring

1 The Red Hall

In the course of the recent restoration of the Neues Museum, surely no other room experienced such an extensive transformation as the Red Hall. Located on the third floor of the historic museum building by Friedrich August Stüler (1843-1855), the Red Hall originally housed the reading room of the Prints and Drawings collection of the Berlin Museums.

The Red Hall owes its name to its red wallpaper. The ceiling and window frames were decorated with contrasting light-coloured mouldings and trompe l'oeil decoration (Fig. 1c). The areas above the windows on both sides are decorated with portrait medallions of well-known printmakers and illustrators of the seventeenth to nineteenth century. In the middle of the western side is the sumptuously stuccoed “Dürer Niche”, where a bust of the German renaissance artist once stood. The building section is divided into two rooms. In the southern quarter there is the so-called servant's room with a passage to the roof.

The rectangular Red Hall's dimensions are 24 m x 9.7 m and a wall height of 4.60 m. The servant's room is 5.45 m x 9.70m. The ceiling in both rooms consists of a segmented arched vault with a crown height of 5.40 m.

1.1 The ceiling construction

A special aspect of the ceiling construction in the second and third floors of the still extensively preserved northeast wing is the aforementioned segmented arched vault on a foundation of a steel structure made of arch trusses and lengthwise running girders. The steel trusses consist of two symmetrical steel arches in the form of a T-profile and are bolted together at the crown [1]. Stüler had designed the part in highly detailed drawings as monolithic, a design that apparently was abandoned for a two-part segmented arch (Fig. 1a). They span the whole breadth of the room and were covered with profiled iron sheets and decorated with figural and hanging ornaments [2]. Only in the so-called servant's room between the Red Hall and the stairway are the arch trusses constructed without coverings. Stüler planned to document the mode of construction in compositional form in the rather unassuming side room. Optically, the deep-set girders rest on ornamented cast-iron consoles. On the load-bearing segmented arches, iron girders were placed in 1-meter intervals, which were held in position by pins arranged on the left and the right of the arches. The spaces between the iron girders were lined with hollow clay pots, also a specially developed material. High-fired gypsum plaster served as the mortar for the hollow pots. The spandrel areas were masoned up out of coarse-pored light construction bricks. Here chalk mortar was used for setting mortar. As floor mortar to the roof a ca. 3 cm strong, bituminous tamped screed was laid.

The 2.8 meters long and 1 meter wide fields of hollow pots were plastered with lime and gypsum mortar finished with an additional smooth and coloured with stencilled painting (Fig. 1b).

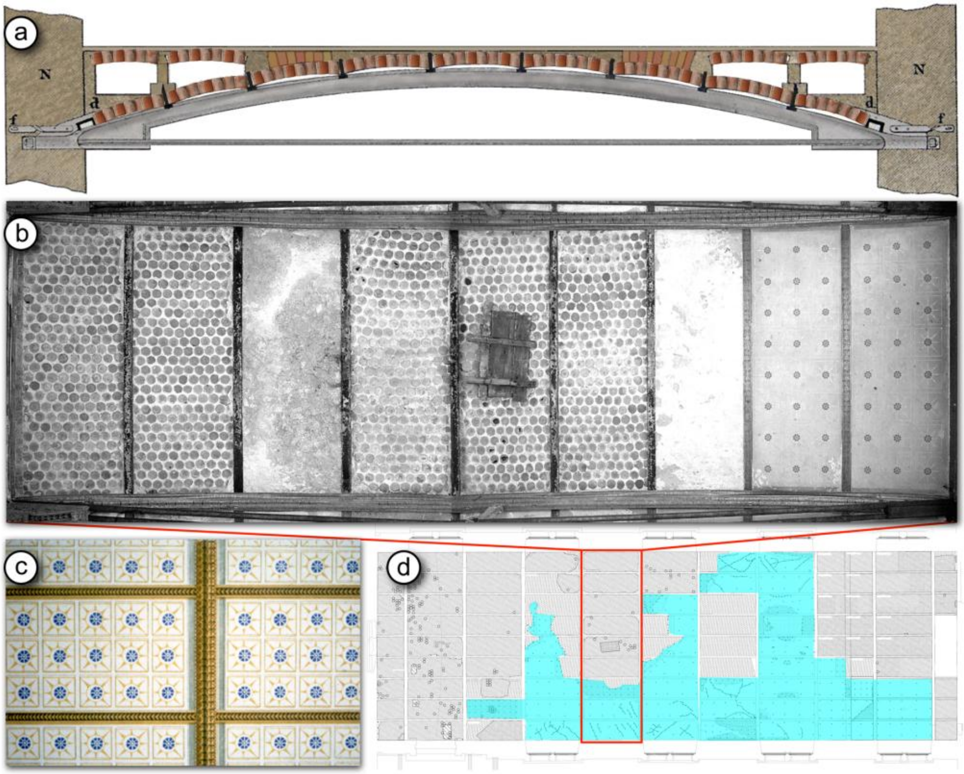

Figure 1: a) Colour Ink Drawing of the steel trusses and the construction of the ceiling with hollow pots after Stüler. b) A segment of the ceiling before restoration. c) Design for the decorative painting of the ceiling in the Red Hall by Friedrich August Stüler. d) Ceiling with extant sections and section designations (adapted from pro Denkmal). The conservation state of the ceiling before restoration remains only 40% of the original plaster and painting (blue).

