Documentation Synthesis and Materials Research

Draft Report

for

Watts Towers State Historic Park

Los Angeles, California

prepared for the
State of California
Department of Parks and Recreation
Southern Division Chief's Office
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I. EXECUTIVE SUMMARY

Italian immigrant Simon Rodia created the Watts Towers between 1921 and 1955. Fully encompassing a tenth-acre triangular lot at 1765 East 107th Street in the community of Watts and reaching a height of almost 100 feet at the highest point, the site contains seventeen integrated sculptures made of steel pipes and rods, wire mesh, and cement mortar. Embedded into the surfaces are salvaged decorative pieces including glass bottle and pottery shards, glazed tile, rocks, and seashells. Surfaces, including the floor, are embossed with designs from iron gratings and Rodia's tools. The Towers are one of only nine works of folk art listed on the National Register of Historic Places and is one of only four designated National Historic Landmarks in the city of Los Angeles.

In 2003 and 2004, Architectural Resources Group (ARG) conducted a comprehensive examination of cracks and fissures in the three tallest towers. ARG investigated and evaluated causes of the fissures and made prioritized recommendations for repair and preventive measures in a Phase I report dated April 29, 2004.

In 2005 and early 2006, ARG conducted Phase II focusing on two specific tasks. For Task 1, ARG synthesized thousands of previous records including condition and repair records, repair databases, photographs, and engineering and material test reports into an accessible, web-based, three-dimensional computer model. Data links at locations on the computer model access records pertaining to defined locations. The model will allow ongoing documentation synthesis through updating and can be used to better assess condition changes over time.

For Task 2, ARG conducted further research into materials and methods for crack mitigation and repair. ARG reviewed the use of corrosion inhibitors and water repellents to determine their efficacy and cost effectiveness on the Towers. When chlorides and carbonation are high, current testing and experience show that corrosion inhibition and water repellency are unlikely to be effective for more than a year or so. Short periods of efficacy would require repeated applications, driving up costs while not guaranteeing adequate protection from water or further corrosion. Furthermore, excessive build-up of inhibitors and repellents may have a long-term negative effect on multiple materials that are as yet not known.

The single most highly recommended action is to maintain the site on an on-going basis. Due to the nature of its construction, crack formation remains inevitable. The variation of original materials and methods used, plus additional variations in repairs, form a patchwork of materials that vary in physical properties. Preservation of the Towers will depend largely on a regularized maintenance program to mitigate cracks as they occur, thereby reducing water ingress, further crack propagation, and loss of surface material. Reducing corrosion of the internal steel armature is also desirable; however, to date, no known "silver bullet" exists that would arrest corrosion in this case. Monitoring, documenting, and repairing cracks as they occur remains the single most effective approach for long-term preservation.

A team approach is highly recommended for continuing the preservation of Watts Towers. Team members should include conservators, conservation scientists, structural engineers, historians, and community representatives. Architectual Resources Group is indebted to the City of Los Angeles Historic Site Curator of the Cultural Affairs Department and the City's Watts Towers contract Conservator and Engineer for their generous help and cooperation during both phases of this project.

II. INTRODUCTION

This report presents tasks accomplished in Phase II and follows Architectual Resources Group's Phase I "Evaluation and Conservation of Fissures Report" dated April 29, 2005. During Phase I of the project, ARG assessed the fissures in the three towers and floor. At the time, background information provided included the 1983 Ehrenkrantz Report and 1983 Conservation Handbook. During Phase II, ARG provided additional documentation.

Recommendations made during Phase I are described in the April 29, 2005 report. In summary, recommendations included:

- Synthesis of Documentation
- Monitoring and Inspections
- Material Testing and Mock-ups
- Discrete Phase II Repairs
- On-going Maintenance Program
- Material Treatments at Towers

Following peer review, California State Parks revised Phase II of the project to focus on two tasks. Task 1 was to synthesize existing documentation and Task 2 was to conduct further materials research specifically for corrosion and crack repairs.

A description of the Watts Towers site with historical context and construction description can be found in the Phase I report and elsewhere. Conditions of the three towers and floor are also noted in the Phase I report, as are treatment recommendations. This report describes further assessment of crack repair materials and methods and provides further recommendations for treatment in addition to the recommendations made in the Phase I report.

III. METHODOLOGY

Architectural Resources Group (ARG) worked with a team of experts to accomplish Phase II Tasks.

David Wessel	Architectural Conservator and Principal, Architectural Resources Group
Katharine Untch	Objects Conservator and Project Manager, Architectual Resources Group
James Cocks	Conservation Technician, Architectual Resources Group
Andrew Lins	Consultant, Head of Conservation Department, Philadelphia Museum of Art
George Wheeler	Consultant, Research Scientist in the Department of Scientific Research, Metropolitan Museum of Art and Director of Conservation in the Historic Preservation Program, Columbia University.
Jon Asselanis	Materials Scientist and Petrographer, Applied Materials & Engineering, Inc
Zuleyma Aguirre	Contract Site Conservator, City of Los Angeles
Mel Green	Contract Site Structural Engineer, City of Los Angeles
Virginia Kazor	Historic Site Curator, Cultural Affairs Department, City of Los Angeles
David Colleen	Principal, Planet 9 Studios
Christian Greuel	Director of Art & Production, Planet 9 Studios

The ARG team conducted several site visits between April 2005 and March 2006 to meet with team members, review tasks and outline a plan of work, review and retrieve existing documentation, conduct a laser scan, conduct materials analysis on site, and take samples for further laboratory analysis. Details of methodology are described separately for each task below.

A. Task 1: Synthesis of Documentation

The Task I goal is to gather all relevant historical treatment information into a single accessible format. To accomplish this task, ARG proposed using a three-dimensional web-based computer model of the Watts Towers site, to which documentation is linked via associated locations. For example, the location of cracks and their previous repairs can be identified on the computer model for accessible condition tracking over time. In addition to location-specific documentation, documents with more generalized information, such as inspection reports, condition survey summaries, and historical correspondence, were linked to the model using a generalized or “no specific location” feature.

ARG’s contract provided sufficient resources to initiate a basic model, with the understanding that over time, additional details and documentation can be added. The intention is for the 3D interface to be a representational facsimile of the architectural features of the monument, thereby allowing intuitive navigation of the information residing in the database. ARG’s approach was to provide a substantial foundation upon which current and future individuals working at the site may easily update the system.

ARG and Ms. Aguirre prioritized documentation used for the first model release. Select documents were converted into electronic formats and files were organized onto a server. (See Figure 1). A more detailed description of file organization and nomenclature can be found in Appendix C. Documentation was synthesized using Microsoft Access™ Database, a readily available software package that allows users to easily update and add new information. Individual repair records were organized into Access database files, one for each sculptural feature. An additional Access database file was generated to organize remaining electronic document files.

Planet 9 Studios, Inc., a firm specializing in three-dimensional modeling of buildings and sites, generated the model from a laser scan of the site. The interactive 3D interface was linked to the existing Microsoft Access™ database files. To ensure the accuracy of this complex structure, Planet 9 had a High-Definition Survey (HDS) done of the site. (See Figure 2.) The Cyrax™ 3D laser scanner was used to scan the site from several different angles. This resulted in a "point cloud", which is a dense array of location samples precisely describing the surface as a large number of discreet points in Cartesian space. (See Figures 3 - 6.) The point cloud was then skinned, transforming the scan data into a polygonal mesh surface. (See Figures 11 - 12.) This high-resolution mesh was then used as an accurate guide to build an optimized version that can be transferred easily over the Internet and rendered in real-time on a personal computer. (See Figures 8 - 10.) Furthermore, the mesh object was divided into components that correlate directly with the unique pre-existing 4' x 4' grid sections identified in the repair database. (See Figures 11 – 12.) The site floor plan resulting from the laser scan did not correspond exactly to the previously assigned 4' x 4' grid system. Rather than re-assign a grid system to match actual 4' x 4' sections (that would have required reassigning hundreds of related locations noted in previous individual documentation records) the previously assigned grid system was stretched to match the data point cloud version. (See Figures 13 – 15.)

Using JavaScript™ technology, each component section of the mesh was hyperlinked to allow the Access database to be polled. This returns a list of all records associated with each particular section. (See Figure 16.) The record in turn was hyperlinked to reveal detailed information. (See Figure 17.) Additionally, each component section of the 3D model may be color-coded based upon particular search criteria. (See Figure 18.) For the first model-release, the criterion was the number of cracks repaired as noted in the existing Access database. This gives the user immediate visual information for sections that have been identified and treated with varying frequencies. It is hoped that this feature will assist in identifying historically problematic areas.

B. Task 2: Materials Testing and Research

The focus for further materials testing and research was to determine the efficacy of water repellents and corrosion inhibitors. ARG explored whether water repellents and corrosion inhibitors could stabilize the structure and prove cost effective with respect to other treatments. In addition to previous tests conducted by ARG during Phase I, ARG reviewed previous documentation, conducted additional analysis, and consulted jointly with George Wheeler and Andrew Lins. The consultants reviewed the Phase I report, previous materials testing that was provided from existing documentation and recommended further testing conducted during Phase II.

Further tests performed by ARG included additional petrographic and chemical analysis of selected mortars, levels of carbonation and chlorides, absorption, and infrared reflectography for moisture content. Appendix D includes individual laboratory methodologies.

Four cross-sections of Rodia's original mortar were selected to test for levels of carbonation and chlorides. Two of these samples were further tested using standard petrographic analysis and identification of chemical composition of the mortars. As with all of Watts Towers, samples selected reflect just that: a small sampling of actual conditions that may be quite varied over the entire site. Test results were compared with previous tests conducted in 1982 for chloride content.

Surface pH was measured at the site by wetting the surface and applying pH test strips. Surface chlorides were measured in a similar manner using Mercoquandt chloride specific test strips and comparing field results with laboratory results. Profiles of pH and chlorides were conducted on cracks where samples were taken from drilled holes in ¼" depth increments. The samples were soaked in distilled water and measured with pH test strips and the Mercoquandt chloride test strips.

ARG conducted surface absorption tests using RILEM tubes. ARG also tested surface temperatures with a thermal camera to determine whether differences in moisture retention could be determined. A ThermaCAM B20HSV from FLIR Systems recorded thermal images at the site. (See Figures 19 – 21.)

IV. RESULTS

A. Task 1: Synthesis of Documentation

1. Creating the new model

The 3D computer model was designed and constructed with a specific purpose in mind: to visualize existing documentation with respect to the condition and conservation history of the site and to provide an easily accessible tool for organizing and storing future condition information. Paramount to its success was the optimization of the model for use on today's personal computers over an Internet connection. Although complete detailed surface-texture documentation may be a desirable feature for the future, providing this feature is still beyond the capacity of present consumer computer-technology, as well as the scope of this phase of the project. A sufficient level of detail for this purpose could be obtained with multiple ground-level locations scans taken with the Cyrax laser scanner with an accuracy level of 1 centimeter.

The process of using 3D laser scanners is analogous to shining a flashlight in absolute darkness: because of the complexity and surface area of a site, pieces of members obscured by foregrounding objects can create small shadows in the point cloud. Because of the intended present-use of this model as a tool for visualizing and analyzing documentation, these shadows, along with the detailed wire mesh surface of the model, were approximated with simpler polygonal shapes based on existing documentation to the highest degree of accuracy possible without implying a false level of precision. Although by no means does the new model provide complete surface documentation of all of the elements and conditions of the towers, it serves well to accurately record the locations of the conditions and repairs. The scans are sufficiently detailed to show many surfaces of the site elements and general enough to provide context.

2. *Linking the Data*

Over the past few decades, extensive documentation has accumulated with regard to the preservation of the Watts Towers. Several individuals have contributed to the documentation over time and have followed various systems of cataloguing, many of which have retained their respective historic naming conventions and organizational systems. Existing documentation includes historical descriptions, condition surveys, materials analysis, engineering assessments, repair records, and historic correspondence. Formats include black and white and color photographic prints, negatives, transparencies and microfiche, x-ray film, hard copy standard 8 ½" x 11" paper reports, 5" x 7" card stock as well as electronically scanned bitmap, JPEG, and PDF files, Procite™ and Microsoft Access™ database files, and Microsoft Word™ document files.

Before ARG's work, the vast majority of files pertaining to the site remained as hard copies, including photographs, records, and reports. These documents have been housed in a 1920s bungalow near the site, eventually overflowing the filing cabinets and stored in boxes. Electronic files were kept on 5 ¼-inch floppy diskettes, 3 ½-inch floppy disks, zip disks, and CD-ROM discs. To date, there has been no network access to a server at the site. Although these storage devices managed to hold many hundreds of digital files, the system was approaching its limits.

A large-scale photographic effort occurred in the mid-1980s, when the site was systematically divided into about 1,500 4-foot by 4-foot grids and photographed by Marvin Rand. The system differs from the other general location naming convention that identifies each individual member of each sculptural feature. While Rand's photographs follow the former system, repair records follow the latter, a more precise location identification system.

Repair records followed different formatting systems. A system begun in 1979 followed a repair number using the 4' x 4' grid system.

The individual member within the grid was identified on the repair card, along with materials used and a picture of the repair. These repairs were entered over time into a computer database, which changed formats several times. The database was textual only and contained no photographs.

Many of the early reports, beginning with the 1959 proposal to save the Towers from demolition, was consolidated in the 1983 Ehrenkrantz Report. Revisions and further reports were added over the years, and the combination resulted in a binder called the *Conservation Handbook*. This binder documents the guidelines, through 1998, for performing repairs.

ARG realizes its own role as one of the many stewards that over time will contribute to the preservation of both the site and its records. The digitization, consolidation, and organization of all files are beyond the present scope of this project. Through establishing a structure and guidelines, however, it is hoped that all files—past, present, and future—may eventually be consolidated into one organizational system. For this phase of the project, ARG synthesized approximately 1,200 of the grid photographs and about 500 repair records and reports, a mere fraction of the total records documenting the site and its repairs. ARG consulted with Ms. Aguirre and prioritized these initial records subsequently used to construct the initial file structure and linkages to the model. ARG provided limited scanning services for documents not yet in electronic formats. With a basic structure in place, future users may contribute new material to the synthesized document system.

The Microsoft Access™ database currently used by the City's conservation team was minimally altered so as not to disrupt the historic nomenclature and use of the system. Database and scanned records collected through December 31, 2005 were used to link to the model. A few records, images, and reports were not identifiable and were left in electronic file folders marked "unlabelled" until they may be adequately identified.

Some previous survey reports have valuable condition information with images that were not yet scanned individually. An example is the 1995 Conditions Survey, *Tall Towers Inspection Report #2*, with 31 pages of appended photographs.

B. Task 2: Materials Testing and Research

A wealth of information, including previous research into original materials used, proposed treatment methods and materials, and on-going re-evaluations of previous repairs, has been gathered and presented over the past half century.

A number of materials and techniques have been previously tested and used as repairs to Watts Towers, including patches and repairs made by Simon Rodia. Subsequent testing and use of materials over the past fifty-plus years have included various water repellents, corrosion inhibitors, mortar mixes, polymers (epoxies, urethanes, acrylics, rubbers, foams), ammoniated, chlorinated and other cleaning agents, and zinc containing galvanizing compounds. Investigations into passive and active galvanic protection have also been undertaken in the past and during Phase I of this project. A history of materials used and tested on the Towers can be found in Appendix B. Although not fully comprehensive, the references give an idea of the many materials and techniques that have already been tested and used.

1. Mortars

Historic descriptions and previous and recent analysis indicate a range of original Portland cement mortars were used by Simon Rodia. Many repairs have been conducted by Rodia and thousands more by others. Subsequent repair mortars have included acrylic and epoxy mixes, admixtures and entrainers, as well as lime mortars. Petrographic analysis of recent samples can be found in Appendix D. Samples were comprised of Portland cement paste and sand without any lime detected.

Previous repairs over several years leave many incongruous or miss-matched surfaces with regard to shapes, color, and texture. While the repair technique may have been well intentioned to distinguish repairs from original surfaces, over time these numerous repairs have resulted in a visual confusion of original artist's intent. In some areas, the repairs have taken over and are more prevalent than any remaining original surface.

In some cases, repairs were made with a rough, unfinished texture on the surface, while in other areas repairs are left recessed. Water and moisture are contributors to deterioration, especially when there is an impediment to its moving freely into and out of adjacent but different materials. Minute differences in surface texture can cause water or moisture to pool, thereby accelerating deterioration or causing further cracking in those areas.

A difference in mortar mixes further exacerbates deterioration. Mortar mixes with considerably different rates of absorption will impede water migration and evaporation, thereby affecting deterioration, the early signs of which will probably be in the form of more cracking. Mortars with admixtures of acrylics, epoxies, or water repellents generally have lower rates of absorption that will tend to concentrate moisture in adjacent original, more absorptive mortars. While an epoxy fill may hold up very well over time, it may cause an increased rate of deterioration or cracking of adjacent original mortar.

Similarly, differences in strengths of repair mortars will impact original mortar mixes. Crack repairs should be slightly weaker than the surrounding mortar to allow further movement and cracking in the repair mortar, rather than in the adjacent mortar being preserved. Repair mortars that are too strong will remain less mobile, causing further cracking in original mortars when the Towers undergo movement. The only exception to this is where a stronger mortar mix would be required for structural reasons as determined by a structural engineer.

2. *Carbonation*

Levels of carbonation were also varied. Of the four mortar samples recently tested, three had non-carbonated pastes with a pH of 13 or greater. One sample was non-carbonated with a pH of less than 10. Surface pH measurements at lower elevations showed pH of about 7. The two depth profiles at existing cracks showed a pH of 11 or 12 near the surface and 7 or 8 from about ½" deep to increasing depths. The varied results indicate the likelihood that some areas of the Towers have non-carbonated mortars that retain a magnitude of corrosion protection due to their high pH, while other patches of mortar are already carbonated. The lower pH at deeper levels along cracks may be indicative of later repairs possibly even Rodia's, over older, already carbonated mortars.

3. Chlorides

Removing chlorides is a difficult, if not impossible, undertaking. Cleaning exposed metal surfaces may improve bonding to repair materials, but any known method of cleaning would probably not be that effective long term. Air abrasives and mechanical methods can remove surface corrosion but are also known to trap chlorides under the abraded surface.

If high levels of chlorides are present, many materials sold commercially for corrosion inhibition may not be effective. If both chloride levels and carbonation are too high, an inhibitor may not be sufficiently applied to retard active corrosion in or under a mortar, as the active chloride corrosion sites will not be pacivated. However, should a lower level of chlorides be present, some efficacy may exist in using corrosion inhibitors for the short term, though frequent reapplication would be necessary. It is also of importance to note where the chlorides are concentrated, whether they be on or near the metal armature, dispersed throughout the mortar layers, or concentrated on the surface, or in cracks. If chlorides are bound within the upper layers of the mortar, the penetrating inhibitors may react there and not be effective in depolarizing chlorides at the steel interface.

Of the samples tested, the range of chloride levels varied from 0.001% to 0.22% by weight concrete (mortar). Previous tests for chloride levels by Erlin Hime Associates circa 1982 indicated chloride levels in mortar samples to range from 0.11 to 0.40 % by weight cement. Converted roughly to percent weight of concrete, the 1982 samples range from approximately 0.005 % to 0.014% by weight concrete.

The suggested maximum acid-soluble chloride content for reinforced concrete (to minimize chloride-induced corrosion) is 0.025% by weight of concrete. (See conversions in AME report dated February 2, 2006 in Appendix D.) The 1982 samples are below the suggested maxium chloride level while some of the recent samples have much higher levels of chloride content.

AME analyzed a profile of chloride content for one sample that showed a spike at 1" depth, corresponding to an interior elliptical crack around the sample's metal core about 0.2 inches from the metal.

No consistent correlation was shown between levels of carbonation and levels of chlorides in any of the samples tested. The sample with the highest chloride content corresponded with one of the non-carbonated mortar with pH above 13.

