Article: The Development of Treatment Protocols at the Watts Towers Conservation Project
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Source: *Objects Specialty Group Postprints, Volume Twenty-One, 2014*
Pages: 345-362
Editor: Suzanne Davis, with Kari Dodson and Emily Hamilton
ISSN (print version) 2169-379X
ISSN (online version) 2169-1290

THE DEVELOPMENT OF TREATMENT PROTOCOLS AT THE WATTS TOWERS CONSERVATION PROJECT

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ABSTRACT

This article provides a review of current and past conservation practices and the development of new treatment proposals for the Watts Towers. The Italian immigrant Sabato (Simon) Rodia built the Watts Towers in the backyard of his house. They consist of 17 interconnected structures, each constructed of a steel core covered with cement stucco and embedded decorative elements. The two largest structures reach a height of 99.5 ft. (30 m). Rodia built the Towers from 1921 to 1954. He did so without assistance and without scaffolding. The Towers are located in the Watts district of Los Angeles County.

A team of conservators, scientists, and research assistants from the Los Angeles County Museum of Art has been working on the review of current and past conservation practices, and the development of new treatment proposals for the Watts Towers since January 2011. After reorganizing and rehousing the extensive treatment archives, the first comprehensive environmental and physical monitoring program in the history of the Towers was established. This program was further expanded when, in 2013, a team from the UCLA Department of Civil and Environmental Engineering joined the effort of Los Angeles County Museum of Art.

This monitoring and measurement program resulted in a significantly improved understanding of the response of the Towers and their individual elements to a variety of environmental stresses, including solar radiation (heat), vibration and deformation due to wind and seismic activities, and corrosion of the metal substrate. It also provided an explanation for the repeated failures of many of the repairs carried out over the past 50 years.

Based on these findings, we are evaluating improved repair and maintenance procedures that promise to be of greater durability, using the recent advances made in building science and the concrete industry. To date, materials that have undergone laboratory and outdoor exposure testing, and that are now applied to the monument on a limited test scale, include elastomeric crack fillers, polymer amended mortars, architectural adhesives, and penetrating water repellents.

Currently we are also evaluating different approaches to corrosion protection, including migrating corrosion inhibitors and embedded sacrificial anodes.

1. INTRODUCTION

The Watts Towers (fig. 1) were built by the Italian Immigrant Sabato (Simon) Rodia in the backyard of his house in the years from 1921 to 1954. They consist of 17 interconnected structures, with the tallest reaching a height of 99.5 ft (30 m). They are owned by the State of California and are currently administered and operated by the Department of Cultural Affairs of the City of Los Angeles. They are located in the Watts district of Los Angeles County.

On December 10, 2010, the City of Los Angeles and the Museum Associates (dba LACMA) signed a Professional Services Agreement for preservation and conservation services. Under this agreement LACMA's Conservation Center was to

- Assess the City's existing conservation and preservation plan for the Watts Towers as embodied primarily in the *Preservation Plan* and *Maintenance and Restoration Guide,* prepared for the State of California by The Ehrenkrantz Group in 1983, and the *Evaluation and Conservation of Fissures Report* and *Documentation Synthesis and Materials Research Report*, prepared by the Architectural Resources Group (ARG) in 2004 and 2006, respectively;

Fig. 1. *Watts Towers*, Sabato (Simon) Rodia, steel, cement, and embedded ornament, 30 m, City of Los Angeles Department of Cultural Affairs; view from the North side (Courtesy of Frank Preusser)

- Conduct periodic inspections and undertake minor repairs and restoration;
- Conduct tests to evaluate new materials and techniques for the repair of cracks and spalls and for the adhesion of loose or detached decorative elements.