Not least the construction of the vaulted ceiling out of a steel frame, hollow pots, and light construction bricks are characteristic of the broad spectrum of unusual and newly developed construction methods and materials that make the Neues Museum one of the outstanding works of industrial construction engineering of the nineteenth century [3].

But the clay pots that were used to reduce the weight in the ceiling construction were not a completely novel invention. Roman builders under

Emperor Hadrian in 119-125 AD had already built amphorae into the coffered dome of the Pantheon.

Stüler, who had first-hand knowledge of the Pantheon, used its rotunda as a model for the construction of the two cupola halls of the museum. This is evident not only aesthetically, but also with respect to the construction technique. Instead of amphorae or clay pots, the upper two coffered rings of the still preserved cupola of the North Cupola Room are masoned up with light construction bricks [4]. These have a high porosity of 57 % and a density of 1.1 g/cm^3. By contrast, the traditional bricks from which the Neues Museum is built have porosity of 21 % and with 1.8 g/cm^3 almost twice the density.

2 On the history of construction and damages

During the Second World War, the Neues Museum sustained serious damages, as did the other buildings on the Museum Island in the centre of Berlin. During the bombing on November 23, 1943, the central stairway with the wall frescos illustrating the history of mankind was completely destroyed by fire. During the Battle of Berlin in February 1945 bombs destroyed the northwest wing as well as the passage to the Altes Museum, damaged the southwest wing as well as the southeast projection, while the roofing of the whole building complex burned.

In the 1980s provisional roofs were constructed. The systematic work on the reconstruction first began in 1986.

Due to water infiltration and the connected chemical conversion of the processed white lead, the foundation tone of the ceiling painting today shows varying intensities of greying and has lost much of its original design as a light-coloured coffered ceiling creating the illusion of stucco (Fig. 1c).

Much more serious, however, was the impact of the development of damaging salts, which led to further total loss of the old plasterwork of the vault, of which at the beginning of restoration only about 40 percent was still present (Fig. 1d).

2.1 Damage diagnosis

As became evident in the course of the restoration work, large parts of the plasterwork below the paint layer on the ceiling was in acute danger of falling. Between the plaster and the plaster base massive salt efflorescence had developed, causing the plasterwork to separate from the substrate (Fig. 2). The salts were primarily magnesium sulphates, as was determined by testing by an external material testing laboratory, and grew up to 8 mm deep salt blooms of needle-like crystals [5]. The salt concentration in the surface areas of the material samples was in the middle to high range, with 0.5-1 M%.

Figure 2: Massive salt efflorescence under the fallen ceiling area.

Most of the ceiling areas were in acute danger. Light vibrations or changes in the room climate led to the danger of a permanent separation of the often hollow plaster parts from the substrate material.

One plaster area fell in the course of the project evaluation. Sections of another plaster area were lost through falling more recently and during the restoration in 2007. Observations after the removal of the salt-contaminated plaster areas support the drastic hypothesis of an acute endangerment.

2.2 The source of the magnesium – investigations on the construction materials

The construction materials are a possible source of the high magnesium contamination in the Neues Museum and the secondary formations are a possible source of the sulphate. In high-fired gypsum, contamination with magnesium oxide (MgO) of ca. 2 M% could be detected [6]. An intentional addition of MgO can also lead to an accelerated setting behaviour of high-fired plaster [7], which can be a technical advantage. According to photometrical investigations (by monoparameter photometer) in our own laboratory ca. 0.4 M % - 0.55 M % magnesium could be detected in the floor screed gypsum mortar of the North Cupola Room. On the other hand, the natural cement used in many parts of the museum turned out to be a possible source of contamination. In this material the soluble magnesium sulphate contamination was with 4 M-% higher by a power of ten. The natural cement was often used as a ground mortar layer under the screed mortar layer.

In the extremely heavy bitumen screed above the Red Hall between 0.4 M % and 0.5M % magnesium sulphate also could be detected. This corresponds to a potential soluble magnesium sulphate content of almost 40 g per square meter and calculated for the entire ceiling surface a theoretical potential of over 116 kg. But it is doubtful whether the mortar originally used as a barrier layer could be a direct source of damage, as it has an extremely low water uptake capacity. Theoretically, however, a partial dissolution of the magnesium sulphate could have occurred in the areas affected by crack formation and water infiltration. Therefore, primarily the plaster mortar with which the hollow clay pot bricks were set needs to be addressed as a confirmable source of the magnesium sulphate contamination.

The massive entry of water during the extinguishing of the fires in the wake of the wartime destruction and from rainfall during the ca. 30 years of neglect of the building are considered to be responsible for the mobilization and accumulation processes.

The accumulation of the damaging salt between the plaster base and the plaster can be traced back to the weak zone, a result of the manufacturing, between both materials as a consequence of the upside down position. The compact plaster layer was originally without a preliminary spraying directly applied to the partially smooth covers of the clay pots and then plastered, which hampered the adhesion of the two materials. In some areas where the adhesion between the two materials is evidently better, the salted moisture diffused all the way to the paint layer and there led to alveolar weathering.

3 The damaging salt magnesium sulphate

The damaging effect of magnesium sulphate is due to its different possible degrees of hydration. The salt is capable of taking up six to seven water molecules per molecule, depending on relative humidity and temperature.