Discrete chloride analysis on mortar surfaces at the site all tested negative for chlorides, as did a previously removed section of corroded steel.

4. *Corrosion Inhibitors*

a) Galvanic

A discussion of galvanic corrosion inhibitors for use at Watts Towers is described in ARG's Phase I report. Active cathodic protection is impractical given the variety of mild steel used for internal armatures and their incongruous joinery.

A commercially available passive system with custom sized sacrificial anodes could be inserted into repairs. A patchwork of uneven sacrificial anodes in juxtaposition to a non-contiguous metal armature may affect neighboring areas, causing increased galvanic corrosion of original metals outside the area to be pacified. This is often seen in the concrete industry as corrosion "rings" or "shadows" where a passive anode protects about 3 feet of rebar, but causes accelerated corrosion in a "ring" or "shadow" just beyond the individual anode's effective area.

When using such a system, multiple anodes are utilized and the spacing between each anode is calculated to prevent this type of shadowing effect. In the case of the Watts Towers, it would be difficult to internally insert a sacrificial anode at pre-set distances to avoid this shadowing effect.

b) Chemical

Chemical corrosion inhibitors generally fall into one of three basic categories: fluorophosphates, nitrates/nitrites and alkanolamines. The fluorophosphates are generally less successful for this type of application. The nitrites and alkanolamines, generally work by raising the pH. They are usually pooled on the surface of the mortar or concrete and allowed to penetrate through to the metal reinforcement. This is fairly old technology and has been often used in boilers or to stabilize steam converters. Calcium nitrites may be more effective with new materials, but its efficacy on Watts Towers will depend on levels of carbonation or chlorides inside the mortar. When levels are low, it can be effective in bringing back an oxyhydroxide surface on the metal.

Sika Ferroguard 903 is an alkanolamine product designed for surface application. It has been tested to penetrate to a depth of 3-inches, which is adequate for most areas of the Towers, as the average depth range of mortars is ½" to 2". Sika Ferroguard 903 is effective in low to high pH so should not be affected by the varying levels of carbonation found in the samples. The manufacturer recommends that the product be allowed to sit on the surface and penetrate for at least 24 hours.

If a surface water repellent is to be applied, then the surface should first be rinsed well to remove a surfactant from the Sika Ferroguard 903 before application of a water repellent.

According to the manufacturer, the chloride content limitation for the Ferroguard 903 effectiveness is between 6 to 12 lbs of chlorides per cubic yard of concrete. This converts to approximately 0.15 % to 0.30 % weight of concrete. Levels of chlorides appear to be sufficiently low to provide some efficacy of the product. However, treating one section without treating adjacent sections of metal may not prove to be that effective overall.

Effective penetration is likely not to be uniform over the entire surface. Previous water repellents and mortar admixtures with low absorption used on the site will likely inhibit penetration. With the variety of mortar mixes, some with acrylics, epoxies or other admixtures, application of penetrating corrosion inhibitors may not result in the inhibitor reaching the metal armature in sufficient quantities to effect inhibition of the metal where it is needed.

The efficacy of penetrating inhibitors may taper off over time. While there may be some temporary increase of pH during the repair campaign, the long-term effectiveness of penetrating inhibitors has yet to be proven. There is no data to show that the benefits from inhibitors could last more than a few years. The Ferroguard alkanolamines have been on the market a relatively short time and as yet have not been field tested for longer term effectiveness for applications on already deteriorated metals in mortar matrixes such as on the Watts Towers.

There is also a level of unpredictability with the effect of repeated reapplications of penetrating inhibitors. Retreating every couple years with calcium nitirite, for example, has not been shown to be effective. While application of calcium nitrates should not impede water repellants, the effects of an excess of calcium nitrite salts from successive reapplications on mortars and other embedded surface materials is yet unknown.

Using inhibitors as admixtures to new mortars has been shown to have benefit in the concrete industry for new rebar, but this does not necessarily apply for metals that are already corroded such as at Watts Towers.

5. *Moisture*

Absorption tests showed a wide range of absorption rates from zero to over two ml/minute. It was difficult to conduct surface absorption tests due to the variety of surface textures and existence of micro-cracks. Selecting a sufficiently smooth surface without existing cracks or previous repairs proved challenging. Some areas noted as Rodia's mortars had almost no absorbency and appeared to have been treated with a water repellent at some time in the past. Some repair mortars also had low absorption.

Due to the variation in materials, thicknesses of metal and mortars, and embedded materials, it was difficult to ascertain moisture retention patterns using an infrared thermal camera. Sample images are described in Appendix A, Figures 14 through 16.

Condensate may also be affecting carbonation and corrosion. The atmosphere is fairly acidic in Los Angeles and at times may have been even more acidic from increased smog levels. Acidic condensate may contribute to lowering mortar pH. Condensate may also bring chlorides and other salts to the surface and concentrated into cracks.

6. *Water Repellents*

Factors affecting water repellency include surface morphology that allow water to pool in small crevices and interfaces with imbedded materials, cracks that will retain water, and materials that impede water evaporation, including embedded materials and repair materials that have lower porosity or absorbency than the original mortars used.

Application of several commercial products to alkali substrates will result in some water repellency, but they may have to be reapplied every year or so, as they will degrade.

Water repellents for reducing the penetration of chloride containing water were investigated in 1982 on behalf of the Ehrenkrantz Group. Included in the study were Hydrozo Clear 30, Hydrozo Clear Double 7, Hydrozo Clear 15, Chemstop Heavy Duty, Chemstop for Concrete, Wacker Silicon and Chemtrete BSM 40. Of the materials tested, Chemtrete BSM 40 was recommended as having the greatest effect on chloride screening.

7. Cracks

Crack development on the Towers remains inevitable given the nature of materials used and construction techniques. Causes of cracking may include Tower movement due to seismic activity, ground settling, wind, daily thermal fluctuations, differences in original mortar mixes, differences in repair mortars, surface texture, mass ratios of metal to mortar in different areas, salt crystallization or deterioration of mortars from salts, corrosion of metals, and/or corrosion jacking. Some of these causes may be relatively minor and, in some cases, it may be difficult to determine precise associations between a crack and its cause. Crack prevention is unlikely ever to be successful. On the other hand, crack mitigation is possible for some causes and can be altered somewhat by treatment methods such as selection of appropriate repair mortars.

Regardless of the cause of cracking, on-going monitoring and maintenance remains the best course of action to reduce egress of water to the metal core and reducing the potential for further corrosion and separation of mortar layers. Specific structural cracks should always be addressed in consultation with a structural engineer and structural repairs designed accordingly.

8. *Evaluation of mock-ups.*

In November 2004, ARG conducted mock-ups of crack repairs. The areas tested were re-examined in March 2006.

In four cases out of five, Jahn mortars showed signs of cracking where one or another edge of the crack repair had separated from the original edge by approximately 1/64" to 1/32". It is likely that the cracks were due to shrinkage of the mortars while curing and lack of adhesion between the Jahn mortar and existing mortar to be repaired. The Jahn mortars are known to be a little "fussy" and require strict adherence to curing conditions, keeping them moist, but not overly wet, over several days to cure properly. The manufacturer recommends specific training for use of their products and does not recommend using any additives or variations such as pigments in their mortars; however, adding dry pigments is a common practice in the field.

In summary, crack repairs as outlined in Phase I should be effective. Lime based mortars without the addition of acrylics or epoxies is preferred. The use of water repellents and corrosion inhibitors may not prove sufficiently effective to warrant their cost. Water repellents may induce water channeling into existing cracks and alter surface appearance somewhat. The use of surface applied water repellents may also inhibit surface penetrating corrosion inhibitors should those be of use in the future.

V. Recommendations

A. Digital Model Advancements

As computer technology advances and further resources become available, enhancements to the computer model can be achieved. While it is tempting to propel a computer model to a full-blown technological wonder, a more pragmatic and economical approach in keeping with the goals of the proposed preservation program is outlined here in order of priority.

1. Further articulate locations on the model to include individual member names, for example “exterior column” or “intermediate band,” using the existing labeling system that has been used for site records. This will allow for more precise locations for data hyperlinks, thereby enhancing assessment capabilities of previous condition records. It will also allow for easier recording for locations of future tests and repairs, a very time consuming process for those not as familiar with specific locations within the site.

2. Document cracks visually on the model so that when the computer cursor passes over a section, the identification of the crack with its associated properties in particular noted dimensions appear with associated dates. This will give a better indication of the change in condition of cracks over time.

3. Display a rendered color-surface on the model based on photographic campaigns to identify additional surface features and conditions. The rendered surface will serve as a photographic document of condition at a unique point in time that can later be compared with future rendered scans.

4. Generate higher resolution models of the site to allow for more detailed recording of surfaces and locations.

5. Integrate high-resolution digital photography with the computer model to provide a more detailed baseline for monitoring condition changes over time. Future 3D snapshots of the site may provide greater levels of precision.

6. Explore additional uses of the model as technology permits. The current model and point cloud, for instance, may be compared with a future 3D laser scan to see if any features have experienced shifting or displacement. Additionally, point clouds may be used to generate models to be used for engineering studies of the towers.

1. Data Clean-up

Files contained in folders marked “unlabelled” need to be correctly identified and labeled according to the established nomenclature. Then these files can be linked to the model.

Single records of multiple page reports containing individual images or analytical tests related to a specific location on the site can be exploded and each image or analysis saved as a separate file in accordance with the established nomenclature. These files can then be linked to the model.

The Microsoft Access™ Database may be updated and refined for ease of use. As future technologies become available, data can be converted. Maintaining the data in a format that is readily available to users is highly recommended. Established database vendors are preferable.

2. Adding new records

ARG prioritized historic records for inclusion with the first model release. Additional records to add include approximately 50 boxes of repair record photographs attached to 5” x 7” index cards that need to be individually scanned and labeled according to established nomenclature.

Existing reports, correspondence, repair records, photographic records, high-resolution scans of X-rays, and any other documents that pertain to the site's condition or preservation may also be added.

Future surveys, assessments, studies, and treatment campaigns should all be added to the existing system of record keeping.

It will be important to utilize the established nomenclature for site locations as well as nomenclature for labeling electronic documents. Nomenclature guidelines can be found in Appendix C.

3. Image Tags

Image tags should be applied to each image and document of the files, establishing copyright and authorship. These tags assist in defining the source of the document when shared over the Internet.

B. Archives

Preservation of existing records is paramount as is their on-going accessibility. Scanning documents to convert them to electronic formats and making them available through the Internet may provide increased accessibility but does not address the preservation of important original documentation. Electronic conversions do not replace the level of photographic resolution or the details required by conservators, scientists and engineers in addressing the overall site preservation. Even after reviewing electronic documentation, individuals will still need to reference original documentation materials for details that can be helpful in determining rates of deterioration and future treatment designs.

During site visits, it became clear that records kept at the site would benefit from the care of professional archivists and archive conservators.

Furthermore, the location of paper-based records at the site does not provide the level of security or environmental conditions conducive to their warranted preservation. ARG strongly recommends that a more appropriate repository, such as a city or state library or archive, be identified where the materials can be appropriately housed, catalogued, and cared for.

As state property, any physical parts from the site should be collected from various individuals and locations and retained in one clean, secure location. Removed parts may include sections that fell off, were removed for analysis, or were removed during repair. All parts should be clearly labeled and catalogued with their original location on the site noted and purpose for removal. The catalogue should use Microsoft Access™ database and follow nomenclature guidelines so that it can be linked to the model.

C. Computer Technology

An improvement to computer technology at the site is highly recommended. The City's conservation team as yet has no site access to a networked server, and the computers have limited capacity to deal with the current volume of records. Still used at the site on a daily basis is a combination of: 3 ¼" and 5 ½" floppy disks, zip disks and CD-ROMs. Data on these various media formats needs to be converted to a server that is maintained by professional information technicians and backed up on a regular basis. Additionally, the computer equipment itself is outdated and should be updated.

Using a laptop in the field with wireless access to a data entry screen can further enhance accurate and up-to-date documentation during on-going repairs. New data can be entered directly into the system, or into a secondary working system with periodic updates to the public website.

D. Update photo documentation

During the next treatment campaign, when scaffolding is erected, new 4-foot by 4-foot transparencies should be taken of the towers for comparison with the photos taken by Marvin Rand from 1987-1992. These images will provide a 15-20 year span of valuable visual information for condition comparisons.

Future photography should include in-frame measurement scale, grey scale and color scale. This will assist image wrapping and future analyses quantifying the exact identity of surface colors and to quantify future color changes, such as fading.

High-resolution photography may also be applied to the model for condition documentation. Images may also be applied to the 3D computer model as a rendered surface. Although the wrapping would not be 100% accurate with regard to alignment, it should be close enough for comparison purposes and for monitoring cracks and other conditions.

E. Treatment

The Towers were constructed with a variety of materials and methods. Inconsistencies in the physical properties of original materials plus addition variations of repair materials make the site a patchwork of physical characteristics. As such, conservation approaches must take into consideration that treatments cannot be designed as if the site consisted of a single set of cohesive materials.

The nature of the materials and methods used to construct Watts Towers dictate the need for on-going maintenance. The history of conditions demonstrates that cracking is likely to continue. Unfortunately, no known “silver bullet” exists that will arrest all corrosion and cracking. Mitigating cracks and their propagation will be the most beneficial approach for long-term preservation of the Towers.

Inspections should continue on an annual basis. Repairs at lower levels should be continued on an annual basis while upper levels requiring scaffolding may be repaired on a five to ten year cycle, leaving the Towers free of scaffolding to be enjoyed for significant periods of time. Regular maintenance is the highest priority, higher even than exactly what repair materials are used as these may change as technology changes over the years. Regardless of the exact repair materials used, cracks should be repaired a soon as possible. Leaving cracks exposed to the elements greatly increases the risk of accelerating corrosion of the interior metal pieces.

A cyclical maintenance plan will help reduce costs over the long-term by mitigating conditions in their early phases. Gaps in regular maintenance will result in more extensive and hence more costly conservation treatments.

A major concern in prescribing materials to be used as fillers and for repairs is the compatibility of materials with regard to strength, density, porosity, texture, as well as visual integration. Repair materials that have large differences in water absorption, can impede evaporation and trap water in the repair material, original mortar, or the interface between the two components. Trapped water may allow for continued reactions, including migration of salts and galvanic corrosion of the armature. Epoxy fills, acrylic admixtures and Portland based cements have lower porosities than the Rodia mortars and may accelerate deterioration by chemical reactions in the presence of water in the original mortar or at interfaces.

Methods for crack repair are outlined in the Phase I report. In addition to previous recommendations, ARG recommends that the cause of each crack be determined (as much as possible) and recorded in the inspection and treatment records. Repair methods for cracks caused by different aspects (corrosion jacking vs. shrinkage of mortars for example) may require different treatments in the future. This information will aide in future assessments of repair materials and methods for each type of cracking.

Lime based mortars are preferred for crack repair for Watts Towers without the addition of any acrylic, epoxy, or other additives. They provide a measure of elasticity for crack repairs that Portland cement based mortars do not.

For wider crack repairs, mortars would benefit from the addition of a matching aggregate to provide similar texture of the repair to the surrounding area. St. Astier Natural Hydraulic Lime (NHL) products can be used for custom mortar mixes to include appropriate color and aggregate matching. St. Astier also provides a line of pre-mixed mortars that may be appropriate for some crack repairs. Data Sheets can be found in Appendix E. Conservators working on repairs should be knowledgeable in conducting color and aggregate analysis for each major area of repair and be able to provide appropriate selections for custom matching.

The galvanic effect of using stainless steel for replacing original mild steel is probably not that big of a factor. Surrounding areas should be monitored for any signs of increased corrosion. The use of polymers for replacement of metal armatures should probably be avoided due to reduced bonding of mortars and thermal variations that could cause increased cracking over time.

While the bulk of this report focuses on the metal and mortars, embedded materials should not be ignored. As an integral work of art, all materials should be inspected regularly and any condition abnormalities should be documented and treated in accordance with best-known treatment methods.

A consensus needs to be reached with regard to the aesthetic nature of repairs. There are several schools of thought concerning cosmetic compensation for areas of loss or damage. Should a repair remain visibly different from the original so that it is distinguishable as a repair, or should the repair be matched as closely to the original as possible? Should repairs match in size, texture, and/or color? Or should repairs match only in size and texture, and not color?

ARG recommends repairs that match the nearby surrounding material fabric as much as possible in size, shape, texture, and color. Close aesthetic matching goes hand-in-hand with matching physical properties of surface textures, absorption and strength, thereby reducing further deterioration by differences in water behavior on unmatched surfaces.

F. Ongoing Research

ARG is confident in its current recommendations for monitoring, documenting, and treating the Towers. As with any long-term preservation effort, on-going research into new materials and methods will be paramount. Continued research in the area of water repellents, corrosion inhibitors and methods of crack repair should follow new developments in these industries as they occur.

As survey and repair data becomes more accessible through the computer model, it will be easier to monitor and determine frequency and rates of cracking in discrete locations. From existing patterns, better conclusions can be drawn over time regarding causes and frequency of cracking as well as effectiveness of repairs. More sophisticated assessments may be made; for example, whether there is more systematic cracking with one particular metal alloy, or more cracking from thermal stresses.

Future analysis on metal alloys may assist with decisions on corrosion inhibitors as the industry develops further. A portable x-ray fluorescence instrument can be used in the field prior to completing repairs on exposed metals, or samples can be taken for SEM/EDS analysis.

While the tasks assigned to ARG were specifically directed at corrosion inhibition, crack repair and water repellents, it is important to continually consider the site as a holistic composite of materials. Focusing primarily on the materials that form the structure of the site, metal armatures and mortar, will continue to have some priority for primary structural reasons. Nevertheless, future research should continue to incorporate the effect of treatment materials and methods on embedded surface materials such as rocks, shell, ceramic, and glass.

Appendix A: Photographic Figures

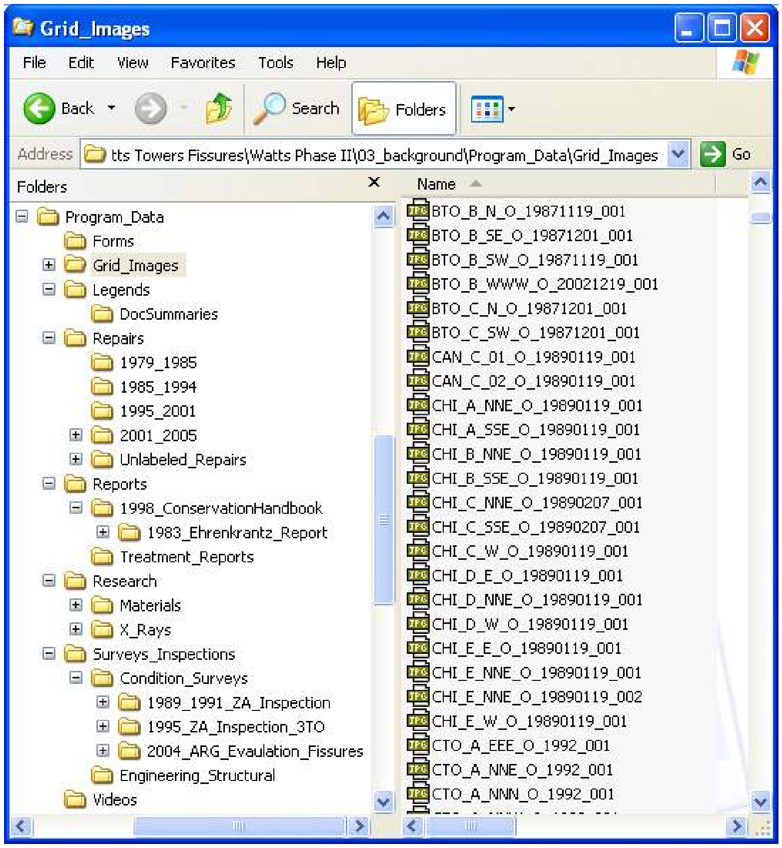

Figure 1 – File organization of existing documentation.