Recurring cracking of the concrete shell and ongoing losses of decorative ornaments are the most visible signs of the deterioration of the Towers. This has been going on since the beginning, and it has been reported that Simon Rodia himself carried out repairs while he was still constructing the Towers. Since he abandoned the Towers in 1954, there have been numerous repair campaigns (1960–1969, 1979–1985, 1987–1994, 1995–2001, and 2001–2005). During these campaigns a variety of mortar formulations and synthetic resins were used, and large sections of the steel supports were replaced. Unfortunately, the cracks reappeared in many of the repaired areas after relatively short periods of time and the loss of decorative ornaments continued. Close inspection of the Towers reveals that most repairs are "repairs of repairs." In 2005, N. J. Bud Goldstone lamented that "*In each* (repair *sic*) *period there have been cracks and new cracks in original Rodia cement and in repairs of every material used to date*" and "*All else is failing*" (Goldstone 2005).

Before considering any alternative to the repair materials and techniques used in the past, it proved necessary to first determine the causes of the deterioration of the monument and the reasons underlying the failures of past interventions.

2. CONSTRUCTION TECHNIQUE AND MATERIALS

Simon (Sabato) Rodia constructed the Towers from 1921 to 1954, when he abruptly abandoned them and moved to Northern California. He built them without a scaffold and had no assistants. He had no design drawings and frequently changed design elements. The Towers consist of 17 interconnected structures with the tallest reaching a height of 99.5 ft. (30 m). Details of the history of the Towers and their construction can be found in Goldstone and Goldstone (1997).

Each segment of the Towers consists of a central steel element covered by wire mesh. Rodia then applied a cement plaster (figs. 2, 3) and embedded decorative ornaments while the plaster was still wet (fig. 4).

The steel elements were tied together with wires; Rodia did not bolt or weld them together. In later restorations bolting and welding became common, making the structure stiffer (fig. 5).

Fig. 2. Cross section of element from the Towers (Courtesy of Kimberly Blanks)

Fig. 3. Cross section of element from the Towers (Courtesy of Blanka Kielb)

Fig. 4. Embedded decorative ornaments (Courtesy of Frank Preusser)

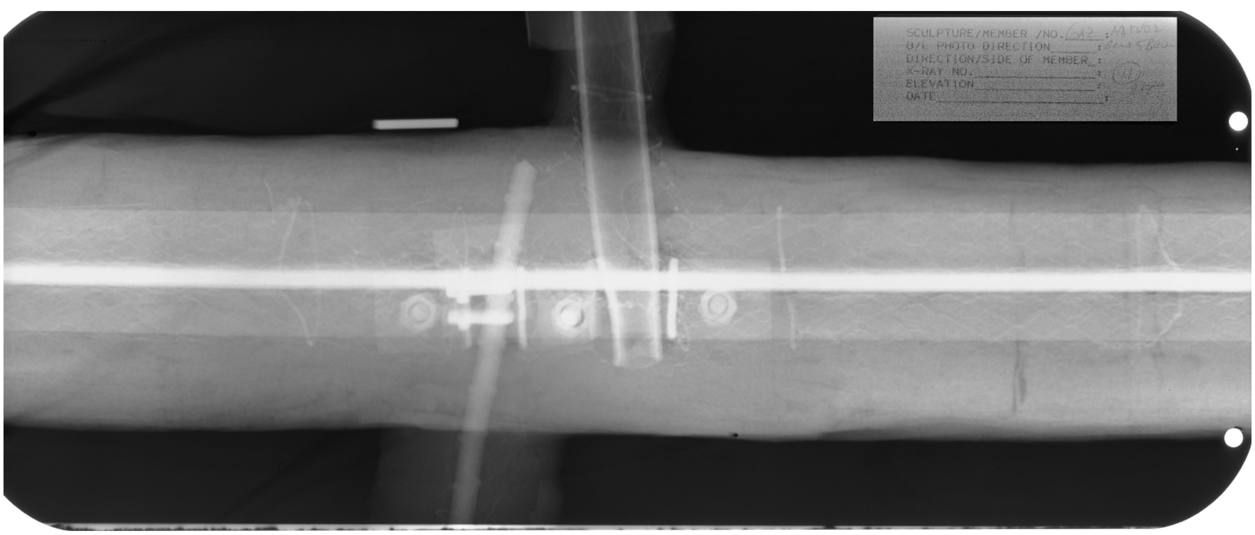

Fig. 5. X-radiograph of bolting (Courtesy of Los Angeles Department of Cultural Affairs)

3. CAUSES OF DETERIORATION

Some previous studies suggested that solar radiation (heat) and vibrations and movements caused by wind forces and seismic events might be the main causes of the development of cracks and loss of ornaments. The cracks then would provide access to water and cause subsequent corrosion of the steel supports. No technical studies were carried out to test the different hypotheses, with the exception of a short study by ANCO Engineers (ANCO Engineers Inc.1989). This brief study confirmed that crack movement is related to temperature fluctuations.