$MgSO_4 \cdot H_2O$ (Kieserite) → $MgSO_4 \cdot 6H_2O$ (Hexahydrite) → $MgSO_4 \cdot 7H_2O$ (Epsomite)

Along with these three salt forms, there are four further hydrate stages in which up to 12 water molecules are consumed per unit cell.

The incorporation of water molecules is connected to an increase in weight and a significant increase of the volume of the salt. In such systems, damage is generally recognized not to come from volume change. Rather it originates after drying, when water causes an anhydrous phase to dissolve and produce a solution highly supersaturated with respect to a hydrated phase [8]. The conversion is dependent on the relative humidity and temperature and starting from a water-free form to the incorporation of seven water molecules in epsomite, attains an increase in volume of 223.2 percent [9]. The critical phase in the formation of the water-rich form epsomite is at a temperature ranging from 0 to 40 °C with a relative air humidity of 25 % to 95 %.

3.1 Salt passivation by salt conversion

Magnesium sulphates are easily soluble structurally damaging salts that can be converted into a largely insoluble compound by ion exchange with another salt solution. Barium hydroxide in an aqueous solution is used for this:

$MgSO_4$	+	$Ba(OH)_2$	=	$BaSO_4$	+	$Mg(OH)_2$
soluble		soluble		insoluble		soluble

The magnesium hydroxide ($Mg(OH)_2$) combines with carbon dioxide in the air in a second step to form largely insoluble magnesium carbonate.

The reaction products of the salt conversion are lower in volume than the original magnesium sulphate. They are considered to be insoluble and stable. Moreover, according to some authors the final product (barium sulphate) also has a consolidating effect [10-11].

In restoration work, barium hydroxide has already been successfully used for decades for the conversion of sulphate salts on wall paintings [12-14].

For the Neues Museum in Berlin, Friese und Protz developed a concept for salt conversion by means of applying barium hydroxide to bricks and plaster surfaces, which had been already used in many areas of the building with success [15]. In this procedure, a high-percentage barium hydroxide solution was sprayed in several cycles on the contaminated masonry and plaster areas. Up to 100 g of magnesium sulphates were found per square metre. To be sure that the concentration was sufficient a little more than 300 g barium hydroxide was used within 8 litres of a saturated solution [16].

In the case of the extant plaster in the Red Hall, however, there was the difficulty that the damaging salt had accumulated in the hollow spaces between the plaster and the plaster base, which necessitated the development of a new conservation method.

4 Task, concept development and preliminary investigations

The dramatic damage dynamics became clear first in the course of the restoration work. Subsequently, a procedure and concept for solving the problem was developed by the former restoration firm Wandwerk Restaurierung GbR in close cooperation with the supervisors (pro Denkmal).

For the securing of the original plasterwork and painted surfaces the following tasks were foreseen: a salt treatment in the described interstices, a filling of the hollow space, the binding of the plaster to the plaster base, and development of an additional suspension and anchoring system.

In the course of concept development and comprehensive preliminary tests, a series of parameters was established and the qualities and possible changes in the plaster and the paint layer in connection with the treatment with barium hydroxide, as well as an appropriate backfilling mortar, were evaluated. Tests were carried out using Ledan D1, a back-fill mortar of Tecno Edile Toscana from Italy that has been used with success for many years in restoration work. The binders of the mortar are lime and cement.

Older publications had already shown that for Ledan products, the bonding values when used in securing of plasterwork on wooden beam systems were slight, with an average tensile strength of 0.018 N/mm^2 [17]. Therefore, an additional securing by means of a back-anchoring was foreseen. Corresponding measurements in situ by an external company (FEAD GmbH) confirmed this hypothesis: the bonding values between Ledan and the brick masonry, tested on a first test surface, were assessed as slight.

For the additional securing, an anchoring system made of stainless steel tubes for the suspension of the plaster areas was developed and tested. The tested samples consisted of the anchors casted in the clay pots with Ledan D1. The attachment and pull-out strength of anchoring systems were tested at the University of Applied Sciences in Kassel. [18], (Fig. 3).

The testing of the implemented system yielded a high variation in pull-out strength. The values varied between 0.56 and 1.52 kN. The number of samples was too small and the distribution of the values too large to achieve statistically significant results. The values thus can only be regarded as sample values. The surface load a securing bolt needs to hold in the case of a homogeneous distribution of mass is 12.5 kg. This corresponds to a weight of 0.123 kN. This value is by a factor of 5 among the lowest of the determined pull-out strength values and was assessed to be definitely sufficient. When pulling the anchors they were pulled out only a few millimetre and wedged again, the clay pots remain undamaged (Figure 3 a-d). The results let to the conclusion, that in case of a break the plaster area can be lowered but will not fall down.