Figure 2 – On location during Cyrax 3D Laser Scanning.

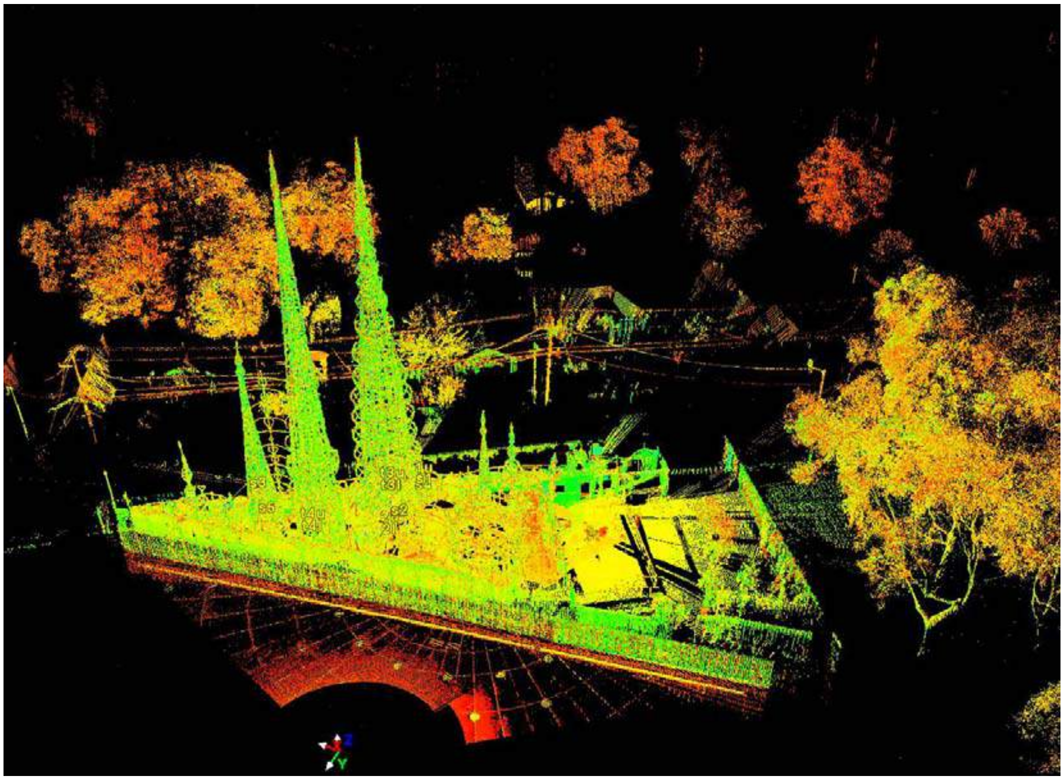

Figure 3 - View of Point Cloud generated by laser scanning. The points are accurate to 1 centimeter.

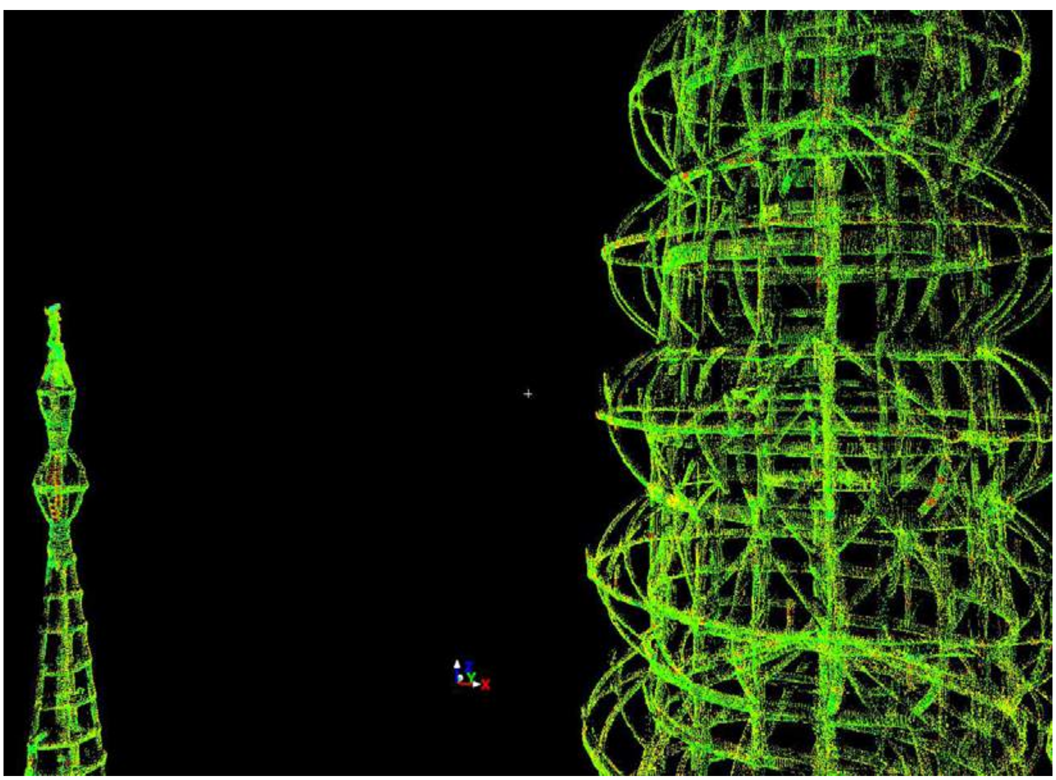

Figure 4 – Detail of point cloud.

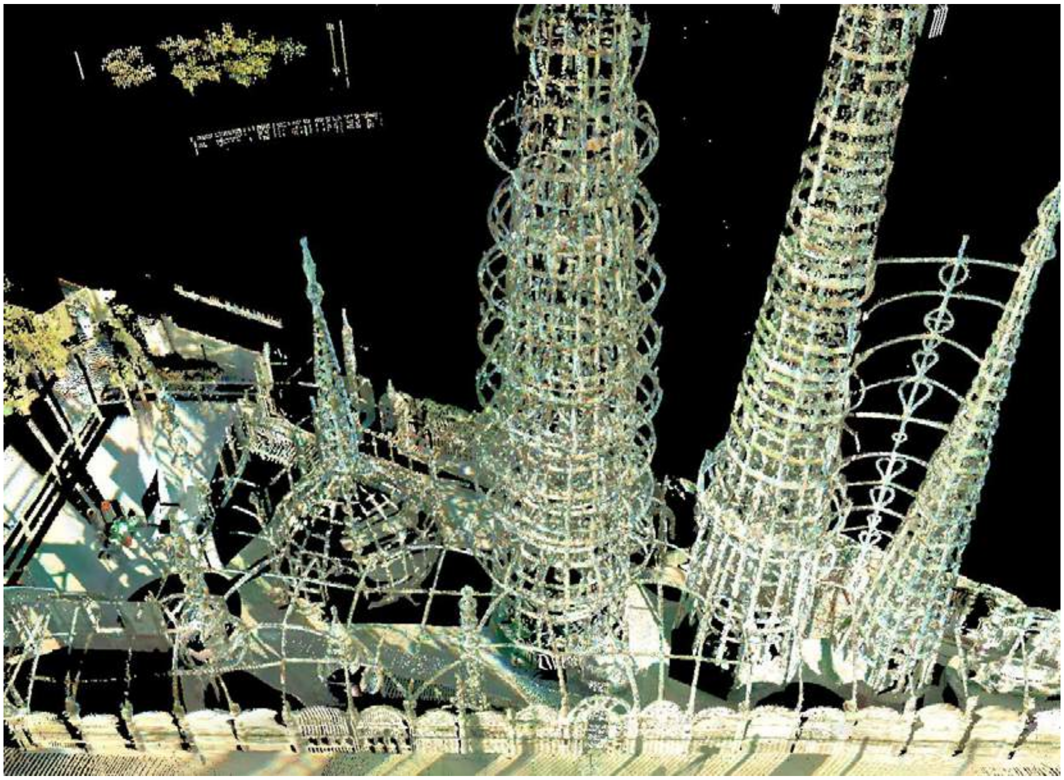

Figure 5 – Rendered point cloud. Black portions within the site are the "shadows" where background elements were obscured by foreground elements in the view of the laser scanner.

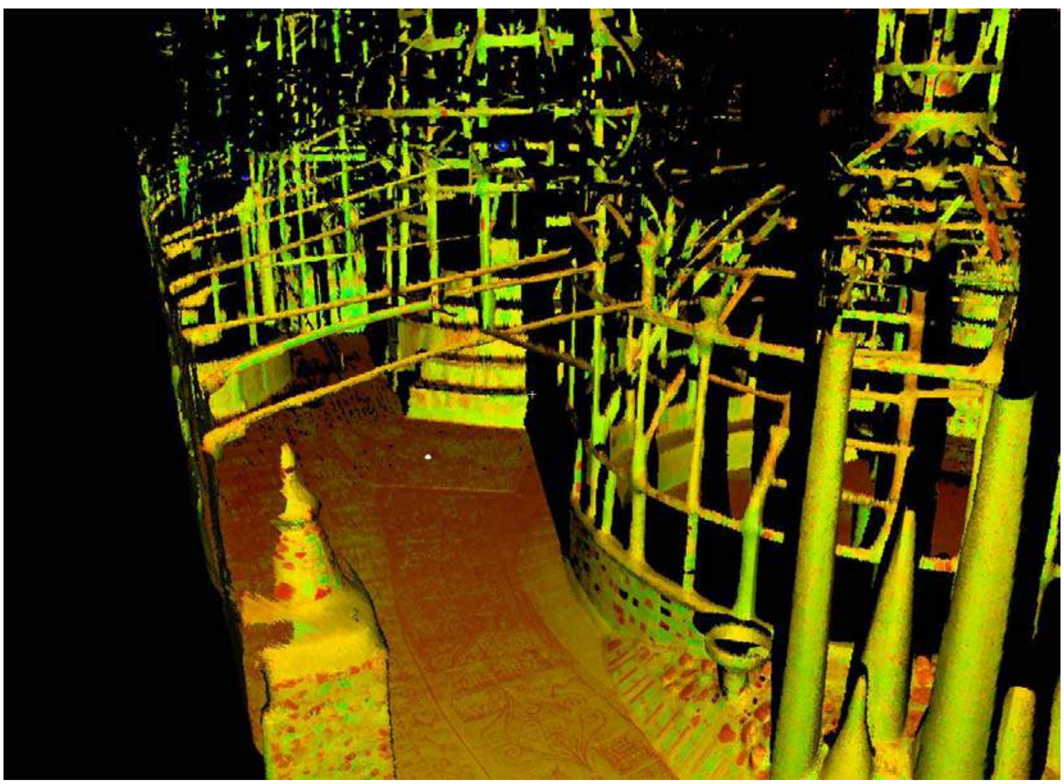

Figure 6 – Rendered point cloud. Note the ornamental floor detailing revealed by the high-resolution laser scanning.

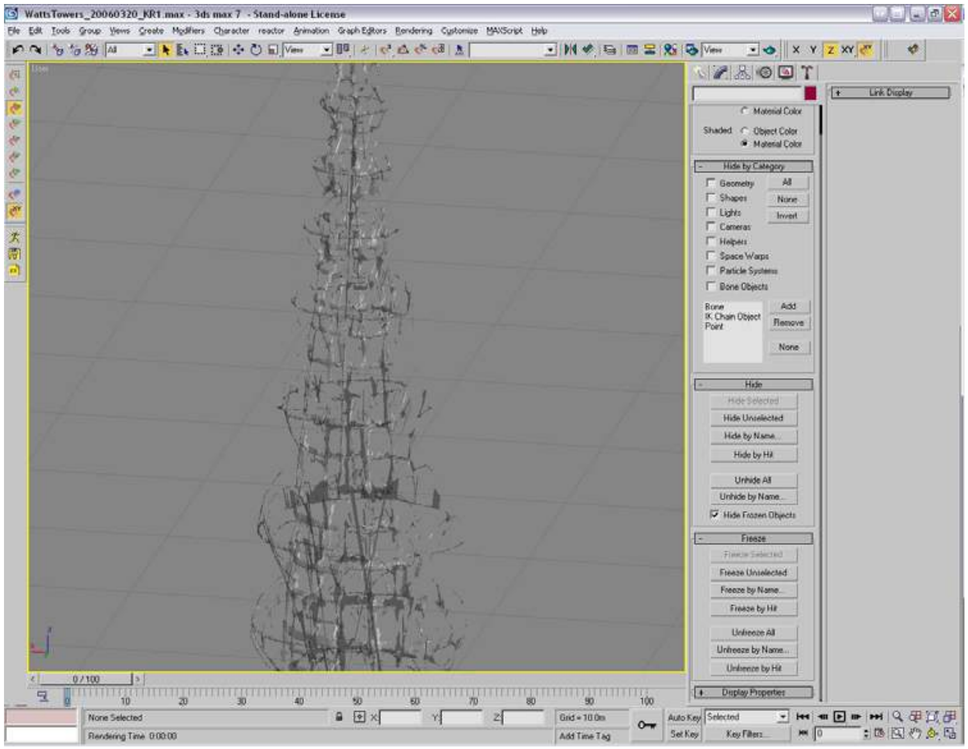

Figure 7 – Center Tower after available points are converted to a polygonal mesh, providing surface. Due to "shadows" in the source data, portions of members are missing.

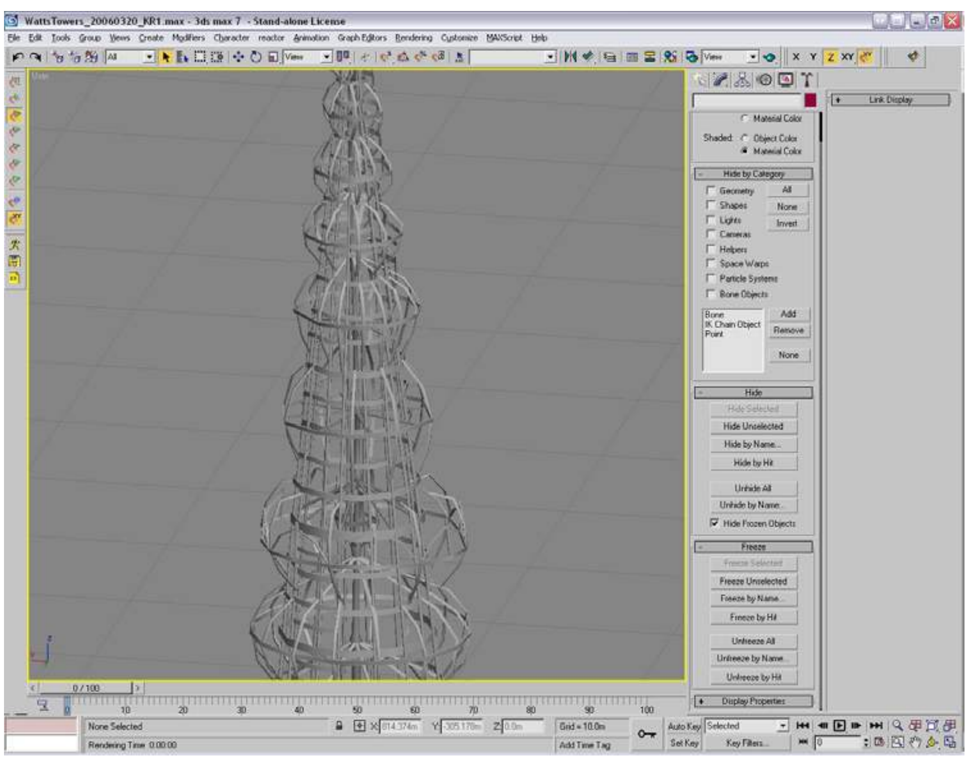

Figure 8 – Optimized reconstruction of members for Internet delivery and real-time rendering. Simplified polygonal shapes approximate members based on available surface photography.

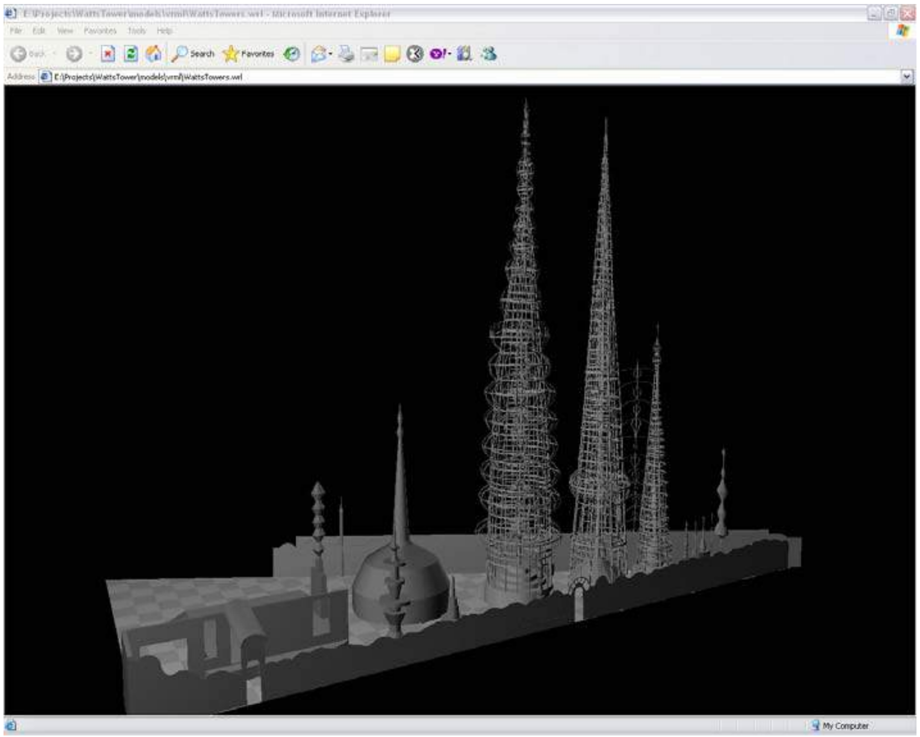

Figure 9 – Model of overall site with members polygonized.

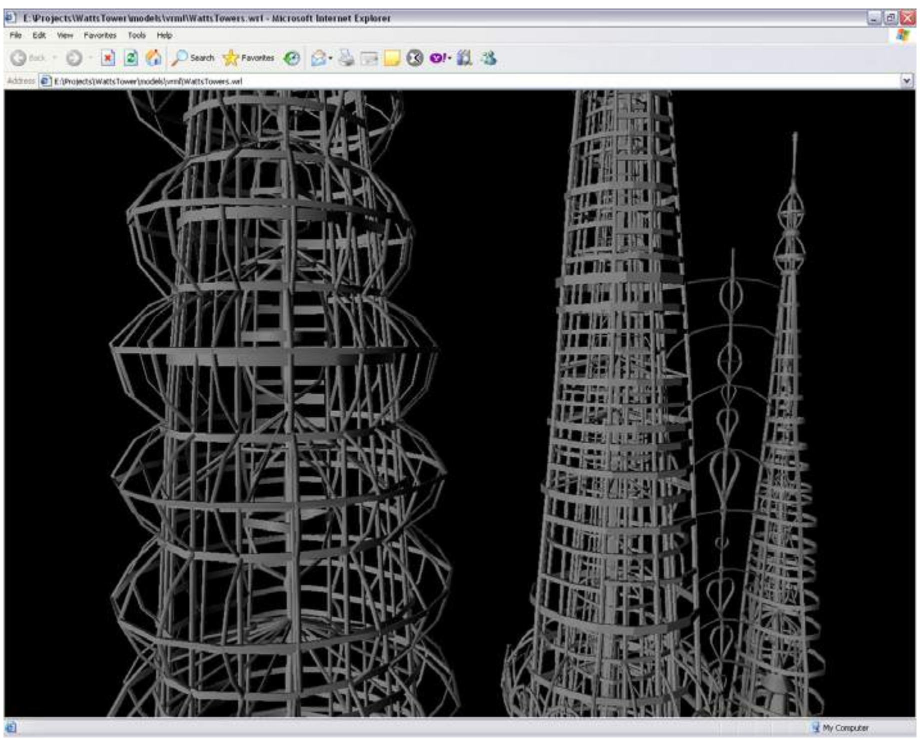

Figure 10 – Detail of three towers with models polygonized.