A review of the treatment records of the past four decades revealed that the treatments were governed by the assumption that the deterioration of the Towers is predominantly caused by the corrosion of the steel supports. This led to large-scale steel replacement campaigns and repairs with traditional cement mortars, epoxy resins, and epoxy-cement mortars. Many of these repairs only lasted a short time, less than 2 years, before new cracks formed. The failures were both adhesive and cohesive (figs. 6–8). Adhesive failure, which is the separation of the repair material from the old mortar, typically

Fig. 6. Adhesive failure of repairs (Courtesy of Blanka Kielb)

Fig. 7. Adhesive and cohesive failure of repairs (Courtesy of Blanka Kielb)

Fig. 8. Loss of cement cover over epoxy repair, adhesive failure of repair (Courtesy of Frank Preusser)

occurred in traditional repair materials such as portland cement, which often failed at the bond-line, and in repairs consisting of a thin cement fill applied over an architectural epoxy paste, which failed adhesively at the cement/epoxy interface. Cohesive failure, which consists of cracks within the repair material, can be found in both epoxy and traditional cement repairs because they are too rigid to accommodate the movement of the sculptures.

3.1 MONITORING OF THE TOWERS' RESPONSES TO ENVIRONMENTAL STRESSES

As a first step in developing a restoration protocol, we decided to determine the effect of environmental stresses on the Towers. Before embarking on an ambitious monitoring program, we did a preliminary study consisting of:

- Installation of an on-site weather station
- Plaster bridges over existing cracks
- Mechanical crack monitoring devices over existing cracks
- Low-cost battery operated accelerometers
- Spot temperature measurements with a laser thermometer

These devices provided us with the following necessary information for a more sophisticated monitoring program:

- Many of the existing cracks are moving (some plaster bridges broke within less than two weeks) (fig. 9). The cracks vary in width from less than 1 mm to 3 or 4 mm.
- Strong winds create g-forces on the Towers comparable to moderate earthquakes
- Temperature differences between the cement plaster and the decorative elements are substantial

Based on this preliminary information we expanded the monitoring program by adding:

- Electronic displacement transducers with data-loggers (fig. 9).
- Thermal imaging using a FLIR E60bx camera.

In January 2013, a team from the UCLA Department of Civil and Environmental Engineering joined our monitoring effort. They installed a tilt meter and an accelerometer on the Center Tower and later added a Wind Observer 2 to measure wind speed and direction, and turbulences in direct proximity of the Tower. They also installed two displacement transducers over existing cracks.

Fig. 9. Plaster bridge and two different types of displacement transducers (Courtesy of Blanka Kielb)

This joint monitoring program resulted in the following major findings:

- Most of the monitored cracks open and close on a daily basis: the cracks close when the sun heats up the concrete and open when the concrete cools down. The movement is smaller than would be theoretically predicted on the basis of the thermal expansion coefficient of the concrete. This is most likely due to the thermal expansion and contraction of the steel core which creates opposite forces.
- Because of the one-sided heating and expansion of the columns, the towers also lean away from the sun (to the north and west) on a daily basis with an approximate displacement of 1 in. at the top of the Center Tower. This results in daily tensile forces on the south and east legs and compressive forces on the north and west legs. Once the sun sets, the Towers return to their original position.
- Confirmation that strong winds (25–30 mi./hour) create g-forces that are comparable to moderate earthquakes. An 11 mi./hour wind creates temporary displacement of approximately 3 in. at the 100 ft. level.
- Vibrations resulting from strong winds or from seismic events occasionally lead to irreversible widening of cracks.