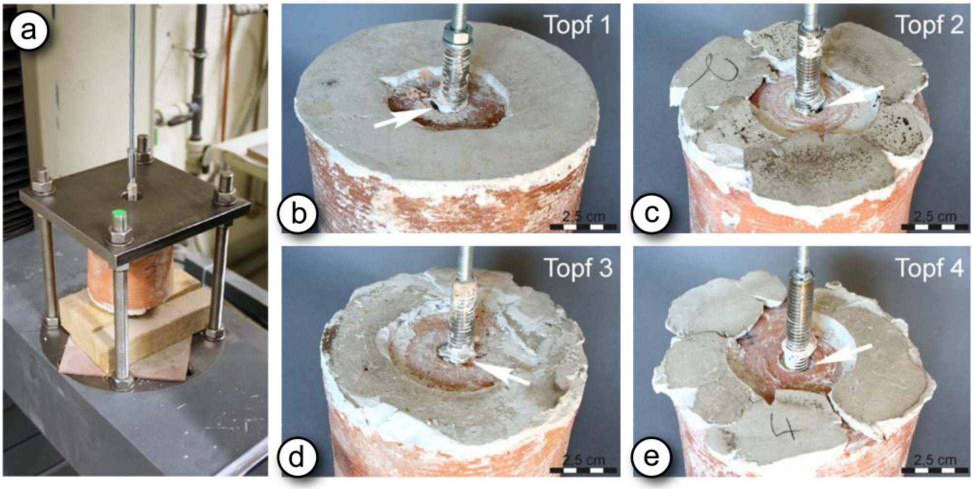

Figure 3: a) the testing equipment by using a universal testing machine. b - e) Crack pattern on tested clay pots. The white arrows mars the edges of the breaks.

4.1 Results of preliminary investigations and stocktaking

The investigation program encompassed the determination of the maximal water absorption, the density, as well as the diffusion properties of water and barium hydroxide solution for the assessment of possible alterations in the paint layer and spot formation. Compact pieces of plaster from the fallen ceiling field served as test samples.

The under layer of plaster was evidently a dense and compact, grey-ochre coloured gauged mortar plaster, in which calcareous spars were clearly discernable. This speaks in favour of a dry hydrated coarse material as the starting material, to which a binder portion of gypsum was added immediately before the processing.

The plaster density including the 1-2 mm thick final plaster layer is 1.66 g/cm^3. The dry plaster of a ceiling area with an area of 2.8 m^2 can have a weight of up to ca. 140 kg. After water absorption by storage in water for 24 hours, the plaster increased in weight by 12 M-%. This corresponds to an open porosity of ca. 21 %. Therefore, the maximum water uptake of a single plaster area results in a weight increase of ca. 16.5 kg.

In the diffusion tests, the water and barium hydroxide solution were precisely dripped using a drop funnel positioned on the rough plaster area on the back of the sample. The solution diffused into the porous body and spread in a radial pattern. After drying, the paint layer was visually evaluated: after the various tests, only the most minimal, barely perceptible colourations of the paint layer surface could be observed.

For each plaster area to be treated cracks, hollow spaces and all subsequent measures were mapped. Detection of the hollows was done by simple knocking. The mapping of the hollowed areas yielded different results (Fig. 4): the extent of the hollow areas varied between 10 and 100% with an average of 63%.

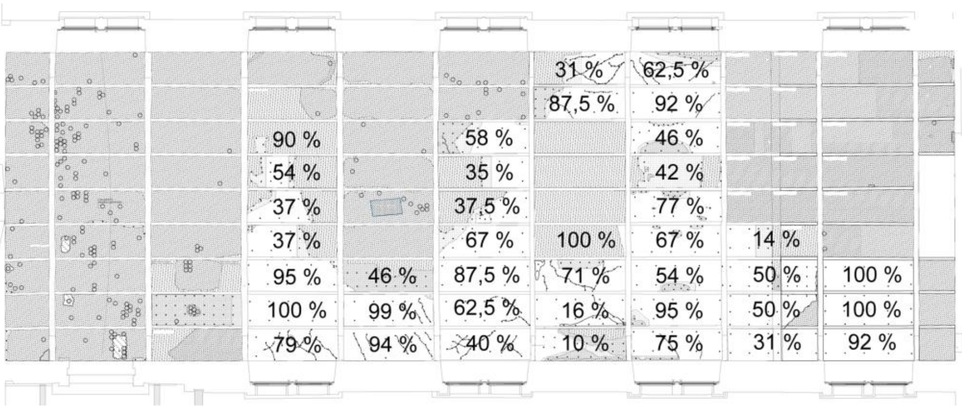

Figure 4: Hollows in percent (drawing adapted from pro Denkmal).

5 The securing concept

The protection of the wall paintings and plasterwork in danger of falling is a central concern in the restoration of architectural surfaces [19]. In the past, within numerous restoration projects flexible and reversible suspension systems for anchoring in wooden girders have been used [20-23]. In such procedures the support was achieved by using a Plexiglas or metal sheet that lay chromatically matched on the paint layer and was bolted to the mostly wooden supporting structure. For aesthetic reasons such a form of securing did not come into question for the ceiling of the Red Hall.

A further difficulty in back-filling large hollow spaces consists in the need to maintain a consistent flow of material and pressure in the low-pressure range [24]. In stone conservation, low pressure techniques for the continual application of consolidation material have already been used [25]. The low-pressure injection technology was developed for the renovation of cement and is usually used for injection into even the finest fractures [26].

The concept for the securing of the plasterwork areas consists of three points:

1) Salt conversion

2) Flat backfilling

3) Implantation of stabilizing bolts

A reconversion of oxidized white lead, as has been successfully implemented in other restoration projects [27], was not an option in the case of the ceiling painting in the Red Hall.

5.1 Securing and installation of the construction

During the conservation work the respective plaster areas were supported by at least six corner steadies (Fig. 5).

Figure 5: Installation of the hose and packer system (photo: Hüttich).