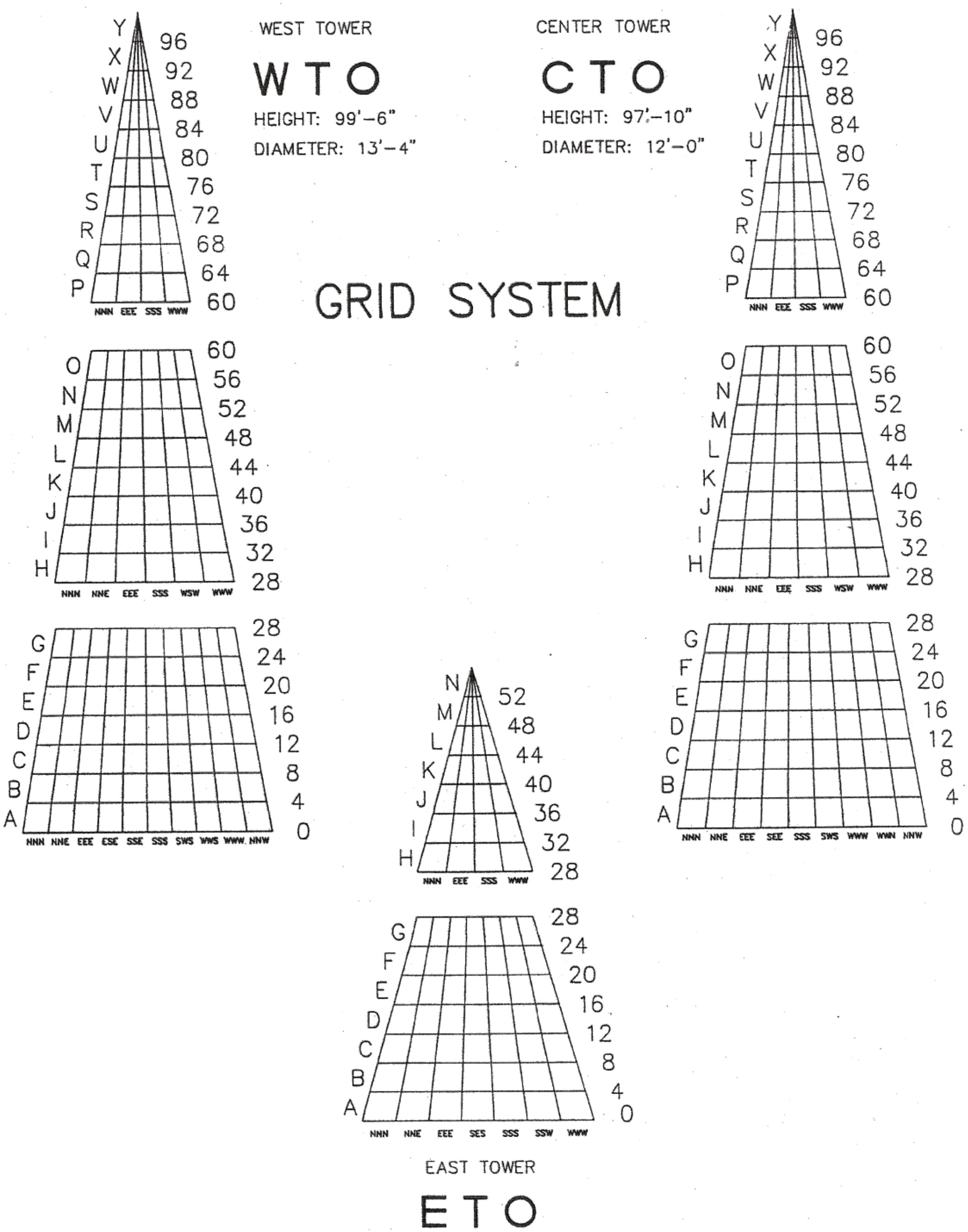

Figure 11 – Previous 4-foot by 4-foot grid system used to map each section of the towers. This grid was used as the base system for mapping areas directly to the computer model.

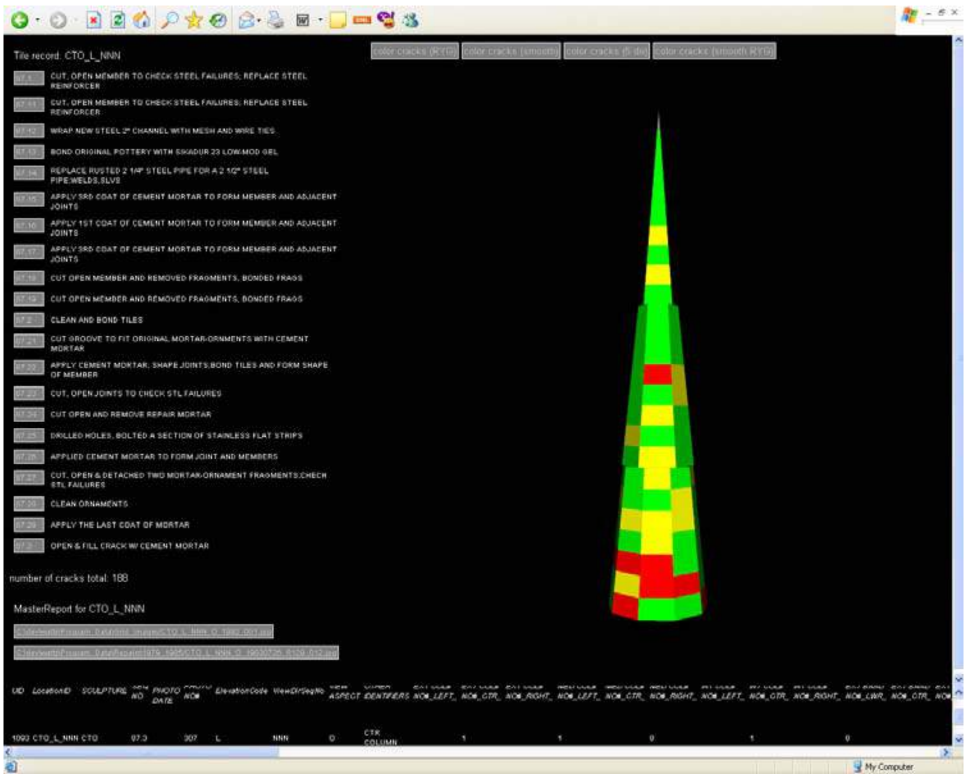

Figure 12 – Prototype of Center Tower Model within interface. The grid system was wrapped to approximate the dimensions of the tower. Different color values may be assigned to different grid sections of each tower, based upon values in the repair database.

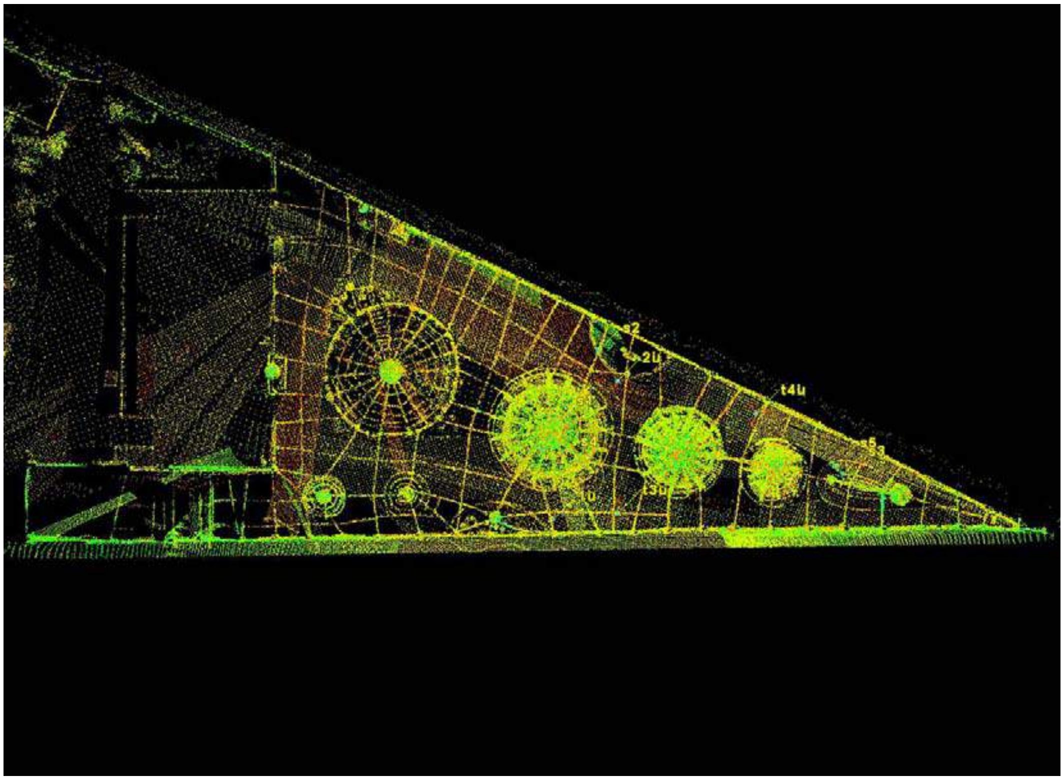

Figure 13 – Site plan generated from point cloud, accurate to 1 centimeter.

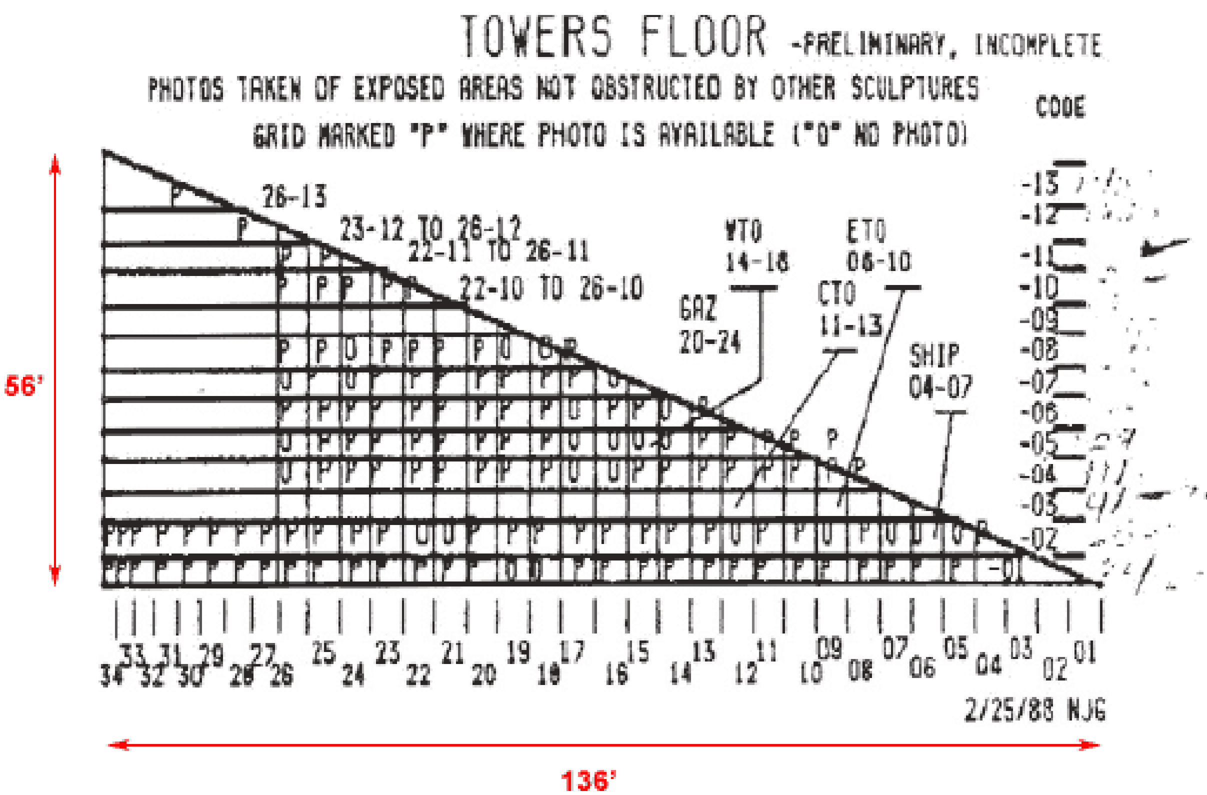

Figure 14 – Previous site layout plans indicated a slightly different aspect ratio and dimension.

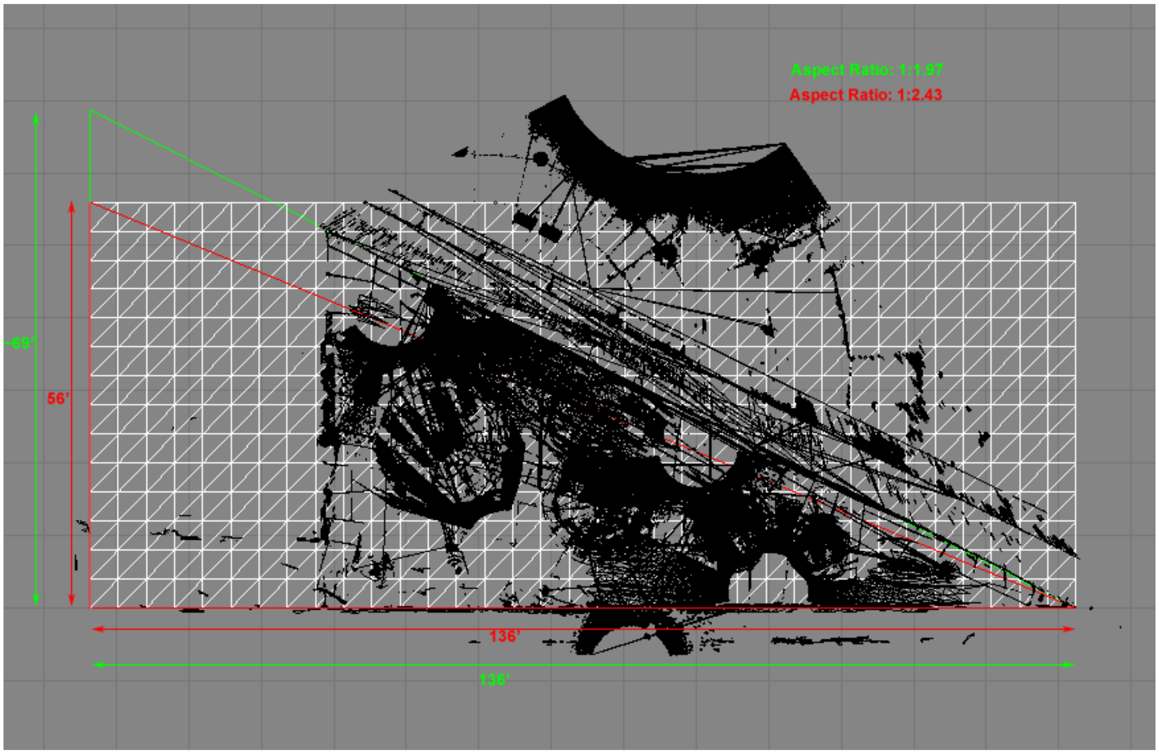

Figure 15 – Previous site layout dimensions highlighted in red; point cloud outline in black and associated dimensions highlighted in green.

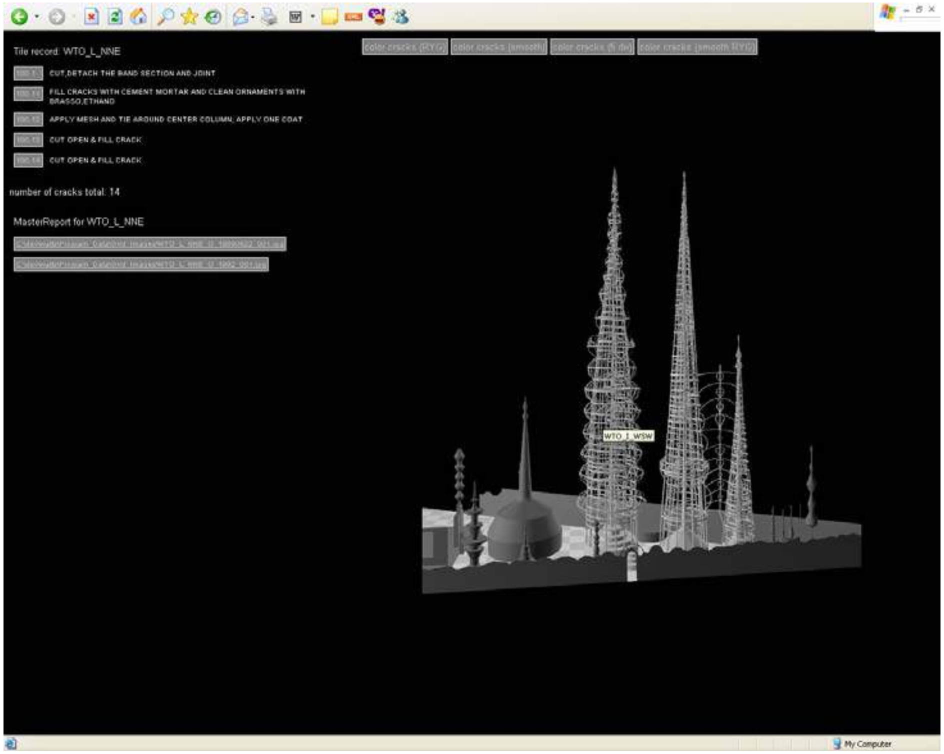

Figure 16 – Model as viewed within the user interface. Clicking on a section of the model displays a list of available records associated with that 4' x 4' grid location.

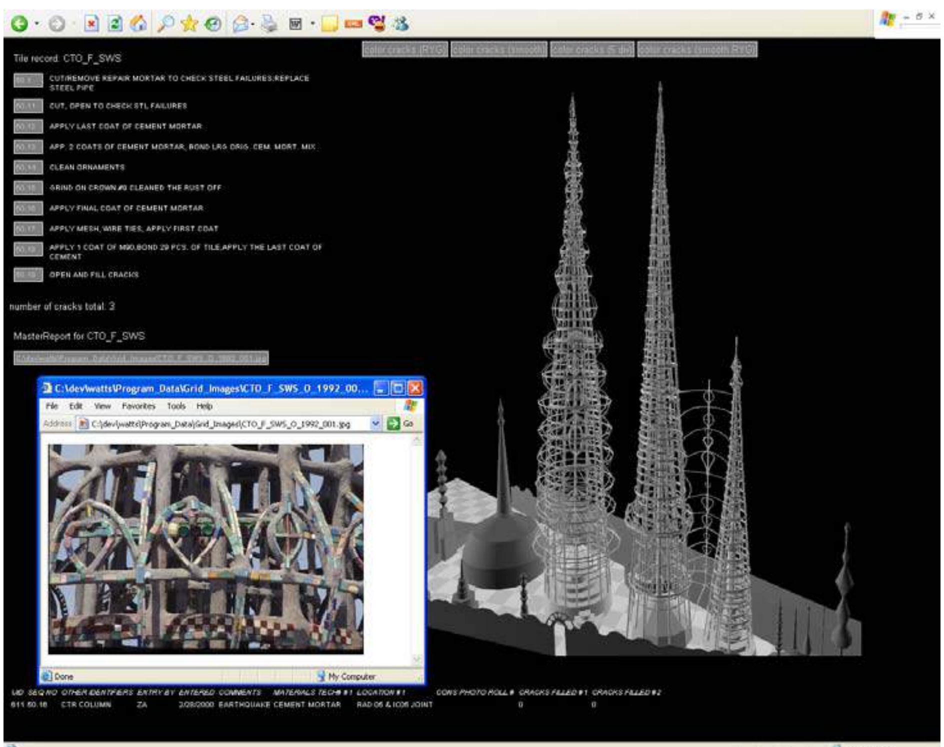

Figure 17 – Selecting one of the records on the left of the interface calls up additional data, relevant documents, or images.