Comparison of a high-resolution laser scan of the whole monument with data from a measured survey conducted in the 1980s showed no permanent displacement of the three tall towers. A ground penetrating radar survey of the floor also showed no changes since 2004.

3.2 REPEATED FAILURES OF PAST REPAIRS

Based on the results of the monitoring program and direct observations on the monuments, one can attribute the failures of past repairs to the following causes:

- Use of rigid repair materials (cement-based and epoxy resins) that could not respond to the thermal and mechanical movements without cracking.
- Application mistakes such as improper surface preparation, lack of pre-wetting, and insufficient wetting after application of cement-based mortars. This led to clearly visible cold joints and adhesive failures between new and old concrete (figs. 6, 7).
- Use of combinations of incompatible materials, such as cement mortars on top of epoxy fills without the use of a bonding agent (fig. 8).
- Use of materials not designed for outdoor use, such as some acrylic resins and cellulose nitrate adhesives that have been used to readhere decorative ornaments.

4. DEVELOPMENT OF NEW REPAIR APPROACH

When discussing the repair and maintenance of the Towers, one has to accept:

- Movement (thermal and structural) as status quo and
- The need for regular retreatment as status quo.

It is our goal to extend the time period between major treatment campaigns (requiring scaffold) from currently only a few years to a period of 20–25 years.

The main goals are as follows:

- Minimize the number of new cracks forming
- Keep water away from the steel cores
- Minimize the loss of decorative ornaments

Since movement has to be accepted as a fact, a successful treatment has to accommodate that movement. The old saying that "any structure develops cracks where it needs them" also applies to the Towers. For repairs to be durable, they need to have flexibility. We therefore decided to explore the use of elastomeric crack fillers (ECFs; expansion joint fillers) for narrow cracks and polymer-modified mortars (PMMs) for larger repairs.

As added protection against future steel corrosion, we are also exploring the application of migrating corrosion inhibitors (MCIs) and penetrating water repellents.

For the stabilization of the decorative ornaments, we realized that we would need a variety of architectural adhesives for the different applications, including a silicone contact adhesive for reattachment of ornaments to cement and an epoxy adhesive for rejoining and consolidation of broken glass and tile fragments. All of them have to be reasonably stable in the outdoor environment of Southern California.

4.1 NARROWING DOWN THE CHOICES

There is a great selection of ECFs, PMMs, water repellents, and architectural adhesives on the market. We made our initial selection based on published data and communication with manufacturers and colleagues. We then obtained samples which we applied to concrete plates that we cast and to commercial concrete tiles and blocks. These samples were then exposed in the laboratory to temperature and humidity cycles, and UV radiation. A similar set was exposed on-site on an exposure rack (fig. 10).

Fig. 10. Exposure rack (Courtesy of Blanka Kielb)

While the samples were aging, we evaluated the working properties (workability) of the different products including, but not limited to, their setting time and the possibility of adding pigment for color-matching.

Based on the results of the laboratory and outdoor exposures and the workability tests, we were able to reduce the number of products to one ECF, four PMMs, and three adhesives, as shown in table 1.

Out of eight PMMs initially evaluated, four were eliminated from further consideration on the basis of rapid setting, high initial shrinkage in workability tests, and pronounced adhesive cracking in tests plates subjected to accelerated aging and prolonged outdoor exposure. The PMMs selected for continued evaluation performed best in the following categories:

- Minimal initial shrinkage
- Good working properties (i.e., ease of placement and finishing)
- Minimal adhesive and cohesive cracking in accelerated aging and outdoor exposure tests

These include two PMMs by BASF with relatively higher compressive and tensile strengths for repairs to load-bearing elements such as columns and posts. We also selected a carvable mortar by Edison Coatings Inc. suitable for shallow, nonstructural repairs, and a low-compressive strength mortar by Rapid Set that can be feather-edged and is ideal for reinforcing broken or fragile edges around ornaments.