In a first step, the drilling down to the plaster base (13 mm) was carried out. This was done as needed on the basis of the detection of hollow spaces. Holes were placed in the centre of the rosette stencils. They were arranged in a grid over the painted area, so that at least 12 openings for injections were distributed over each area of 2.8 m^2. 4 injection openings and anchors thus secured each square meter of plaster surface. These had to be capable, if necessary, to continuously support a weight of 12.5 kg.

The painted layer areas of each bay run parallel to the segmented arch vault, each with a different slant. At the crown in the centre of the vault (see Fig. 1a&b and Fig. 5) there is a slight slant in both directions toward the adjacent metal girders. Going toward the walls, the slant increases from 8 % to 13.5 %, 21 %, and up to 28 %. The danger of an accumulation of moisture and the development of damages is thus highest along the lowest parts of the plaster areas. To prevent a moisture build-up and the development of water spots, holes (6 mm) for drainage tubes were placed along the lowest parts. These were placed in the corner areas of the light-coloured square stencils. The drainage tubes were set in the holes, sealed with Teflon tape and a hose was installed on each that connected them to the suction apparatus.

To prevent an uncontrolled leakage of liquid through cracks in the plasterwork, all visible cracks were sealed using a solution of volatile hydrocarbons (cyclododecane) that was applied multiple times. In the course of the work, the flanks of the plaster areas on the vault girders turned out to be a further weak point. Here the metal along the flank of the connecting areas had been smoothed over with a thin and today predominantly loose and brittle lime mortar. The loose strips of mortar were removed and the metal surfaces cleaned of loose particles and dust. In the flank area a commercial bonding compound was used as a new mortar, since this also produces the needed adhesion on the metal material.

The holes for the injection of the hollow spaces and the surrounding paint layer were protected with cyclododecane and two-ply Japanese paper. Filling packer was put into the injection openings. For that, rubber plugs with an opening in the centre were fixed after inserting a light metal pipe in these openings. On the lower end of the opening a transparent filling hose was attached fitted with a closing valve for the flexible dosage of material.

The filling apparatus used was a low-pressure membrane pump (Model 2041 101-0 MC-Bauchemie). The pump is driven by compressed air and the injection pressure is continuously variable from 1 to 10 bar. A maximum of 6 filling hoses per injection cycle was connected to the pump. To produce the suction, a commercial industrial wet vacuum with a 1200-watt suction capacity was used. To maintain a sufficiently strong suction, only 6 drainage tubes were attached.

5.2 Salt conversion

Through the upper row of the hose system an amount of 5 litres highly concentrated barium hydroxide solution was directed into the hollow space between plaster and the plaster base. The electrical conductivity of the reaction liquid was measured beforehand. A possible liquid excess was sucked out through the lower row of hoses with help of a low vacuum of around 0,5 bar.

In the hollow space between the plaster and plaster base the magnesium sulphate dissolves and reacts directly with the dissolved barium hydroxide.

Insoluble barium sulphate is directly precipitated. The precipitate was partially in the form of white precipitate in the interstice and the excess was sucked out as a clear milky liquid (Fig 6b). Each plaster area was divided into two subareas and about half of each area was treated. The results obtained varied in most cases. Electron conductivity measurements revealed a reduction up to 36 %, with an average value of 9%, in relation to the initial solution (Fig 7), which indicates a successful precipitation reaction. In the individual subareas, however, much more significant results were obtained and the result of the salt reduction was evaluated For example, the right half of a test field treated with 4 l barium hydroxide solution, of which almost 2 l could be removed by suction. In this case the electrical conductivity of both the applied liquid and the extracted liquid was measured. The applied liquid had an electrical conductivity of 26.6 mS/cm; this corresponds to a content of 9.6 g/l barium hydroxide. The sucked out solution, on the contrary, had an electrical conductivity of only 16.96 mS/cm and thus could be reduced by ca. 36 % and corresponds to a content of 7.8 g/l dissolved substances. The concrete examples as well as the results of the whole campaign speak for a successful precipitation reaction of magnesium sulphate into slightly soluble barium sulphate in the hollow area.