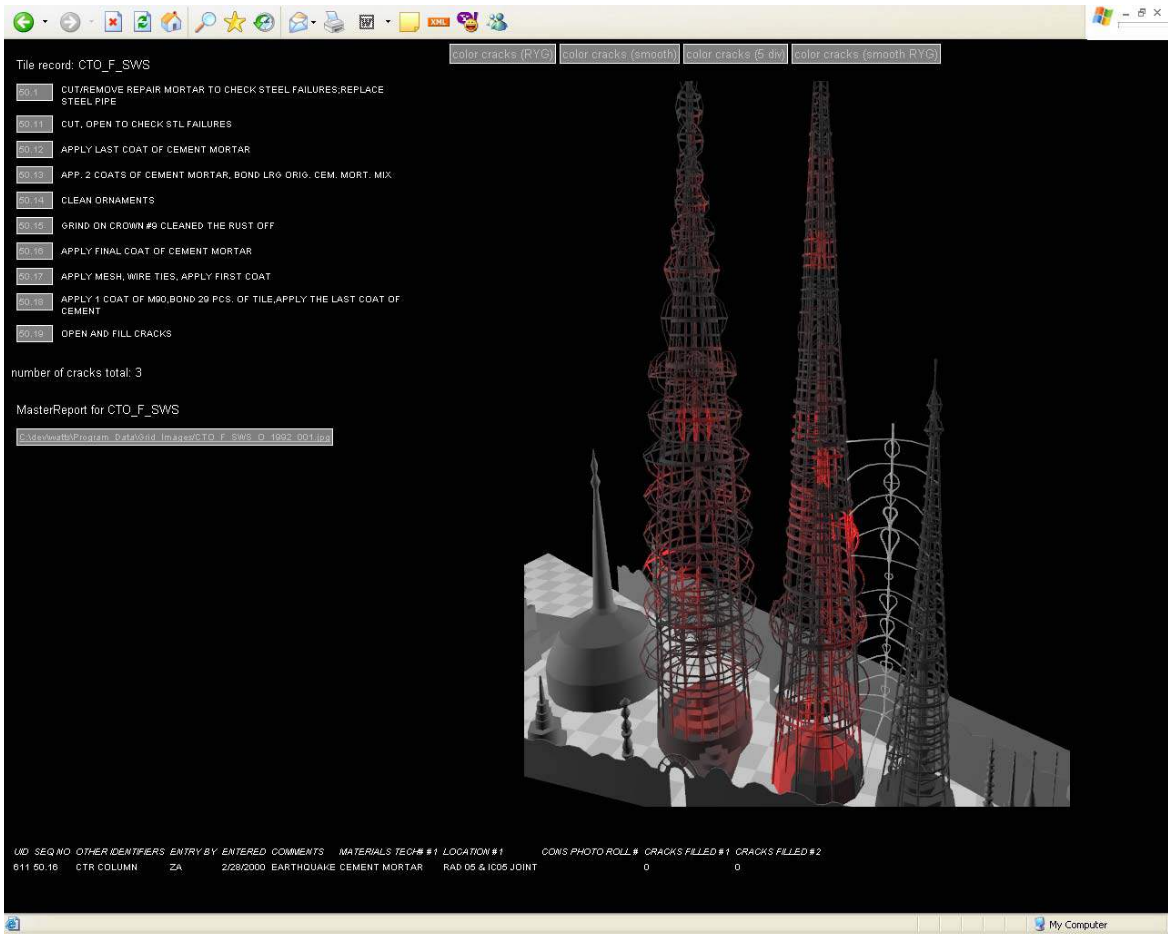

Figure 18 – The model can be color-coded based upon particular values in the database, such as cumulative number of cracks repaired per section.

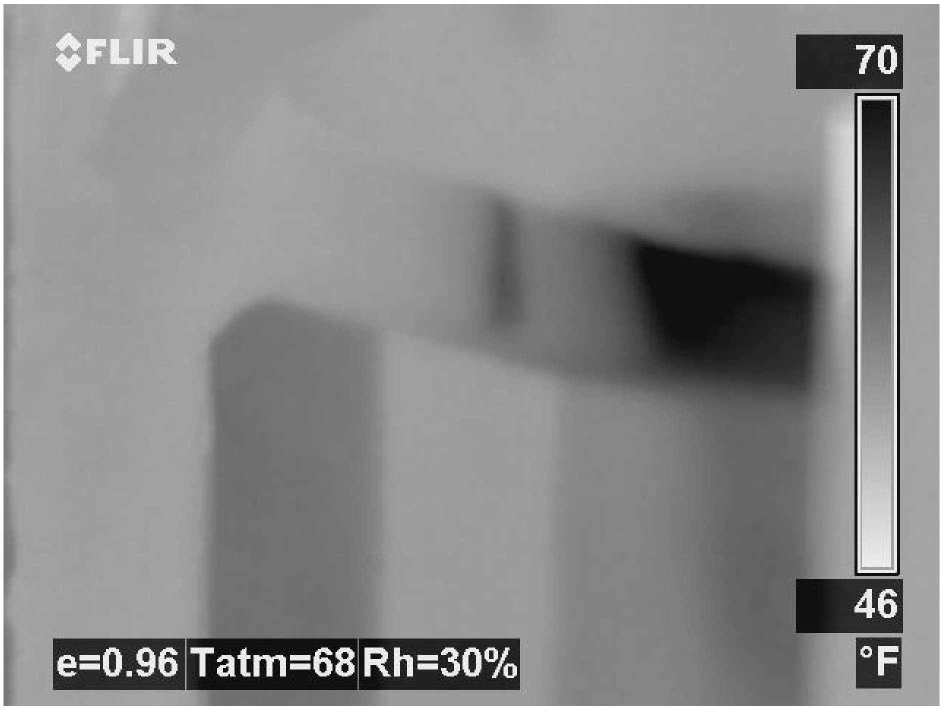

Figure 19 – ThermaCam Image. Dark areas show higher temperatures due to sun on surface. Light areas are in shadow and are cooler.

Figure 20 – ThermaCam Image at Ship of Marco Polo. Light areas are higher temperature. Glazed tiles reflect more energy than surrounding cement mortars. Tiles in foreground have cooler surfaces. Variations in mortar color are largely due to thermal variations from sunlight and shadows.

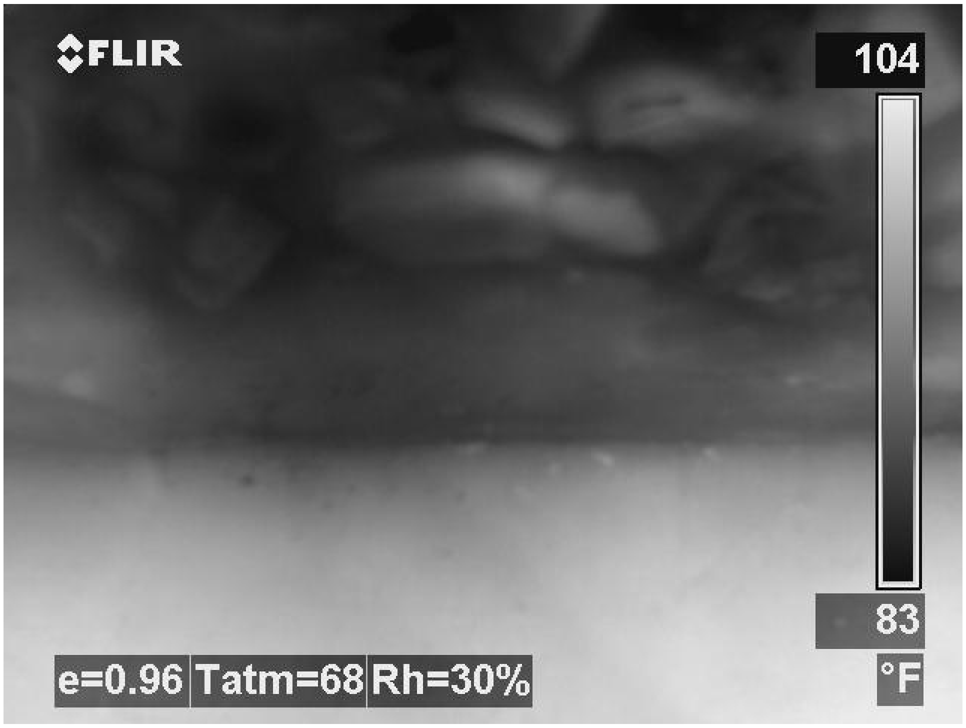

Figure 21 – ThermaCam Image of floor and interior wall. While the floor reflects a higher temperature, the wall has embedded rock that emits less heat. The darker area of the floor showed some moisture, which was more visible to the naked eye.

Appendix B:
History of Materials Used and Tested

Appendix B
History of Materials Used at Watts Towers

Purpose

This summary outlines previous and recent materials used on the Watts Towers. While not comprehensive, the information provides an overview of the variety of materials tested and used prior to the current contract with Architectual Resources Group.

1) Iron

Original: Found pieces of iron alloys (including various grades of steel) were used originally, including pieces from the nearby railroad and metal scrap yards. Elements included angle, rods, pipes, channels or railroad ties, generally lap joined and wrapped with copper or iron wire. No bolts, screws or welds have been found in the original work.

Repairs: Repair specifications from circa 1979 through present recommend replacing corroded iron elements with stainless steel. Corroded elements not deemed for replacement have had loose mortar chiseled away, sections sawed off, stainless steel replacement, spliced or wrapped as original; or old iron sandblasted, cleaned with compressed air, application of rust inhibitor (ZRC Cold Galvanizing Compound) and application of new patch mortar. Some of the pipes retained water. (1981). Nylon or Teflon rod to replace iron section. (1990's?)

2) Mortars

Original: Original mortars varied in composition, color and texture. Most commonly used was a grey colored sand-lime-cement mortar with very coarse aggregate. Green, yellow, read and blue pigments were also used. Mortar depth ranges from ¼ inch to 1½ inches with typical thickness at ½ inch.

Analysis: Original mortars tested 1959 (Smith Emery), 1979, 1983 (Eherenkrantz) and petrographic analysis 1983. Aggregate: cement 21/4 – 3:1. Aggregate: crushed granite or poorly rounded natural sand. Mortars are Portland cement based, strength similar to Type M (no lime) though it is possible lime may also have been used in small quantities. Air-entrained mortars found at 67 – 75 ft high. May have been later patches. Chlorides present, no correlation with height, though highest values were at lower and upper levels. May have used unwashed sand in some original mortar mixes.

Repairs: Repair mortars indicated in circa 1979 specifications is to mix 1:3 cement:sand with 90% water 10% Acryl 60. 1983 1:3 cement:quartz/calcite sand. Recommends no more than 10% Acryl 60 to allow effectiveness of alkyl-alkoxy-silane.

Sikadur Hi-Mod 2 part epoxy bonding agent on bare armature before patching mortar.[1]

3) Surface Decorations

Original: A variety of materials are embedded into the mortars.

a) Glass
b) Ceramic (glazed and unglazed)
c) Shell
d) Pebbles, rocks, clinker and stone
e) Cast stone

Repairs: Opticon UV for glass-to-glass bonds.[2] Brasso or Noxon to clean glazed tiles.[3]

4) Coatings

a) Corrosion Inhibitors

ZRC Cold Galvanizing Compound, a zinc primer in epoxy ester.[4]
Duro Naval Jelly (for corrosion removal)

b) Water Repellents

Alyl-alkoxy-silanes tested, including Wacker H, Cydrozo Clear, Chemtrete BSM-40R and Chemstop. Chemtrete BSM-40R recommended. Test procedure did not measure water vapor permeability.[5]

c) Crack and Gap Fillers

Dow Corning 795 silicone building sealant for temporary fill of small fissures and cracks.[6]

Dow Chemical RTV 738 recommended for gaps les than 3/8”.[7]

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[1] Ehrenkrantz, 1983 p 184
[2] Ehrenkrantz, 1983 p 183
[3] Conservation Handbook, 1990 Section 4.1.4.3
[4] Conservation Handbook 1990 Section 4.1.5.3
[5] Twilly & Goldsone 1982 as referenced in Ehrenkrantz, 1983, p 195-199.
[6] Ehrenkrantz, 1983 p 187
[7] Conservaiton Handbook 1990 Section 4.1.4.5.2

Polyethylene foam backer rod for temporary crack fill.

d) Consolidants

DF 104 (a silicone resin or polyalkylmethylsiloxane resin) mixed with Acryloid B-72 (an acrylic resin)[8]

[8] Conservation Handbook, 1990 Section 4.1.5.3

Appendix C:
Documentation Guidelines

GUIDELINES FOR FILE ORGANIZATION AND NOMENCLATURE

Making documentation more accessible and useful as an analytical tool requires creating a consolidated, sustainable system of organization and nomenclature. This system of organization and nomenclature for both physical and digital information was also necessary in order to link the information to the 3D computer model. The system employed by ARG closely follows existing file and nomenclature systems used at the site; however, some modifications were necessary to allow computerized access. Document files were formatted, named, and organized into a hierarchical electronic file system that incorporates a wide range of formats, addresses the volume of all previous documentation, and provides flexibility for including future repairs and additional documentation. These Guidelines explain the justification and formats for digitization, naming, and organization of documents relating to the preservation of Watts Towers.

I. Organization of Files

Files were first categorized into one of eight broad categories and divided into subfolders. These include: Forms, Grid_Images, Legends, Repairs, Reports, Research, Surveys_Inspections, and Videos.

A. Forms

The `Forms` directory was created to house all blank forms used for identifying or treating the site.

B. *Grid_Images*

The `Grid_Images` directory includes all photographs of the site that incorporate the 4-foot by 4-foot grid system of documentation. At the time being, this is confined to the photographs of Marvin Rand during the late 1980s. It is possible that over time, as future documentation projects occur, future grid photographs will be added to this directory. This directory does not include photographs of repairs.

1. Unlabeled_Grid_Images

Photos from the Marvin Rand contracts with unknown specific grid locations were placed in the directory `Unlabeled_Grid_Images`.

2. Unlabeled_Images

Photographs of the towers without identified associated repair treatments and without specific grid locations were placed in the `Unlabeled_Images` folder to await naming. It is hoped that the creation of the 3D model and attachment of photographs will assist in identifying the proper grid location, and that the need for such a directory would eventually become nullified. Images in this location have retained their original directories to assist with identification.

C. Legends

Documents depicting previous naming systems, terminologies, and site maps are located in the `Legends` directory. Documents summarizing documentation are subdivided into the following directory: `DocSummaries`

D. Repairs

Images and text showing specific areas of treatment were categorized as repairs and placed in the `Repairs` directory. These files were subdivided into repair campaigns, designated by year range. Although this is the only area, at present, to employ a year range in the filename, it is hoped that this will assist in eliminating confusion for the addition of future files. The directory was separated into the following categories.

1. 1979_1985

The repair campaign from the Office of the State Architect occurred from 1979 through 1985. This repair directory is thus named `1979_1985`. Repairs were documented on repair cards, consisting of 5-inch by 7-inch cardstock with handwritten or typewritten locations and a photograph. Many of the cards consisted of the exact same repair with the exact same picture; these duplicates were not entered into the organizational system. The specific member undergoing repair is determined by the repair number and grid location. This member location is also documented on each of the sheets.

2. 1985_1994

No repair cards from the repair campaigns from 1985 through 1994 were included at the writing of this report.

3. 1995_2001

Digital photographs of areas requiring repairs from 1995 to 2001 were incorporated into this directory.

4. 2001_2005

The FEMA-funded repair contract spanning from 2001 through 2005 employed a system of marking photocopies of the Marvin Rand photographs to denote cracks and intended repairs. These repair sheets were attached to pages that denote intended treatment. Both pages were incorporated into each repair document.

5. Unlabeled Repairs

Images and repairs with unknown locations or dates were placed in the `Unlabeled_Repairs` directory. As with the unlabeled photographs in the `Grid_Images` directory, original directories were retained until images are identified.

E. Reports

Written documents, including those with pictures within the document but not otherwise classifiable, were placed in the `Reports` directory. Certain reports, such as the *Conservation Handbook*, contained many documents and were subdivided. Others included memos, meeting minutes, and treatment reports. Those adhering to one of the mentioned categories were filed in their respective directories; others remain in the

Reports directory and are not fully subdivided. Those in the latter category include the types of documents—Logs, Memos, Meeting Minutes, Applications, and Notes—whose type is included in the filename. The rest of the report documents were subdivided into the following directories:

1. *The Conservation Handbook*

The *Watts Towers Conservation Handbook* is comprised of reports, historical documents, and several revised conservation guidelines. The *Conservation Handbook* is located in its own directory, `1998_ConservationHandbook`, and further subdivided. The 1983 *Ehrenkrantz Report*, which was a section of the 1998 *Conservation Handbook*, is located in directory, `1983_Ehrenkrantz_Report`, which is once again divided into `1983_Ehr_Appendicies`. The binder in full was scanned, named, and organized to maintain the report's original order.

2. *Treatment Reports*

Treatment Reports are documents summarizing campaigns on particular site features or sculptures. Some of the documents contain hundreds of photographs of individual repairs, which may someday merit additional placement as individual files in the `Repairs` directory.

F. *Research*

The `Research` directory designates all reports, notes, tests, or correspondence that relate to areas of research and development of future site conservation guidelines. Many of the files were placed in the following subdirectories:

1. *Materials_Research.*

This directory was created for files focusing on material research.

2. *X_Rays*

This directory was created to house preliminary digitization of the 10 X-Rays taken of samples in 1999.

G. *Surveys and Inspections*

This section contains condition surveys and site inspection reports.

1. *Condition Surveys*

Documents and reports that refer to specific locations of existing conditions of the towers were placed in the `Condition_Surveys` directory. ARG's Phase I Report from 2004, containing fissures inspection and drawings, is located in this directory.

2. *Engineering & Structural*

Documents and reports focusing on the engineering and structural analyses of the towers were placed in the `Engineering_Structural` directory.

H. Videos

The `Videos` directory was created to house future digitization of film and video footage, documentaries, and clips pertaining to the site. No items were included at the time of writing this report.

In general, as more documents are converted to digital formats, folders and subfolders may be added. File location changes will necessitate changing the database links if the newly added or changed file locations are to work renamed with the 3D model.

II. Formatting of Digital Files

When deciding the naming and formatting conventions of the files, it is important to bear in mind the target format for this database. For the purposes of this project, the final format is for use over the Internet. Previously, many of the digital files for the site had been stored as bitmap (.bmp) files, and their names often contained spaces and symbols (#, &, -) that were not compatible with the Internet and differing operating systems. Although it was hoped that as much information is retained as possible, changing certain naming and formatting conventions were deemed necessary to consolidate all forms of documentation into one accessible system.

In this case, the most appropriate current format for photographs, when shared over the Internet, is the JPEG (.jpg) compression system. This format is a standardized image compression mechanism designed for compressing either full-color or grayscale photographic images. The JPEG format is "lossy," meaning that the compressed image is not quite the same quality as the original image. Some consideration was given to using an uncompressed image file format, such as TIFF (.tif); however, these formats proved to consume an extraordinary amount of file space, especially considering the number of files and repairs on-hand, as well as the goal format of the database.

An additional concern was having an acceptable level of bandwidth. This, combined with downloading speed concerns, precluded the use of uncompressed files, such as TIFFs.

Another consideration was the use of the GIF (.gif) format. This system uses up to 8-bit (256 colors) and compresses the image for use over the Web. Generally, GIF files are at 72 dpi and are rarely used for high-resolution photographs or for printing purposes. The JPEG format proved the superior choice and was used as the compression format for all documents.