Past treatments had primarily utilized acrylic resins such as Paraloid B-72 and, occasionally, polyurethane adhesives, epoxies, and cellulose nitrate for ornament reattachment. Many of these treatments have failed over the span of 10–20 years. Our main criteria for evaluating adhesives were durability in an outdoor environment, flexibility to accommodate thermal movement, UV stability, workability, and appearance when applied under transparent glass, particularly green bottle glass which is ubiquitous on-site.

Table 1: Products Initially Chosen for Evaluation

Material Type	**Manufacturer**	**Product Name**	**Application**
PMM	BASF	MASTEREMACO N 1500 HCR Vertical Overhead Mortar	Deep repairs in load-bearing sculptural elements
PMM	BASF	MASTEREMACO N 400 Repair Mortar	Deep repairs in load-bearing sculptural elements
PMM	Edison Coatings Inc.	Custom System 45	Shallow, nonstructural repairs
PMM	Rapid Set	WunderFixx	Ornament edging
ECF	Dow Corning	790 Silicone Building Sealant	Crack filling
ECF	Dow Corning	795 Silicone Building Sealant	Crack filling
Adhesive	Dow Corning	3145 RTV	Reattachment of ornament to cement
Adhesive	HXTAL	NYL-1	Glass-on-glass/tile-on-tile joins
Adhesive	Silicone Solutions	Low-viscosity series: 6001-T, 6001-T3, 6604 M, and 6004 M	Low-viscosity silicone adhesives for ornament consolidation

Eighteen adhesives, including eight epoxies, five silicones, three aliphatic polyurethanes, and two urethane acrylates, were evaluated for application behind ceramic, glass, and shell ornaments. Silicone adhesives performed best in terms of workability and thermal and UV stability, showing the following characteristics:

- Excellent adhesion after accelerated thermal cycling and outdoor exposure
- No noticeable discoloration under accelerated UV exposure
- Minimal saturation of the cement substrate
- Ease of application and cleanup

The urethane acrylate adhesives were discontinued from further testing after initial workability tests showed that they cured too quickly in an outdoor environment and were difficult to clean up. Many of the epoxies and aliphatic urethanes tested were disqualified on the basis of long cure time, poor/inconsistent adhesion to cement in accelerated thermal and outdoor aging tests, and/or yellowing under prolonged UVA/UVB exposure.

Our final selection of adhesives includes the Dow Corning 3145 adhesive/sealant for use as a contact adhesive for detached glass, ceramic, and clamshell ornaments; a series of injectable silicones of varying viscosities by Silicone Solutions (6604 M, 6004 M, 6001-T, and 6001-T3) for injection behind ornaments and into cracks; and HXTALNYL-1 for the stabilization of tight glass-on-glass joins. Of the epoxies tested, HXTAL showed the least oxidative and UV-catalyzed yellowing, performed best in thermal cycling, and was one of the top performers in outdoor exposure tests.

We evaluated a total of eight expansion joint fillers/building sealants for crack repair, including three polyurethanes, one polyurea, and four silicone sealants. Our evaluation criteria included workability, adhesive peel strength, aesthetic integration, and prolonged outdoor exposure. The silicone-based sealants performed best in terms of:

- Ease of application and cleanup
- Adequate working time for a two-layer joint design
- Excellent adhesion to the cement
- Highest expansion/compression capability

While the polyurethane sealants performed well in workability and adhesion tests, we eliminated them from further consideration due to their lesser movement capability and life expectancy of 7–10 years, as compared to 20–25 years for silicone-based sealants. The polyurea sealant was disqualified because it performed poorly in adhesion tests, had a short working time, and was difficult to manipulate. Our final candidates, the Dow Corning 790 and 795, were selected due to their superior workability and availability in small cartridges and an assortment of base colors to facilitate color-matching.