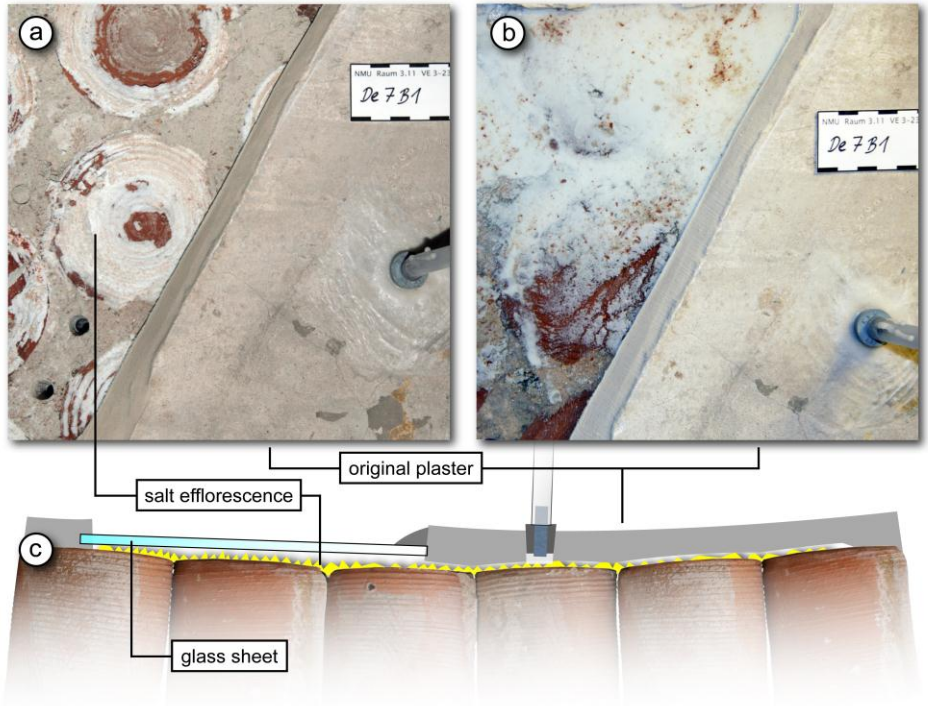

Figure 6: a) A test field area with massive salt efflorescence b) showing white deposit during the treatment. c) The preparation of the test field.

Investigations of the extracted precipitate residues of the sucked solution confirmed the successful course of the conversion process. The white loose material was barite, as was established by XRD analyses.

In three plaster areas a slightly increased electrical conductivity of the sucked solution was obtained compared to the applied one (see Fig. 7). In these cases, one could assume that other soluble salts increased the conductivity or that no reactive materials were present in the hollow space.

Figure 7: Change in electrical conductivity in percent, comparison of the starting solution and the extracted solution. (based on: pro Denkmal).

After the barium hydroxide treatment and the immediately subsequent filling of a test area, damp spots and brown water markings developed in the course of the testing phase. After the filling with ca. 3 l of salt conversion liquid on the ca. 1 m^2 large plaster area, moisture could be discerned along some fine cracked areas. Immediately after the filling with Ledan (D1) no changes in the paint layer were visible. After a dwell time of two days, however, brown stains and water markings emerged. Light damp spots were observable, which emerged as dark grey areas on the white-ochre final coat plaster.

To keep the penetration of dampness as low as possible, it thus turned out to be advantageous to reduce the dampness as much as possible after the salt treatment. To this end, cold-dried compressed air (2 bar) was pumped through the hose system into the treated interstice over a period of 6 hours. On one plaster area, the drying process in the interstice between the plaster and plaster base was monitored by means of electrical conductivity measurements via a deep borehole heat exchanger installed through the drainage holes. Here it was possible to establish that before a further application of damp to the plaster system, a drying phase of 3 days was advisable.

Despite intensive pretesting and an ongoing optimization of the procedure, the risk of water stain formation existed, which despite numerous cautionary measures could not always be prevented. In one test area, changes of the paint layer manifested after the barium hydroxide treatment. After the filling of about 3 l, diffuse dampness could be discerned solely along some of the finely cracked areas. Also immediately after filling with the Ledan suspension, no changes in the paint layer were visible. After a dwell time of two days, however, brown stains and water markings emerged on the paint surface. The brown stains were most probably caused by the organic components of the glue painting. Water markings that developed and spots consisting of organic floating particles could be successfully almost completely repelled with a hydrogen peroxide solution (30 %) in the course of the evaluation of the measures. For this an application of the solution in up to 10 steps was necessary.

5.3 Backfilling

After the salt conversion and drying, the hollow space was filled using the same apparatus. For this step the plaster was secured partially lengthwise with cushioned slats and corner steadies (see Fig. 5).

Via the upper hose and packer row, backfilling mortar (Ledan D1) was filled into the hollow space with the help of a membrane piston pump under low pressure. Here a continuous filling pressure of 2 bar was used. The ratio of dry powder to water was 2:1. The pump was not able to transport a backfilling mortar with a high proportion of solid material with sufficient reliability. The backfilling was carried out half a surface at a time, the filling of the Ledan suspension in batches. A precise visual observation of the plaster area during the measure was crucial to mitigate uncontrolled leaking backfill suspension or to interrupt the process if water stains occurred. During the discharge of the mortar from the hoses in the lower plaster area, the flow was interrupted, and in order to reach all hollow areas the mortar was injected again for a few seconds. A further available control was the discharge tubes for the drainage, out of which often backfill mortar was discharged in a successful backfilling. For each area, depending on the state of the hollows, between 5 and 15 l of Ledan-suspension was injected. The mortar created a force-locked bond between the base and the plaster material. This could be confirmed both by knocking tests and in the course of the follow-up examination by the firm FEAD GmbH on a test area.

After backfilling and a dwell time of 3 days, the cyclododecane could be removed. The removal was carried out by blow-drying, whereby the hydrocarbon evaporated without leaving any residue.

5.4 Back anchoring

To achieve a recommended additional protection, after the removal of the hoses from the fill holes a new drilling was made in the same holes that went into the stable base material (7-10 cm). In the cases in which the drilling of one of the thin-walled tops of the pot bricks was punctured, a specially developed suspension system brought results. The restorer Carsten Hüttich and the mechanical engineer Martin Reußner were decisively involved in the development of the system. The stainless steel tubes served as stabilizing bolts, on which an external threading was cut. These were pushed over light metal tubes and both tubes inserted into the bore hole and into the hollow pot brick. Both tubes were fixed with rubber plugs in the middle of the hole. In order to increase the stability and load capacity of the component a defined amount of fill mortar (350 ml) was injected with a hand gun through the light metal tube into the pot brick. The mortar filled up the clay pot to a height of about 5 cm and ensured an interlocking of the stabilizing bolt with the hollow pot brick (Figs. 8 b). Per hollow pot filling this leads, as preliminary testing had established, to a weight increase of ca. 500 g. In the case in which the compact setting mortar was drilled, the borehole expanded upwards conically and as already described was injected with mortar.