Images and Repair Cards were retained as JPEG files, while Reports and Repair Records were combined into Adobe PDF (.pdf) documents and, when necessary, scanned areas were compressed as JPEG files. Their specific compressions are discussed in further detail, for each file format. It is important to bear in mind that these formatting goals are for present computer usage over the Internet and are meant to be of analytic use in the present and in the immediate future. As memory capacities and bandwidth and computer speeds increase, future resolutions and scanning may increase as well.

Documents linked to the 3D model must reside in a file server that can be easily accessed by the 3D computer model. Installation and maintenance of the files will remain the responsibility of the Owner. All original files on these floppies, CDs, and Zip disks were returned in their original formats and without conversion to reside with Ms. Aguirre.

A. Conversion of Previously Scanned BMP Files

Most photographs were previously scanned at a resolution of 200 dpi, at a size of about 0.8 Megapixels (MP). The formats varied between photographs, as some were already compressed JPEG files, while others were BMP files. If the file was already a compressed JPEG, no further compression or conversion was carried out. If a BMP, the file was converted to a JPEG at the maximum quality possible.

Grid Images that had been previously converted into medium-quality JPEG images measured about 800 x 1,000 pixels, at about 50 KB. The same resolution files, converted from BMP to JPG at the maximum quality were about 600 KB. For some files, particularly whole pages that had been saved as BMPs, the resulting file size exceeded 5 MB. Larger file sizes and with minimal compression will compensate the slight loss of quality from the conversion of formats, yielding some additional analytic information through crisper resolution and color formatting. At some point in the future, these previously scanned photographs should be among the first to be re-scanned at significantly higher resolutions.

B. Compression and Quality of Scanned Items

ARG scanned about 600 slides and several thousand pages of reports. The slides were saved as JPEG files, with JFIF encoding (the most common and universally accepted), at "High" quality. In most cases, "High Quality" resulted in an image that was nearly indistinguishable from the "Maximum Quality," and resulted in a file size as little as half as large. Given the present constraints of Internet bandwidth and computer speeds, a balance of a larger resolution with color quality was preferable.

C. Resolution of Scanned Materials

Bearing in mind the present limitations of bandwidth connections and computer speeds, the establishment of present resolutions was no easy matter. In general, an acceptable file size for each item was determined to be approximately 1.5 Megabytes. This, when compressed as a JPEG at High Quality, resulted in a resolution of about 4 Megapixels, a resolution comparable to many digital cameras on today's market. Over time, resolutions and file sizes will grow as technology permits for a project of this scope. In the meantime, the target resolutions and file sizes of the different data formats serve the present objectives.

1. Resolution of Slides

Much of the existing documentation and images exist on 35mm color slides. An acceptable level of detail is revealed at 2400 by 1800 pixels (about 4 MP). This resolution is obtained when a slide is scanned at 900 dpi and yields a file size of about 1.5 MB per photo when compressed as a JPEG at high quality. This should provide enough resolution and clarity to identify small cracks.

2. Resolution of X-Rays

Given the nature of X-Ray photography, a high resolution is recommended for the scanning of X-Rays. In the existing sample, a portion of one X-Ray was scanned at a resolution of 1200 dpi. It is recommended that future scanning of X-Rays be the same resolution or higher.

3. Resolution of Repair Cards

Repair Cards, the 5-inch by 7-inch cardstock depicting various repairs to individual members, contain handwritten and typed descriptions of repairs made. Each card also contains a 3-inch by 3-inch color print of the repair adhered to the cardstock. Although a resolution of 200 dpi is found to be acceptable, a preferable resolution is at 450 dpi, resulting in a file approximately 3500 by 2200 pixels (8.4 MP) for each card. The resolution of the 3-inch color print then measures approximately 1500 by 1500 pixels (about 2.4 MP).

4. Resolution of Condition Records

Condition Records contain hand written information on each repair, as well as information of the pre-existing condition of the area that is typed or handwritten onto 8 ½ by 11-inch sheets of paper. The first page contains a chart, which is typically handwritten and already entered into the repair database. The second or third page contains handwritten charts or drawings, either with colored pens over a photocopied page or drawn from scratch. These latter pages assist when identifying the specifics of each repair made. Scans of each page should be at 300 dpi (8.4 MP). This resolution can allow enough detail to show the subtleties of the drawing of each repair. Multiple pages for each repair record can be combined into a PDF file.

<u>Resolution of Reports</u>

For most typewritten pages in reports, a resolution of 200 dpi (4 MP) is sufficient for scanning. These files can then be combined into a PDF and compressed at High Quality through Adobe Acrobat, yielding a file size as little as 25 KB per page. However, when drawings, photographs or graphic charts are involved, a minimum resolution of 300 dpi is recommended and, when added to a PDF document, should have Maximum Quality, yielding a file size around 100 KB per page. Although the quality and resolution is inferior to direct scanning of photographs, this compression format appears to be acceptable for reports, particularly reports which number hundreds of pages.

It should be noted that it is preferable, when possible with what is at hand or in the future, to convert reports, memos, and letters directly from their digital, word processing format into PDF. This provides more efficient file compression and higher quality resolution, while giving greater flexibility to future searching capabilities. Using Adobe Distiller, particularly at high or maximum quality, is preferable to Adobe Writer.

III. Nomenclature of Files

Tens of thousands of repair records, photographs, and reports exist to describe the ongoing maintenance and condition of the site. Thus it is essential to have a naming system for these files that incorporates all past documents, current technological limitations, and the way in which documentation of the towers will change in the future. In this context the general philosophy of the naming conventions follows the order from the largest, most identifying features to the smallest, most precise. In this context, the nature of each type of document affects the appropriate naming system.

A. Previous Methods of Nomenclature

Digital files for the Watts Towers have previously been named, largely, by the context of their respective folders, directories, and storage devices. The file names often contained spaces and symbols (such as #, &, -). This system of file nomenclature and organization, although perhaps adequate for small numbers of files on an isolated machine, becomes more difficult to organize and manage as the number of files and accessible users grow.

Existing systems of naming locations and parts of the site were used as much as possible. Two general systems have been used over time, often in combination. One system consists of naming each "member" of the towers; for example an "interior column" or an "exterior band" with an associated number and height location. Another system was adapted by Marvin Rand for photographing the entire site by dividing features into 4-foot by 4-foot surface area grids and assigning an associated name. The system comprised roughly 1500 4-foot by 4-foot grids sections, and the photographs were generally labeled by sculpture, height, radial location, view aspect, and date. Details of site location nomenclatures previously used are described in the `Legends` directory.

The latter system, 4-foot by 4-foot grid system was the appropriate system for the present state of the model. In adapting the methodology for the naming of digital files, a series of previously established guidelines were noted:

1. Site Feature Abbreviations

In the previous nomenclature system, each sculpture was referenced through a three-letter acronym. These designations were noted as follows, with any differences from the ARG "Site Plan" from the 2004 Phase I report noted in parentheses:

```
ATO – "A" Tower (Tower #1)
BTO – "B" Tower (Tower #2)
BBQ - Barbeque
CAN – Canopy
CTO – Center Tower
CHI – Chimney
ETO – East Tower
FLR – Ornamental Floor
GAR - Garage
GZO - Gazebo
HOU - House
NWA – North Wall
OVE – Overhead members connecting between site features
```

```
SHI – Ship of Marco Polo
SWA – South Wall
WTO – West Tower
```

2. Height Abbreviations

The heights for the entire site were divided into 25 segments, each 4-feet in height, and represented through a letter, A-Y.

3. Radial Locations

Radial locations apply to some of the sculptures, including the towers and gazebo, and were represented differently for different sculptures, but most of them were shown through a combination of letters: N, S, E, or W. In the case of larger sculptures, such as the three towers, these were shown through three-letter combinations, such as NNE, SWS, or WWW. For smaller sculptures, such as the Ship of Marco Polo (SHI), these designations consisted of one or two letters only, such as N or E. For linear areas, such as the North Wall (NWA), these parts were designated through use of a two-digit number, such as 04 or 31. For planar sculptures, such as the Floor (FLR), two sets of two-digit numbers were used to denote each segment.

4. View Aspect

Because most photographs, and thus viewing angles, were taken from the outside looking in, the View Aspect was usually designated as “O.” Certain sculptures necessitated different viewing angles. One such example includes the South Wall (SWA), which has both and Exterior/Outside (designated “O”) and an Interior/Inside (designated “I”). Other sculptures, such as the Gazebo (GAZ) necessitated documentation in a different manner, with a Center/Column (designated “C”), a Fountain (“F”), an Exterior/Outside (“O”), and an Interior/Inside (“I”).

5. Date Expressions

The date was generally expressed in historic photographs, if at all, in the Month/Day/Year format. Many photographs contained no in-frame date; therefore the concluding year of the contract was used to estimate the date of the photograph.

B. Guidelines for Nomenclature of Digital Files

Filenames containing spaces and punctuation marks can cause a variety of problems when accessed through the Internet. It is therefore suggested that they be removed when at all possible. In the case of naming these files, an appropriate replacement for a space is the underscore (“_”), as well as a creative use of truncation. In this system, an underscore is used typically for dividing various acronyms or representations, while capitalization of beginning letters is used, generally for reports, to combine two title words (“approved materials” becomes “ApprovedMaterials”). If necessary, a scanning sequential number is added as a suffix to a filename, to prevent duplicate locations and dates from overwriting differing contents.

Files used for the Program Data followed the previous methods of nomenclature where appropriate. In some instances, however, the process of digitization required some alteration. These naming systems, then, are noted for the following formats:

1. *Nomenclature of Images*

The file naming for Images, including Grid Images, X-Rays, and images with known locations, is based on the following structure, separated by underscores:

```
Site feature, elevation level, radial location, view aspect,
date, scanning sequential number, file format (.jpg)
```

The abbreviations previously established are used in naming these files. The date format, if known, once reorganized to Year/Month/Day, assists with organization. If the date is not known, the year of the particular contract conclusion resulting in the documentation has been used. A scanning or page sequence number is added to the end of the filename, consisting of a three-digit number, beginning with 001, used to distinguish between different photographs taken of the same area on the same day. Examples from typical areas include:

```
ATO_C_W_O_19871201_001.jpg
CTO_E_NNW_O_1992_001.jpg
GAZ_A_SSW_F_19870417_003.jpg
```

Some areas employ a different location system, such as areas with a linear trajectory. This includes the North and South Walls (NWA, SWA). Instead of using a combination of letters, a two-digit number system is used instead. Examples include:

```
NWA_A_21_I_19871103_002.jpg
SWA_B_02_O_19870511_001.jpg
```

Another site feature that trumped the traditional nomenclature system includes planar site features, such as the Floor (FLR), which has been represented, instead of Height and Location, as a series of two, two-digit numbers representing different grid locations on the floor. These locations are explained in documents in the `Legends` directory. Examples include:

```
FLR_34_03_O_19880104_001.jpg
FLR_16_07_O_19880104_004.jpg
```

New photographs of individual members and features should follow the same format, with use of the sequential scanning number to designate between shots of the same areas photographed on the same day. Ideally additional location details would be in-frame and noted in the database. Additional details describing, for example, conditions within each photograph may be entered into the database record and need not be added to the filename.

2. *Nomenclature of Repair Cards:*

Naming the repair cards follows a similar order to the grid images, although a repair number must be associated with the filename. The repair number is represented through a three-digit numerical sequence, preceded by the letter "R." For example, Repair 1 is designed R001. This repair number follows the date of the repair. For example:

```
CTO_N_WSW_O_1983411_R132_003.jpg
```

Several repair cards contain the exact same photograph and handwritten information. These duplicate cards were discarded from the digitization process.

3. *Nomenclature of Condition Records:*

Naming the records from surveys and inspections follows a similar order to the grid images, although the suffix changes with the file format, from .jpg to .pdf. Example:

```
CTO_C_EEE_O_20030103_001.pdf
```

4. *Nomenclature of Documents and Reports*

The digital files containing reports are named with the same formatting rules as other digital files (sans spaces or punctuation marks) in the following order:

```
Year, author’s initials, type of document, subject/site feature
(if applicable), file format (.pdf)
```

Further information can be retained from the reports; however, this material is best extruded in the database. The year, in the four-digit format, represents the completion year of the document; appendices or revisions were saved as separate documents and named after their respective years. Authorship was condensed, if provided by an individual, to the first letter of the first and last names. If the report was prepared through a small group of individuals, the first name appearing alphabetically in the group was used. If the report was prepared through a firm, a three-letter acronym was used.

Type of document was divided into the following categories:

```
      Revision, TOC (table of contents), Proposal, Plan, Guide,
Treatment Reports, Memo, Application, Notes, Lists, Minutes (Meeting
Minutes), Overview.
```

For example, a one-page memo from Rosa Lowinger in 1992 on materials testing and analysis reads:

```
1992_RL_Memo_MaterialsComments.pdf
```

The *Conservation Handbook* has a slightly different naming system, which arose from the necessity of maintaining the original order of the files. This included the insertion of additional fields, including the insertion of chapter markers in addition to the series mentioned above. Note the file folder itself, however, follows the naming conventions mentioned above. As an example, a mortar study in the *Ehrenkrantz Report* reads:

```
1983_Ehr_Plan_I_ii_b2_MortarStudies.pdf
```

Appendix D:
Materials Analysis

ARCHITECTURAL RESOURCES GROUP
Architects, Planners & Conservators, Inc.

January 9, 2006

Virginia Kazor
Hollyhock House
4800 Hollywood Boulevard
Hollywood, CA 90027

Re: Watts Towers Phase II
ARG #04094

Dear Virginia,

We appreciate your lending us samples from the towers perform tests for levels of chlorides and carbonation of the cement mortars.

Samples will be taken to AME laboratories in Oakland, California. Any unused sample will be returned to the site.

Sample ID	Description
1 Rodia	CTO m. CO6 or 7 green layer cement ½"x7"x4"
2 A, B, C, cut into 3 sectors	ETO. TC02, 4"x6" dia, Rodia + 1980's repair
3 Rodia	ATO.05, 14"x5"x½" embedded mortar w/ shell + ceramic
4 CTO E MC07 ? Rodia	8"x6"x6" mortar

Sincerely,

Katharine Untch
Conservator and Project Manager
415-652-7324

cc: Sean Woods, California State Parks
Zuleyma Aguirre, Site Conservator, City of Los Angeles

Principals
Bruce D. Judd, FAIA
Stephen J. Farneth, FAIA
Takashi Fukuda
Aaron Jon Hyland, AIA
Naomi O. Miroglio, AIA
David P. Wessel, AIC

Senior Associates
Deborah J. Cooper, AIA
Gee Heckscher, AIA
Wendy Hillis, AIA
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Cathleen A. Malmström, AIA
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RECEIVED
FEB 07 2006
ARG

February 2, 2006

Project Number: 106044C

Ms. Katherine Untch
ARCHITECTURAL RESOURCES GROUP
Pier 9, The Embarcadero
San Francisco, CA 94111

Fax Transmittal: (415) 421-0127

Subject: Mortar Chloride Content and Carbonation Testing
Watts Towers
Los Angeles, California

Dear Ms. Untch:

Per your request, Applied Materials & Engineering, Inc. (AME) has determined the chloride contents and depth of carbonation on mortar samples reportedly removed from from the above-captioned project.

SAMPLE IDENTIFICATION

Four (4) mortar samples were delivered to our laboratory. Table I gives the sample identifications and approximate dimensions. The mortar samples are shown in Photo 1.

PROCEDURES & RESULTS

Chloride Content

The chloride content tests were performed in accordance with the procedures described by the Germann Instruments Rapid Chloride Test (RCT). The precision of the RCT compares favorably with AASHTO T 260 potentiometric titration.

Eight (8) chloride content tests were performed. One test was conducted for Samples 1, 3 and 4. A chloride content profile was performed on Sample 2 by taking powdered samples at ¼" increments to the depth of the encased steel pipe.

The results of the tests are given in Table II. Figure 1 shows the chloride content for all the samples. The chloride content of the mortar samples ranged from 0.001% (Sample 2c) to 0.22% (Sample 3).

Watts Towers Chloride Content and Carbonation Tests
Ms. Katherine Untch
Architectural Resources Group
February 2, 2006
Page 2

For Sample 2, the chloride content was highest near the encased pipe, compared to the exterior portions. Figure 2 shows the chloride profile for Sample 2.

Carbonation Depth

The depth of carbonation was determined on freshly sawn cross-sectional pieces. The sawn cut surfaces were sprayed with a pH indicator solution made by Germann Instruments (Rainbow Indicator). Carbonated cement paste is indicated by a green color change to the paste. The green color indicates a pH of 9.0. Yellow (barely discernible) or orange colors indicate the paste has a pH less than 9.0. Non-carbonated cement paste changes to purple or dark purple in color.

The paste in Sample 1 was carbonated to a depth of 0.16", but extended deeper along cracks and voids. The paste in Sample 2 was carbonated to the depth of the encased pipe (the full thickness of the mortar). The paste in Sample 3 was not carbonated. Sample 4 had an irregular carbonation front and was carbonated to an average depth of approximately ⅜".

Photos 2 through 5 show the cross-sectional slices through all the samples. The top section was not treated with the pH indicator. The bottom section was treated with the pH indicator.

FINDINGS AND DISCUSSION

According to American Concrete Institute's ACI 222R-13, Manual of Concrete Practice, the suggested maximum acid-soluble chloride content for reinforced concrete (to minimize chloride-induced corrosion) is 0.20% by weight of cement. Assuming a typical 5 sack concrete mixture weighing 3815 lb/yd^3 (dry state), the maximum acid-soluble chloride content would be 0.025%, by weight of concrete.

Of the 4 mortar samples tested, all had chloride contents that were near or exceeded 0.025% by weight of concrete (mortar).

The carbonation of the mortar pastes varied from complete carbonation of the entire mortar cover (Sample 2), to no detectable carbonation at all (Sample 3).

Please call if any questions arise.

Sincerely,

APPLIED MATERIALS & ENGINEERING, INC.

Jon Asselanis
Materials Scientist/Petrographer

Reviewed by:

Armen Tajirian, Ph.D., P.E.
Principal

APPLIED MATERIALS & ENGINEERING, INC.

TABLE I

SAMPLE IDENTIFICATION AND DESCRIPTIONS

Watts Towers, Los Angeles, California

AME Project No. 106044C

Sample ID	Features	Approximate longest dimension (in.)	Approximate Maximum Width (in.)	Approximate Maximum Thickness (in.)
1	Green color coat	8⅝	5	¾
2	Encased steel pipe	15⅝	4¼	3
3	Embedded ceramic fragments	13½	2½	½
4	Embedded ceramic fragments and multiple mortar layers	6⅛	4⅝	2⅞

APPLIED MATERIALS & ENGINEERING, INC.