Finally, as part of our strategy to reduce water ingress and slow the corrosion rate of the steel armature, we assessed the performance of six water repellents. Our evaluation was based on pre- and post-treatment water absorbency measurements on cast cement plates and depth of penetration tests. Because of the strict VOC regulations in Southern California, we had to exclude one water repellent, Protectosil CHEM-TRETE 40D, that performed well in the initial tests. Another well-performing water repellent, Wacker SILRES BS 1701, was eliminated due to its incompatibility with the Dow Corning 790 sealant. A third product was disqualified on the basis of poor depth of penetration. This left us with three products for further evaluation:

- Protectosil CHEM-TRETEBSM400-BA (VOC-compliant)
- Wacker SILRES BS 290 (dilutable in VOC-exempt solvent, parachlorobenzotrifluoride)
- Dow Corning Z-6689 (dilutable in VOC-exempt silane solvent)

4.2 IN SITU TESTING

After we narrowed down the number of products under consideration, we decided to start a program of in situ testing, carrying out limited repairs in areas of failed previous repairs. The main purposes of the in situ tests are as follows:

- Develop and refine the best application procedures for our selection of materials and prepare standard operating procedures for different circumstances.
- Identify any problems that may exist with the proposed repair strategies and adjust the procedures accordingly.
- Evaluate the performance of these test repairs through long-term monitoring. Ideally this monitoring should last at least 2 years (past repairs appear to have failed within an 18-month period).

To date, in situ testing has resulted in a number of important findings:

- PMM repairs should always be executed with a bonding agent. Repairs without a bonding agent tend to show adhesive failure between the repair mortar and the old cement stucco. We are expecting the PMM repairs to fail at some point and develop cracks. However, we want the repairs to fail cohesively so that they can be repaired in the future using an ECF instead of having to remove the whole mortar repair (as we have to do now with the old repairs). We are planning experiments with designed cuts, hoping to be able to influence the location of the new cracks to make future repairs easier.
- The PMM curing behavior is significantly altered by the addition of certain pigments. We therefore started experimenting with mineral silicate paint for the aesthetic integration of the repairs.
- Epoxy resin repairs are abundant at the Towers and the ECF DC790 does not adequately bond to one type of epoxy previously used. Even the application of a manufacturer recommended primer could not overcome this problem. DC795 together with a manufacturer recommended primer allowed us to overcome this obstacle.

While we continue the in situ testing and monitoring of PMM and ECF repairs, we are now expanding this program to address other aspects of the overall repair and preservation plan. We are also evaluating the effectiveness of the latest generation of surface-applied, amino-based MCIs to mitigate corrosion in the steel armature. MCIs reduce the rate of corrosion induced by chloride ingress and carbonation by forming a protective film in both the anodic and cathodic areas. Test applications of Cortec MCI-2020 on fragments of the Towers that had been removed (replaced) in the past were quite successful, and we are beginning in situ testing, consisting of:

- Corrosion potential measurements before MCI application, using a copper/copper sulfate half-cell
- Application of the MCI by brush or infusion
- Corrosion potential measurements 4 weeks after MCI application and then every 6 months.

We also selected areas of the monument for the test application and monitoring of the water repellents that passed our initial test and comply with the California VOC regulations.

5. COMPATIBILITY TESTING

Since the final restoration plan will involve many steps and a variety of materials, we also had to verify that individual materials and their solvents (if applicable) are compatible and do not adversely affect each other.

Our compatibility tests showed that the DC790 adhered poorly to one of the epoxy resins ubiquitously used in past restorations, Sikadur 23, a low-modulus structural epoxy adhesive. To resolve this issue, we performed off-site adhesion tests using the ECF in combination with an adhesion promoter, Primer P, which is an alkoxysilane resin-based primer recommended by Dow Corning for use on masonry surfaces. While the Primer P performed well, it was discarded because it contains an alcohol component that inhibits the cure of the DC790 if there is not sufficient time between primer and sealant application.

We therefore tested another ECF, DC795 Silicone Building Sealant, in combination with the adhesion promoter DC 1200 OS Primer for use in repair areas that contain Sikadur 23. The DC795 has similar working properties to the DC 790 and is available in 11 base colors. Off-site adhesion tests between the DC795 and Sikadur 23 have shown promising results with the OS 1200 Primer.