Figure 8: Model of the suspension system with stabilizing bolts in a clay pot before (a) and after (b) filling.

After a dwell time of three days the filling tubes could be pulled out of the stainless steel anchors and the bore hole below the level of the paint layer force-closed sealed with a gypsum-lime mortar. In a further step a final rendering stuff was applied and smoothed flush with the paint layer. After drying of this rendering layer the chromatic retouching was carried out on a new stencilling.

6 Summary and evaluation

37 plaster areas altogether were treated over a period of three months. The ca. 103 square meters large original plasterwork is today secured by about 400 securing bolts. 290 l highly concentrated barium hydroxide solution was applied, of which about 50 l could be recovered. The conservation and passivation of the damaging salt could be determined by

conductivity measurements and through analysis of the extracted residues. 340 l of backfilling suspension was injected all over as backfilling mortar.

The use of a low-pressure injection pump made possible a controllable and complete treatment of large hollow areas. By using the filling system in a grid process, several steps of the process could be carried out using the same apparatus. This made the work easier, reduced costs, and minimized an endangering of the painted surface.

The missing areas of the ceiling and wall surfaces were newly plastered and the ceiling vault areas reconstructed in a tonally contrasting stencil painting. After the restoration under the direction of the restorer Eberhard Taube and the reconstruction of mouldings and decorative painting and with the new red wallpaper the exhibition hall presents itself today again in a condition befitting its name [28-30].

Acknowledgements

We thank architect Stefan Schäfer for advice and instruction in the low-pressure injection technique; and we thank restorer Eberhard Taube, Carsten Hüttich, Bernhard Irmer, Annett Baumeister and the restoration planning by restorer Claudia Vollmann (pro Denkmal) for their constructive cooperation.

References

[1] Lorenz, W., Kernform und Kunstform - Preußische Konstruktionskunst im Zeichen der Industrialisierung, in Das Neue Museum Berlin - Konservieren, Restaurieren, Weiterbauen im Welterbe, Stiftung Preußischer Kulturbesitz, Staatliche Museen zu Berlin (SMB), Bundesamt für Bauwesen und Raumordnung (BBR) & Landesdenkmalamt Berlin (LDA), eds., Leipzig 2009, pp. 38 - 43.

[2] Haber, G.J., Riemann, M. “Metallische Bauplastik”, in Das Neue Museum Berlin - Konservieren, Restaurieren, Weiterbauen im Welterbe, SMB, BBR & LDA, eds., Leipzig 2009, pp. 194 - 195.

[3] Lorenz, W., The Berlin „Neues Museum“ - a microcosm of Prussian building technology against the background of beginning industrialization, in Structural Studies, Repairs and Maintenance of Historical Buildings VI,. Brabbia, C.A., Jager, W., eds., Southampton 1999, 389-398.

[4] Wedekind, W. Baumeister, A. Schellhase, L. 2009 Die Salzreduzierung im Norkuppelsaal, in: SMB, BBR & LDA (eds.). Das

Neues Museum Berlin - Konservieren, Restaurieren, Weiterbauen im Welterbe. Leipzig 2009, 211 - 213.

[5] Höpcke, M., Ergebnisse der IC-Messungen, Pendelbögen zu den Entnahmebereichen 50/51, unpublished investigation report, Gesellschaft für Materialprüfung und Baustofforschung mbH (MBF), Berlin 08.08.2007.

[6] Siebel, E. ed., Handbuch der Werkstoffprüfungen, Bd. 3: Die Prüfung nichtmetallischer Werkstoffe, Berlin 1941.

[7] Lucas, G., Die stofflichen Besonderheiten von Hochbrandgipsmörtel, ZKG International (56) (2003) 54-65.

[8] Steiger, M., Crystal growth in porous materials – I: The crystallization pressure of large crystals, Journal of Crystal Growth, (282), Issues 3-4, (2005), 455-469.

[9] Goudie, A. S., Sodium sulphate weathering and the disintegration of Mohenjo-Daro, Pakistan, Earth Surface Processes (2) (1977) 75-86.

[10] Toniolo, L., Colombo C., Realini, M., Peraio, A., Positano, M., Evaluation of barium hydroxide treatment efficacy on a dolomitic marble", Annali di Chimica (91) (2001) 813-821.

[11] Sayre. E.V., Direct deposition of barium sulphate from homogenous solution within porous stone, in Conservation of Stone. 1970 New York Conference on Conservation of Stone and Wooden Objects, Volume 1, second edition, The International Institute for Conservation of Historic and Artistic Works (IIC) ed., London 1971, 115 - 118.

[12] Matteini, M. Moles, A., Twenty years of application of "barium" on mural paintings: Fundamentals and discussion of the methodology, ICROM Committee for Conservation: Preprints of the 7th triennial Meeting, Copenhagen, 10-14 September 1984, 15-19.