TABLE II

CHLORIDE CONTENTS IN CONCRETE

Watts Towers, Los Angeles, California

AME Project No. 106044C

Sample ID	Depth from Exposed Surface (in.)	Meter Reading (mV)	Chlorides by Weight of Concrete (%)
1	0 to ½	67.3	0.020
2a	0 to ¼	106.7	0.004
2b	¼ to ½	115.2	0.002
2c	½ to ¾	138.3	0.001
2d	¾ to 1	48.6	0.045
2e	1 to 1¼	64.8	0.022
3	0 to ½	12.7	0.220
4	0 to ½	47.0	0.049

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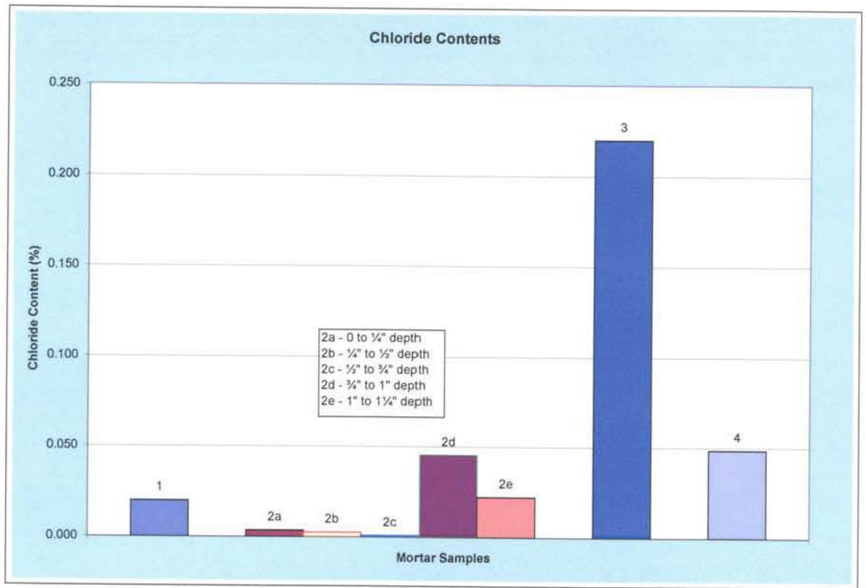

Figure 1. Chloride Contents of Watts Towers Mortar Samples

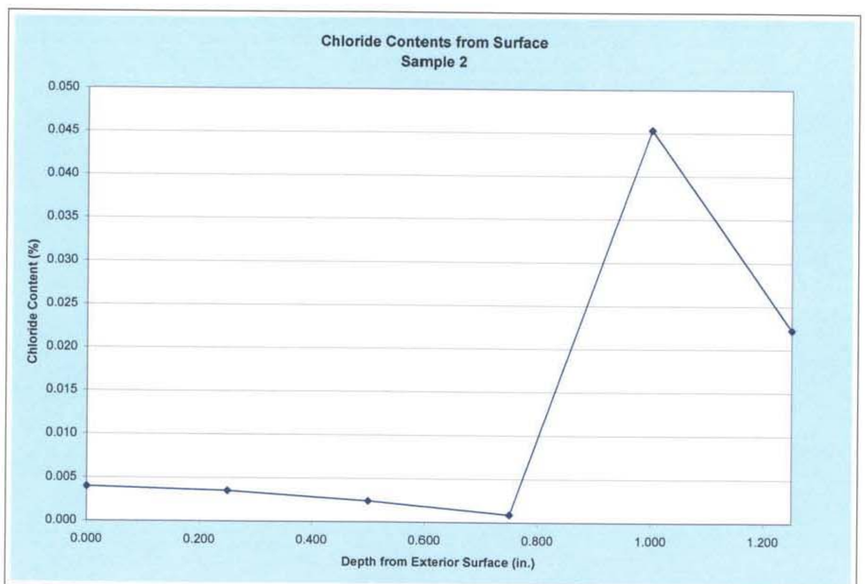

Figure 2. Chloride Profile for Watts Towers Mortar Sample 2

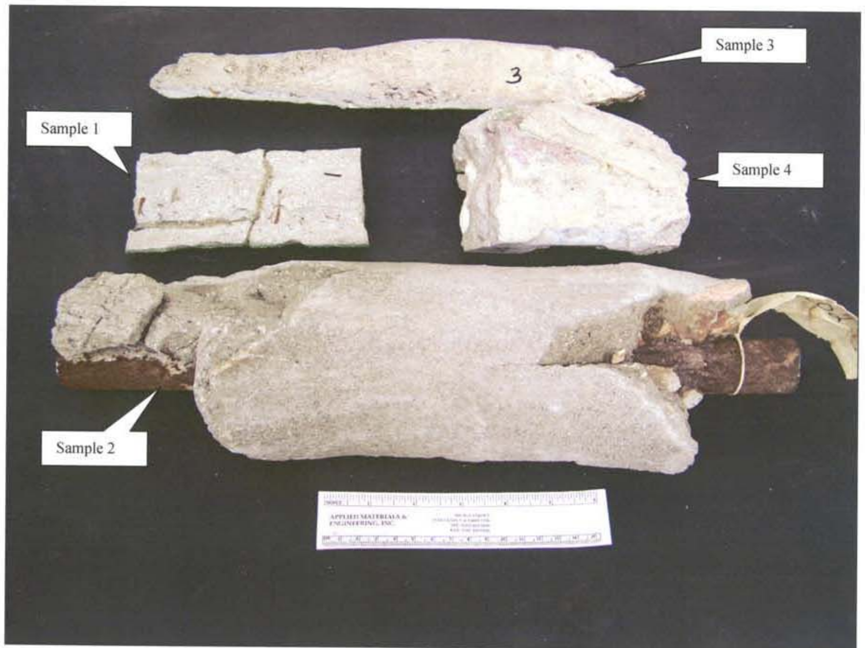

Photo 1. Mortar samples, as received

Photo 2. Sample 1 cross-sectional slices. The bottom section was treated with a pH indicator solution. The purple color of the paste indicates a pH greater than 13 (non-carbonated paste).

Photo 3. Sample 2 cross-sectional slices. The bottom section was treated with a pH indicator solution. The paste changed from yellow to green in color, indicating the entire thickness had a pH of less than 10 (carbonated paste).

Photo 4. Sample 3 cross-sectional slices. The bottom section was treated with a pH indicator solution. The purple color of the paste indicates a pH greater than 13 (non-carbonated paste).

Photo 5. Sample 4 cross-sectional slices. The bottom section was treated with a pH indicator solution. The purple color of the paste indicates a pH greater than 13 (non-carbonated paste).

Photo 2. Sample 1 cross-sectional slices. The bottom section was treated with a pH indicator solution. The purple color of the paste indicates a pH greater than 13 (non-carbonated paste).

Photo 3. Sample 2 cross-sectional slices. The bottom section was treated with a pH indicator solution. The paste changed from yellow to green in color, indicating the entire thickness had a pH of less than 10 (carbonated paste).

APPLIED MATERIALS & ENGINEERING, INC.
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March 12, 2006

MAR 2 1 2006
ARG

Project Number: 106044C

Ms. Katherine Untch
ARCHITECTURAL RESOURCES GROUP
Pier 9, The Embarcadero
San Francisco, CA 94111

Fax Transmittal: (415) 421-0127

Subject: Petrographic Examination of Mortar
Watts Towers
Los Angeles, California

Dear Ms. Untch:

Per your request, Applied Materials & Engineering, Inc. (AME) has performed a petrographic examination on mortar samples, reportedly removed from the above-captioned project.

SAMPLE IDENTIFICATION

Two (2) mortar samples were selected for examination from four (4) mortar samples previously tested for carbonation and chloride contents, as described in our report dated February 2, 2006. Table I gives the sample identifications and approximate dimensions of the samples used in the petrographic examination. The mortar samples are shown in Photo 1.

PROCEDURES & RESULTS

Petrographic (Optical) Examination

A petrographic examination was performed to determine the microstructural characteristics and mineralogical composition of the mortar samples.

The examination was conducted in accordance with ASTM C 856, "*Standard Practice for Petrographic Examination of Hardened Concrete*." The following procedures were performed:

1. The specimens were reduced in size to fit onto standard petrographic glass slides and allowed to air dry on a warming plate (90°F) for approximately 1 to 2 days.

Watts Towers Mortar Petrographic Examination
Ms. Katherine Untch
Architectural Resources Group
March 12, 2006
Page 2

Subsequently the specimen surfaces were ground on diamond-bonded metal grinding discs until finely lapped surfaces were obtained. The lapped sides were mounted on glass slides with clear epoxy and thinned to 15 to 20 microns. These "thin-sections" were examined with a polarizing light microscope to magnifications up to 400x.

2. The volumetric proportions of the mortar were determined from finely lapped cross-sectional slices of the mortar. The volumetric proportions of paste and aggregate were determined using a computer controlled motorized stage capable of discrete movements in two directions (x and y). The interval between points was 1.5 mm (0.06"). The lapped surface is viewed with a variable zoom stereomicroscope at magnifications up to 70x.

The results are as follows:

<u>Sample 2</u>

The mortar was composed of approximately 33% portland cement paste and 53% subround to angular siliceous sand. No hydrated lime or fragmental limestone particles were detected. The sand was mainly composed of feldspar, quartz, pyroxenes, and miscellaneous volcanic rock fragments. The sand was well graded and relatively coarse grained. The maximum particle size was approximately 0.14". There were occasional inclusions of neat portland cement paste, typically 0.20" across, or less.

The cement paste was completely carbonated. The air content was approximately 14%, with approximately 3% of the voids spherical in shape with diameters less than 0.25 mm (0.01"). The small spherical air voids are considered to be incidental entrapped air and not purposely entrained air-voids. No deleterious or unusual reactions were observed. Voids generally contained no secondary mineral deposits. Microcracking was nil.

The estimated water-cement ratio (w/c) was 0.55 ± 0.05. Based on the estimated w/c and volumetric proportions of cement paste, the calculated sand-cement ratio was approximately 4.4:1.0.

Photos 2 through 5 show some of the typical features of the mortar microstructure of Sample 2.

<u>Sample 4</u>

The mortar was composed of approximately 49% portland cement paste and 44% subround to angular siliceous sand. No hydrated lime or fragmental limestone particles were detected. The sand was mainly composed of feldspar, quartz, pyroxenes, and miscellaneous volcanic rock fragments. The sand was well graded and relatively coarse grained. The maximum particle size was approximately 0.14". There were occasional inclusions of neat portland cement paste, typically not much larger than 0.13" across.

APPLIED MATERIALS & ENGINEERING, INC.

Watts Towers Mortar Petrographic Examination
Ms. Katherine Untch
Architectural Resources Group
March 12, 2006
Page 3

The cement paste was typically not carbonated, except for sporadic light carbonation around air voids. The air content was approximately 7%, with approximately 1% of the voids spherical in shape with diameters less than 0.25 mm (0.01"). The small spherical air voids are considered to be incidental entrapped air. Some air voids were filled with ettringite, but no deleterious or unusual reactions were observed. Microcracking was generally low.

The estimated w/c was 0.50 ± 0.05. Based on the w/c and volumetric proportions of cement paste, the calculated sand-cement ratio was approximately 2.3:1.0.

Photos 6 through 9 show some of the features of the mortar microstructure of Sample 4.

A summary of the petrographic examinations are given in Table II. Additional details of the petrographic examination are attached as Appendix A.

SUMMARY

1) The mortar was composed of portland cement and well graded siliceous sand. No hydrated lime or fragmental limestone was detected.

2) The estimated sand-to-cement ratios ranged from 2.3:1.0 to 4.4:1.0.

Please call if any questions arise.

Sincerely,

APPLIED MATERIALS & ENGINEERING, INC.

Jon Asselanis
Materials Scientist/Petrographer

Reviewed by:

Armen Tajirian, Ph.D., P.E.
Principal

Samples will be held for 30 days after submittal of final report and then discarded unless notified in writing. Storage of held samples will be billed monthly. There is a $100 per month storage fee. Return shipment charges are the responsibility of the client.

APPLIED MATERIALS & ENGINEERING, INC.

TABLE I

SAMPLE IDENTIFICATION AND DESCRIPTIONS

Watts Towers, Los Angeles, California

AME Project No. 106044C

Sample ID	Features	Approximate longest dimension (in.)	Approximate Maximum Width (in.)	Approximate Maximum Thickness (in.)
2	Encased steel pipe	15⅝	4¼	3
4	Embedded ceramic fragments and multiple mortar layers	6⅛	4⅝	2⅞

APPLIED MATERIALS & ENGINEERING, INC.

TABLE II

PETROGRAPHIC EXAMINATION SUMMARY

Watts Towers, Los Angeles, California

AME Project No. 106044C

	Sample 2	Sample 4
Aggregate Volume, %	53	49
Paste Volume, %	33	44
Air Content, %	14	7
Binder	Portland cement	Portland cement
Aggregate Type	Siliceous	Siliceous
Aggregate to Cement Paste Ratio, by volume	1.64:1	0.91:1
Estimated Aggregate to Cement Ratio, by mass	4.4:1	2.3:1

APPLIED MATERIALS & ENGINEERING, INC.

Photo 1. Cross-sections of mortar samples examined.

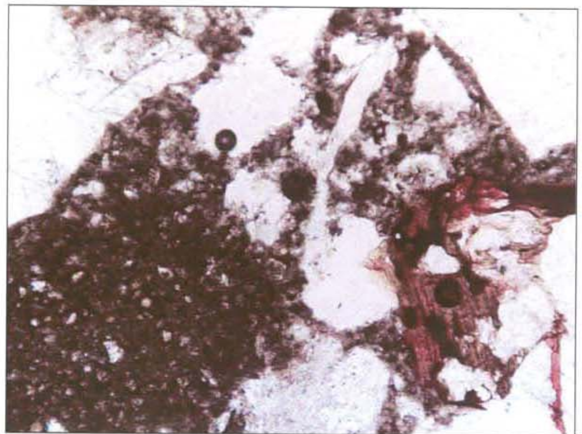

Photo 2. Photomicrograph showing the microstructure of Sample 2. The dark area in the lower left corner is an inclusion of neat portland cement paste. 100x magnification, plane-polarized light illumination

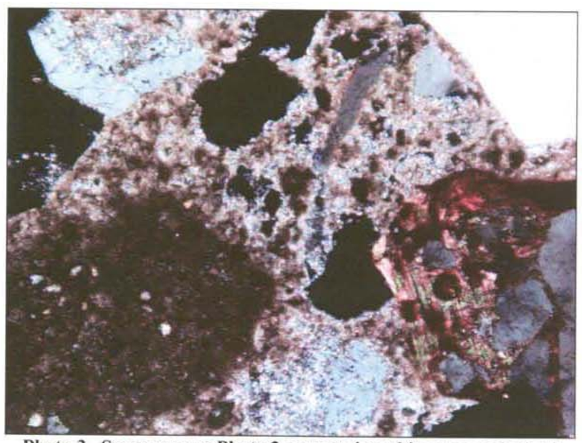

Photo 3. Same area as Photo 2 except viewed in cross-polarized light. The cement paste is completely carbonated (brightly colored area).

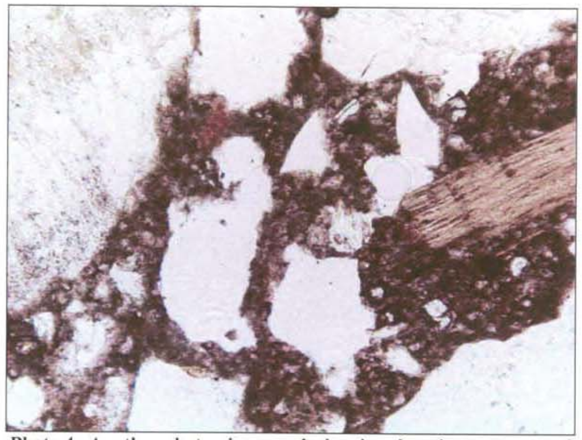

Photo 4. Another photomicrograph showing the microstructure of Sample 2.

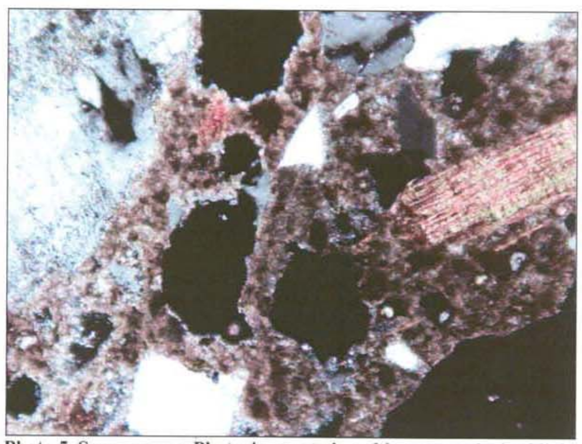

Photo 5. Same area as Photo 4 except viewed in cross-polarized light

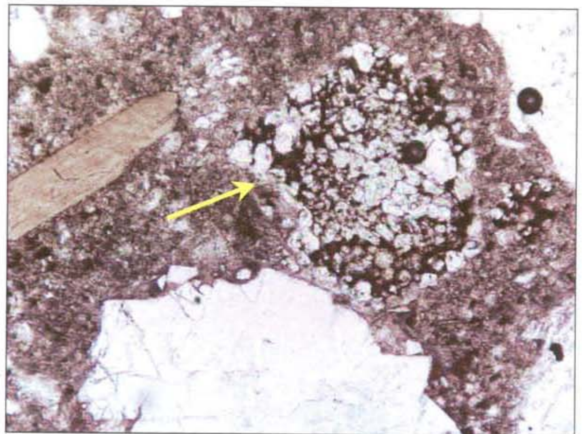

Photo 6. Photomicrograph showing the microstructure of Sample 4. The arrow points to a large unhydrated portland cement clinker particle (belite cluster). 100x magnification, plane-polarized light illumination

Photo 7. Same area as Photo 6 except viewed in cross-polarized light

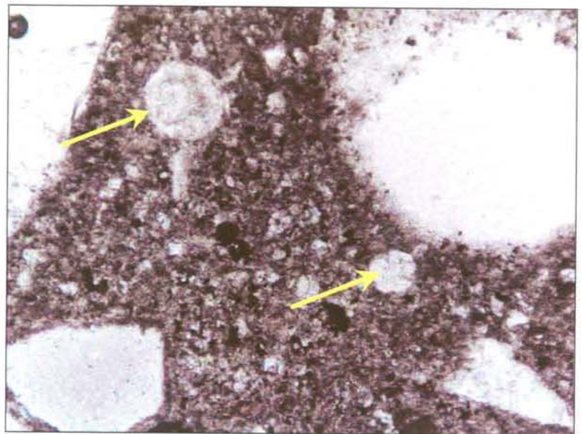

Photo 8. Another photomicrograph showing the microstructure of Sample 4. The arrows point to small spherical air voids filled with ettringite. 100x magnification, plane-polarized light illumination

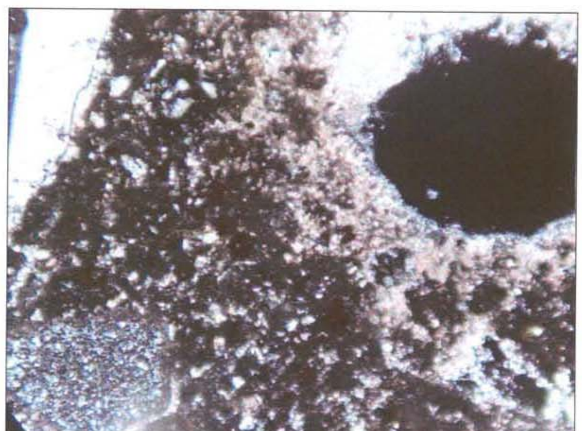

Photo 9. Same area as Photo 8 except viewed in cross-polarized light. The air void in the upper right corner is surrounded by carbonated cement paste.

APPENDIX A

PETROGRAPHIC DATA SHEETS

APPLIED MATERIALS & ENGINEERING, INC.

Petrographic Examination
Macroscopic Analysis

Client: Architectural Resources Group
Project: Watts Towers
AME Project Number: 106044C
3/12/2006

Sample ID: 2

GENERAL AGGREGATE PROPERTIES:

Maximum Size Aggregate (MSA), in.: 0.14 (excluding paste lumps)
Volumetric Proportions (% Aggregate): 53
Distribution: Good
Segregation: None
Flat & Elongated Particles: < 5%
Aggregate/Paste Ratio: 1.64 :1.0
Gap Graded: No
One Size: Well graded

1.5 mm Grid Point Count		
	Count	%
Paste	210	32.5
Residual Lime	0	0.0
FA	345	53.3
Entrained Air	17	2.6
Entrapped Air	75	11.6
Total	647	100.0
Aggregate/Paste Ratio		1.64
Total % Air		14.2
Total % Paste		32.5

Coarse Aggregate Rock Types: No Coarse Aggregate
Major: ----
Minor: ----
Trace: ----
Shape and Texture: ----

Fine Aggregate Mineral Species and Rock Types:
Major: Quartz, feldspar, chert, volcanic rock fragments
Minor: Green hornblende, biotite, pyroxenes
Trace: Serpentine, chlorite, lumps of portland cement paste up to 0.20" across
Shape and Texture: Subround to angular

Reinforcement: Expanded metal lath around embedded metal pipe

Air Content:
Entrained: 3%
Entrapped: 12%
Total: 14%

Cement Paste:
Color: Medium gray
Scratch Hardness: Hard
Surface Carbonation Depth, in. (Determined by pH): Completely carbonated throughout section

Cracking and Other Features: Shrinkage cracks typically terminating at crack parallel to embedded pipe at approxiamtely 1" depth

MISCELLANEOUS SAMPLE INFORMATION: Semi circular cross-section nominally 1.5" thick surrounding embedded pipe.