Another compatibility issue was identified between the DC790 and two Wacker water repellents, the BS 1701 and BS 290 (diluted in ShellSol D-38), both of which caused swelling and loss of elasticity in submersion tests. While the BS 1701 was eliminated from further evaluation, we found that we can substitute the ShellSol D-38 with anhydrous ethanol as a diluent for the BS 290 without any adverse effect on the DC790. Further testing is still needed to evaluate the compatibility of the ECF with our low-VOC solvent alternatives for water repellents, the parachlorobenzotrifluoride and silane solvents.

6. FUTURE WORK

Quite a lot remains to be done before the treatment and maintenance plan can be finalized. We still need to fully evaluate the MCI and the water repellent, and develop a long-term monitoring and maintenance plan.

7. CONCLUSION

A multiyear monitoring program has resulted in a far improved understanding of the causes of deterioration of the Towers. The cracking of the cement cover is predominantly caused by structural movements due to heat, wind, and seismic activities. Once cracks are formed and water can reach the steel cores, corrosion adds to the deterioration factors. The loss of decorative ornaments is mostly caused by differential thermal expansion and contraction, weakening the bond between the ornaments and the cement. Vibrations caused by strong winds accelerate the process.

To achieve a long-lasting restoration, one needs to plan a combination of treatments consisting of crack repairs, corrosion protection with MCIs, and the application of a penetrating water repellent. Materials used for crack repairs and adhesives used for ornament stabilization and/or reattachment should be flexible to accommodate structural movements and stable in an outdoor environment. We have identified and tested a range of materials and developed treatment protocols.

Continuous monitoring and maintenance will also be essential for the long-term preservation of the Towers.

ACKNOWLEDGMENTS

We greatly appreciate the support and contributions of Mark Gilberg, Charlotte Eng, Yosi Pozeilov, Terry Schaeffer, Allison Akbaroff, Emma Guerrard, Kimberly Blanks, Charles Dickson, and LACMA Director and CEO Michael Govan who initiated and supported the project.

Special appreciation goes to the team from the UCLA Department for Civil Engineering, Robert Nigbor, Ertugrul Taciroglu, Andrey Kozhukovskiy, Jackson English, Erica Eskes, and Sophia Poulos.

The project would not have been possible without the generous financial support of the Angell Foundation, the James Irvine Foundation, The Ahmanson Foundation, the National Science Foundation, and the Bank of America.

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SOURCES OF MATERIALS

MASTEREMACO N 1500 HCR Vertical Overhead Mortar (BASF Corporation), MASTEREMACO N 400 Repair Mortar (BASF Corporation), Rapid Set WunderFixx (CTS Cement Manufacturing Corporation)
White Cap Construction Supply
(800) 944-8322
www.whitecap.com/shop/wc/home

Custom System 45
Edison Coatings Inc.
3 Northwest Dr.
Plainville, CT 06062
(860) 747-2220
www.edisoncoatings.com/index.html

790 and 795 Silicone Building Sealants (Dow Corning Corporation)
Smalley & Company
2358 E. Walnut Ave.
Fullerton, CA 92831
(714) 441-4100
www.smalleyandcompany.com/default.aspx

Dow Corning 3145 RTV MIL-A-46146 Adhesive/Sealant
Ellsworth Adhesives
W129 N10825 Washington Dr.
Germantown, WI 53022
(800) 888-0698
www.ellsworth.com/Home/

HXTAL NYL-1
Talas
330 Morgan Ave.
Brooklyn NY 11211
(212)219-0770
http://talasonline.com/

Low-viscosity series: 6001-T, 6001-T3, 6604 M, and 6004 M
Silicone Solutions
338 Remington Rd.
Chuyahoga Falls, OH 44224
(330) 920-3125
http://siliconesolutions.com

Cortec MCI-2020
S.M.A.R.T. Distribution
5521 Oak View Dr.
Mainville, OH 45039
(513) 602-5944

Protectosil CHEM-TRETEBSM 400-BA (Evonik Degussa Corporation)
The Sherwin Williams Corporation
(800) 524-5979
http://protective.sherwin-williams.com/

Wacker Chemie AG SILRES BS 290
Brenntag Solutions Group
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