[13] Matteini. M., In Review: An Assessment of Florentine Methods of Wall Painting Conservation Based on the Use of Mineral Treatments, in The Conservation of Wall Paintings: Proceedings of the symposium organized be the Courtauld institute of Art and the Getty Conservation Institute, London, 13-16 Juli 1987, Gather, S. ed., London 1991, 137-48

[14] Leitner, H., The treatment of wall paintings affected by salts: an interdisciplinary task as seen from a conservator's perspective,

Bauinstandsetzen und Baudenkmalpflege: eine internationale Zeitschrift (11) (2005) 365-380.

[15] Friese, P., Protz, A., Salze im Mauerwerk – Möglichkeiten zur Entsalzung und Salzumwandlung, in Entfeuchtung/Entsalzung, ed. H. Venzmer, FAS Schriftenreihe (10) (1999) 211 – 220.

[16] Schwieger, O. Die Barium-Hydroxid-methode als Möglichkeit der Salzpassivierung, in Konservierung, Restaurierung und Ergänzung im Neuen Museum Berlin - Zwischen ursprünglichen Intentionen und neuen Entwicklungen, Verband der Restauratoren e.V., Siegl Verlag, Munich 2013, 92-96.

[17] Ettl, H., Schuh, H., Putzsicherung mit Ledan TB 1, in Putzsicherung. Sicherung von Malerei auf gemauerten und hölzernen Putzträgern. Beiträge einer Fortbildungsveranstaltung der Restaurierungswerk-stätten des Bayerischen Landesamtes für Denkmalpflege am 17. November 1992, ed. M. Petzet, Arbeitshefte des Bayerischen Landesamtes für Denkmalpflege, Vol. 79, Munich 1996, 37-42.

[18] Rüdrich, J., Ausreißfestigkeiten von Ankersystemen aus Tontöpfen des Neuen Museums (Museumsinsel Berlin)", unpublished inestigation report, Angewandte Materialuntersuchungen (AM Göttingen), Göttingen, 09.23.2006.

[19] Petzet, M. ed., Putzsicherung. Sicherung von Malerei auf gemauerten und hölzernen Putzträgern. Beiträge einer Fortbildungsveranstaltung der Restaurierungswerkstätten des Bayerischen Landesamtes für Denkmalpflege am 17. November 1992. Arbeitshefte des Bayerischen Landesamtes für Denkmalpflege, Band 79. Munich 1996.

[20] Leitner, H., Paine, S., Is wall-painting restoration a representation of the original or a reflection of contemporary fashion?: An Austrian perspective, in Restoration: is it acceptable? Oddy, A. ed., London 1994, 51-65.

[21] Hošek, J., Skupin, L., Aufhängung der Decke des Hauptsaales im Schloss Troja, Wiener Berichte über Naturwissenschaft in der Kunst (6-8) (1991) 67 - 84.

[22] Furdyna, J., Conservation Work in the Interior of the Kupe Synagogue in Kazimierz/Krakow, Biuletyn - Journal of Conservation Restoration (14) (2003) 48-61.

[23] Wendler, E., Die Wiederbefestigung der Putzschale durch rückseitig fixierte Anker, Denkmalpflege Informationen, edition A (92) (2005) 22-25.

[24] Adams, G.W., A practical technique for injection of consolidants behind wall and ceiling paintings, APT bulletin 37, (2-3) (2006) 33-36.

[25] Schoonbrood, J.W.M., Low pressure application technique for stone preservatives, in Thiel, M.-J. (Hrsg.) Conservation of stone and other materials: proceedings of the International RILEM/UNESCO Congress "Conservation of Stone and Other Materials: Research-Industry-Media", Paris, June 29-July 1, 1993, E. & F.N. Spon Ltd., London 1993, 512-518.

[26] Schäfer, S., Zur Injektion mineralischer Füllgüter, unpublished Diploma Thesis, Civil Engineering Faculty, field of study Architecture at the Hochschule für angewandte Wissenschaft und Kunst (HAWK), Holzminden 2004.

[27] Leitner, H., Rückwandlung von oxydiertem Bleiweiß an Deckenmalereien in der Burg Strechau, Steiermark", in Wandmalerei, Sgraffito, Stuck, Koller, M., Prandtstetten, R. eds., Restauratorenblätter, Vol. 9, IIC Austrian section, (1988) 116-119.

[28] Taube, E. Roter Saal und Dienerzimmer, in Das Neue Museum Berlin - Konservieren, Restaurieren, Weiterbauen im Welterbe, SMB, BBR & LDA eds., Leipzig 2009, 173-176.

[29] Taube, E., Hüttich. C., Wedekind, W. "Der Rote Saal im Neuen Museum", in Konservierung, Restaurierung und Ergänzung im Neuen Museum Berlin - Zwischen ursprünglichen Intentionen und neuen Entwicklungen, Verband der Restauratoren e.V., Siegl Verlag, Munich 2013, 184-189.

[30] Walter, L.J. Eine Tapete mit Durchblick – Die Entwicklung einer transparenten Japanpapiertapete zur Wiedergewinnung der raumprägenden Farbigkeit des Roten Saales, in Konservierung, Restaurierung und Ergänzung im Neuen Museum Berlin - Zwischen ursprünglichen Intentionen und neuen Entwicklungen, Verband der Restauratoren e.V., Siegl Verlag, Munich 2013, 190-196.