106044C Petro Mortar Macroscopic 2 Page 1

Petrographic Examination
Microscopic Analysis

Client: Architectural Resources Group
Project: Watts Towers
AME Project Number: 106044C
3/12/2006

Sample ID: 2

Thin-section (TS) Number(s):	1046
CEMENT PASTE PROPERTIES:	
Carbonation: Determined by thin-section:	Completely carbonated, medium to heavy, except for inclusions of portland cement paste, which were lightly carbonated
Calcium Hydroxide Content (CH)*:	Not determined due to carbonation
Size:	----
Distribution:	----
Transition Zone (TZ) Development:	----
Capillary Void Porosity (CVP):	Moderate
Unhydrated Portland Cement Particles (UPC's), %*:	4 to 5%
Shape:	Subround to subangular
Type:	Belite clusters, rare belite
Size:	Occasional large belite clusters, some up to 0.220 mm
Pozzolans*, Additives and Pigments: *percent of cement paste volume	None detected
Estimated water-binder ratio (w/b): (Binder = cement + pozzolan)	0.55 ± 0.05
Secondary Deposits:	None
Deleterious Reactions:	None
Fiber Reinforcement (type and amount**): **percent of sample volume	None
Microcracking:	
Radial:	Low
Transverse:	Low to nil

MISCELLANEOUS CEMENT PASTE INFORMATION:

Good paste hydration

106044C Petro Mortar Microscopic 2 Page 2

Petrographic Examination
Macroscopic Analysis

Client: Architectural Resources Group
Project: Watts Towers
AME Project Number: 106044C
3/12/2006

Sample ID: 4

GENERAL AGGREGATE PROPERTIES:

Maximum Size Aggregate (MSA), in.: 0.14
Volumetric Proportions (% Aggregate): 44
Distribution: Good
Segregation: None
Flat & Elongated Particles: < 1%
Aggregate/Paste Ratio: 0.91 :1.0
Gap Graded: No
One Size: Well graded

1.5 mm Grid Point Count*		
	Count	%
Paste	246	48.5
Residual Lime	0	0.0
FA	223	44.0
Entrained Air	6	1.2
Entrapped Air	32	6.3
Total	507	100.0
Aggregate/Paste Ratio		0.91
Total % Air		7.5
Total % Paste		48.5

*Bulk mortar, excluding pigmented mortar or mortar inclusions over 2" across

Coarse Aggregate Rock Types: No Coarse Aggregate
Major: ----
Minor: ----
Trace: ----
Shape and Texture: ----

Fine Aggregate Mineral Species and Rock Types:
Major: Quartz, feldspar, chert, volcanic rock fragments
Minor: Chlorite, biotite, pyroxenes
Trace: Opaques, hematite(?), lumps of portland cement paste
Shape and Texture: Subround to angular

Reinforcement: None

Air Content:
Entrained: 1%
Entrapped: 6%
Total: 7%

Cement Paste:
Color: Medium gray
Scratch Hardness: Hard
Surface Carbonation Depth, in. (Determined by pH):
Sporadic carbonation in bulk paste, typically not carbonated

Cracking and Other Features: Inclusions of mortar fragments up to 2.5" across, including red and green pigmented mortar, and ceramic

MISCELLANEOUS SAMPLE INFORMATION: Irregular shaped fragment of mortar approximately 6⅛" x 4⅝" x 2⅞

106044C Petro Mortar Macroscopic 4 Page 3

Petrographic Examination
Microscopic Analysis

Client: Architectural Resources Group
Project: Watts Towers
AME Project Number: 106044C
3/12/2006

Sample ID: 4

Thin-section (TS) Number(s):	1048, 1049
CEMENT PASTE PROPERTIES:	
Carbonation: Determined by thin-section:	Bulk paste sporadic, spotty light to medium carbonation
Calcium Hydroxide Content (CH)*:	15 to 18%
Size:	Medium to large
Distribution:	Uneven
Transition Zone (TZ) Development:	Nilt to thin
Capillary Void Porosity (CVP):	Moderate to moderately low
Unhydrated Portland Cement Particles (UPC's), %*:	4 to 5%
Shape:	Subround to subangular
Type:	Belite clusters, rare belite
Size:	Occasional large belite clusters, some up to 0.220 mm (one cluster measured 0.400 mm across)
Pozzolans*, Additives and Pigments: *percent of cement paste volume	None detected
Estimated water-binder ratio (w/b): (Binder = cement + pozzolan)	0.50 ± 0.05
Secondary Deposits:	Ettringite filling some voids
Deleterious Reactions:	None
Fiber Reinforcement (type and amount**): **percent of sample volume	None
Microcracking:	
Radial:	Low
Transverse:	Low to nil

MISCELLANEOUS CEMENT PASTE INFORMATION:

Good paste hydration

106044C Petro Mortar Microscopic 4 Page 4

RECEIVED
MAR 1 4 2006
AME, INC.

CHEMICAL ANALYSIS OF MORTAR SAMPLES

PROJECT: Watts Towers
Project No. 106044C

JOB NO. C-4692-06

MARCH 13, 2006

MICRO-CHEM LABORATORIES
635 Bret Harte Drive
P.O. Box 485
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MICRO-CHEM LABORATORIES

635 Bret Harte Drive • P.O. Box 485 • Murphys, CA • 95247 • (209) 728-8200 • FAX 209-728-8251 • www.micro-chem.com

March 13, 2006

Applied Materials & Engineering, Inc.
980 41st Street
Oakland, CA 94608

Job No. C-4692-06

Attn: Mr. Jon Asselanis

Re: Chemical Analysis of Mortar Samples
Project: Watts Towers
Project No. 106044C

In response to your request, two samples of mortar were received for chemical analysis. The samples were reportedly obtained from the above referenced project. The objectives of the analyses were to determine the portland cement and sand contents as represented by the supplied mortar samples.

Test Method

The composition of the mortar from Sample Nos. 2 and 4 was determined according to the chemical procedures described in ASTM C1324-05, "Standard Test Method for Examination and Analysis of Hardened Masonry Mortar." The cement to sand ratios were calculated assuming the mortar contained no hydrated lime or fragmental limestone.

Sample Descriptions

The following samples were received.

Sample No.	Mass, g	Description
2	92.4	Watts Towers, 106044C
4	102.6	Watts Towers, 106044C

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Job No. C-4692-06
March 13, 2006
Page 2

Chemical Analysis

1. The determined values were as follows.

	Sample No. 1	Sample No. 2
SiO_2, %	3.76	7.71
CaO, %	14.86	20.85
MgO, %	0.36	0.94
Insoluble Residue, %	70.62	51.27
Loss on Ignition, %:		
110°C	0.88	5.01
550°C	3.24	5.34
950°C	5.96	4.18

2. The calculated proportions of portland cement and sand of the mortars were as follows.

	Sample No. 1		Sample No. 2	
	%, by mass	Parts, by volume	%, by mass	Parts, by volume
Portland Cement	17.91	1.0	36.70	1.0
Mortar Sand	70.62	4.6	51.27	1.6
Cement:Sand	1:3.9	1:4.6	1:1.4	1:1.6

Applied Materials & Engineering, Inc.
Job No. C-4692-06
March 13, 2006
Page 3

Should any questions arise concerning the findings of this report, please contact the undersigned.

Respectfully submitted,
MICRO-CHEM LABORATORIES

William R. Nickison
Assistant Petrographer

WRN/jamc
C469206

Sample Disposition: The samples will be stored for a period of one month and thereafter discarded. Charges for additional sample storage time and/or shipping of the samples will be billed to the client.

Watts Towers Phase II — Crack profile Chlorides and pH

Sample	weight (gm)	water (ml)	Cl (ppm)	pH
WTO_A_left edge of steps				
1a	0.1	2	0	12
1b	0.1	2	0	12
1c	0.3	6	0	7
1d	0.2	4	0	7
1e	0.1	2	0	7
1f	0.2	4	0	7
WTO_A_Exterior Column 14				
2a	0.1	2	0	11
2b	0.2	4	0	8
2c	0.3	6	0	8
2d	0.1	2	0	7
Control		3	0	7
NaCl soln			positive	

Appendix E:
Material Data Sheets

NHL 2

Main Data and Application Recommendations

Product specification: pure and Natural Hydraulic Lime (NHL). Contains no additives.
Conforms to European Norm EN 459 and French Norm NFP 15.311
Strength factor: 2 (Feebly hydraulic)
Residue @ 0.09 mm: 5%
Whiteness index: 76
Available (free) lime Ca(OH)2 after slaking: 50-55%
Packing: 55 lbs. (25kg) Bags

Density (volumetric weight) : typical 31.2 lb/ft³ (500 gr. / liter)
Surface cover: 362 sqft/oz (cm² per gram: 11000)
Expansion : < 3/64" (1 mm)
Residue of quick lime after slaking: <1%
Shelf life: 8-12 months kept sealed and dry

MORTARS	Compressive strength - PSI(N/mm2)				Elasticity Moduli 10^3psi (Mpa)		
MIX RATIO	EN459*	1 : 2	1:2.5	1 : 3	1 : 2	1 : 2.5	1 : 3
7 DAYS		90(0.62)	77 (0.53)	68 (0.47)			
28 DAYS	290(2.00*)	215(1.48)	198(1.36)	197(1.25)	1309(9025)	1421(9800)	1305(9000)
6 MONTHS		557(3.84)	435(3.00)	418(2.88)	1827(12600)	1744(12030)	1699(11800)
12 MONTHS		580(4.00)	420(2.90)	420(2.90)	1815(12515)	1744(12030)	1725(11900)
24 MONTHS		616(4.25)	435(3.00)	399(2.75)	1939(13375)	1740(12000)	1704(11750)
Consumption for 1 yard³ (1m³) of mortar lbs +/-10% (kg. +/- 10%)		472(280)	378(224)	283(168)			

* Incoming European Norm EN 459 (mortar ratio 1:1.3 with ISO 679 Sand)

Mixing: can be mixed in cement mixers.
Application by Spray Gun: possible.
Working temperatures: not below 40°F or above 85°F. Make sure that high suction materials are thoroughly dampened before application. Avoid rapid drying due to high temperatures or strong winds by curing with a light water mist several times a day if necessary. Protect from frost, rain, direct sun and strong wind for a minimum of 96 hours.
SUITABLE FOR LATH WORK/INJECTION/GROUTING: see relevant sheets.
Reworking: possible within 24 hours.

Mortar Uses
MASONRY/POINTING 1 VOLUME OF NHL 2 : 2 VOLUMES OF SAND
Choose well graded sands (#6 (3mm):#200 (75microns)). See also "*General Guidelines – Sands for NHL mortars*".
PLASTERING: *on earth or friable supports, after preparation and cleaning, dampen with a 1:20 solution of NHL2/water applied in 2 coats.*

A. Scratch Coat 1/8" –3/16"(3 - 4 mm) 3 VOLUMES OF NHL 2 : 5 VOLUMES OF SAND
This coat is applied by casting on to a still damp but not over saturated support and is left as cast to provide good keying.
B. Brown Coat 5/8" – 3/4"(15-20 mm) 1 VOLUME OF NHL 2 : 2 VOLUMES OF SAND
Can be applied in 2 passes of min. .3/8"(1cm) Second pass only after first is reasonably dry.
C. Finish Coat 3/16" (5mm) 1 VOLUME OF NHL 2 : 2.5 VOLUMES OF SAND
The dosage / thickness may vary in accordance with the desired finish and the sand used. In smooth floated finishes if very fine sands containing clay are used the binder (NHL) quantity will be reduced.

Please also refer to General Guidelines: NHL Plasters.

The above details are given for information purposes only. Final dosages and application should be checked with our technicians. The Factory reserves the right to alter specifications.

NHL 3.5

Main Data and Application Recommendations

Product specification: Pure and Natural Hydraulic Lime (NHL). Contains no additives.
Conforms to European Norms (EN 459) and French Norm NFP 15.311

Strength factor: 3.5 (Moderately hydraulic)
Density (volumetric weight) : typical 40.6 lbs / ft^3 (650gr / litre)
Residue @ 0.09 mm: 6.5%
Surface cover: 274 sqft/oz (cm^2 per gram: 9000)
Whiteness index: 72
Expansion : < 3/64"(1mm)
Available (free) lime after slaking $Ca(OH)_2$: 20%- 25%
Residue of quick lime after slaking: < 1%
Packing: 55 lbs. (25kg) Bags
Shelf Life: 8-12 months kept sealed and dry

MORTARS	Compressive strength - PSI(N/mm2)				Elasticity Moduli 10^3psi (Mpa)		
MIX RATIO	EN459*	1 : 2	1:2.5	1 : 3	1 : 2	1 : 2.5	1 : 3
7 DAYS		109(0.75)	83 (0.57)	77 (0.53)			
28 DAYS	507(3.5*)	273(1.88)	213(1.47)	194(1.34)	1306(9010)	13051(9000)	1170(8070)
6 MONTHS		1029(7.1)	774(5.34)	571(3.94)	2213(15260)	1958(13501)	1805(12450)
12 MONTHS		1087(7.5)	855(5.90)	565(3.90)	2216(15280)	1975(13620)	1907(13150)
24 MONTHS		1251(8.63)	870(6.00)	576(3.97)	2535(17480)	1999(13785)	1982(13670)
Consumption for 1 $yard^3$ ($1m^3$)- of mortar lbs +/-10% (kg. +/- 10%)		514(305)	411(244)	364(216)			

* Incoming European Norm EN 459 (mortar ratio 1:1.3 with ISO 679 Sand)

Mixing: can be mixed in cement mixers.
Application by Spray Gun: possible.
Working temperatures: not below 40^0F or above 85^0F. Make sure that high suction materials are thoroughly dampened before application. Avoid rapid drying due to high temperatures or strong winds by curing with a light water mist several times a day if necessary. Protect from frost, rain, direct sun and strong wind for a minimum of 72 hours.
SUITABLE FOR LATH WORK / LIME CONCRETE/INJECTION/GROUTING : see relevant sheets.
Reworking: possible within 12 hours.

Mortar Uses: MASONRY/POINTING/ CAPPING/ BEDDING/ ASHLAR

Binder: sand ratio: from 1:1.5 to 1:3 depending on the support/background conditions, the size of the joint and the fineness of the sand. Always use well graded sands (#6 (3 -4mm) down to #200(75 microns)). See also "*General Guidelines – Sand for NHL mortars*".

PLASTERING

A. Scratch Coat	1/8" – 3/16"	(3-5mm)	1 volume of NHL 3.5 : 1.5 volumes of Sand – Cast on.
B. Brown Coat	5/8" – 3/4"	(15-20mm)	1 volume of NHL 3.5 : 2 volumes of Sand*
C. Finish Coat	3/16" – 3/8"	(5-10mm)	1 volume of NHL 3.5 : 2.5 volumes of Sand

With very fine sands possibly containing clays the binder content may have to be reduced.
**At this dosage the consumption is approx. 2.05 lbs. (0.35kg). of NHL 3.5 per square yard (m^2) for each 1/8" (m) thickness.*

Please also refer to General Guidelines: NHL Plasters.

The above details are given for information purposes only. Final dosages and application should be checked with our technicians. The Factory reserves the right to alter specifications.

NHL 5

Main Data and Application Recommendations

Product specification: pure and natural hydraulic lime. *Contains no additives.*
Conforms to European Norm (EN 459) and French Norm NFP 15.311
Strength factor: 5 (Eminently hydraulic)
Residue @ 0.09 mm: 7%
Whiteness index: 67
Available (free) lime Ca(OH)2 after slaking: 15% - 20%
Packing: 66 lbs. (30kg) Bags

Density (volumetric weight) : typical: 43.7 lb/ft³ (700 gr. / litre)
Surface cover: 244ft² /oz (cm² per gram: 8000)
Expansion : < 3/64" (1mm)
Residue of quick lime after slaking: < 1%
Shelf life: 8-12 months kept sealed and dry

MORTARS	**Compressive strength - PSI(N/mm2)**				**Elasticity Moduli 10^3psi (Mpa)**		
MIX RATIO	**EN459***	**1 : 2**	**1:2.5**	**1 : 3**	**1 : 2**	**1 : 2.5**	**1 : 3**
7 DAYS		284(1.96)	245(1.00)	128(0.88)			
28 DAYS	725(5*)	319(2.20)	290(2.00)	217(1.50)	1566(10800)	1595(11000)	1450(10000)
6 MONTHS		1060(7.31)	857(5.91)	770(5.31)	2610(18000)	2472(17050)	2450(16900)
12 MONTHS		1346(9.28)	1282(8.84)	942(6.50)	2684(18510)	2506(17280)	2342(16150)
24 MONTHS		1567(10.81)	1277(8.81)	1131(7.80)	3117(21500)	2613(18020)	2527(17430)
Consumption for 1 yard³ (1m³) of mortar lbs +/-10% (kg. +/- 10%)		590(350)	472(280)	393(233)			

* Incoming European Norm EN 459 (mortar ratio 1:1.3 with ISO 679 Sand)

Mixing: can be mixed in cement mixers.
Application by Spray Gun: possible.
Working Temperatures: not below 40⁰F or above 85⁰F. Make sure that high suction materials are thoroughly dampened before application. Avoid rapid drying due to high temperatures or strong winds by curing with a light water mist several times a day if necessary. Protect from frost, rain, direct sun and strong wind for a minimum of 48 hours.
SUITABLE FOR LATH WORK / LIME CONCRETE/INJECTION/GROUTING: see relevant sheets.
Reworking: possible within 8 hours.

Mortar Uses: MASONRY/POINTING/CAPPING/MASS WALL BEDDING/ FOUNDATION/SEA DEFENCE WALLS/CHIMNEY STACS/NEW BUILD (Masonry)
Depending on the conditions of the support/background, the fineness of the sand and the size of the joints, binder : sand ratio values vary between 1: 1.5 to 1:2.5

Choose well graded sands (#6 (3 or 4mm) down to #200 (75 microns)). See also "*General Guidelines – Sand for NHL mortars*".

PLASTERING
A. Scratch coat 1/8 " – 3/16" (3 - 5mm) 1 volume of NHL 5 : 1.5 VOLUMES OF SAND Cast on recommended
B. Brown Coat 5/8" – 3/4" (15-20mm) 1 volume of NHL 5 : 2 VOLUMES OF SAND * (1:2.5 max)
**At this dosage the consumption is approx 2.34 lbs (0.4 kg) of NHL 5 per square yard (m²) for each 1/8" (m) of thickness*
C. Finish Coat 3/16" – 3/8" (5-10mm) USE NHL 3.5 OR NHL 2, see relevant sheets

Please also refer to General Guidelines: NHL Plasters

The above details are given for information purposes only. Final dosages and application should be checked with our technicians. The Factory reserves the right to alter specifications.

Ecomortar G - Ready-Mix

Premixed pure & natural hydraulic lime and sand mortars for building, pointing, repointing, plastering and finishing in a variety of colors

The absence of cement, ashes, gypsum and other pozzolanic additions together with its other qualities, make Ecomortar G highly suitable for repair and conservation work on traditional, vernacular and historic buildings. In new build the properties of Ecomortar G will allow joint free construction, dispersion of condensation and will accommodate small settlement movements.

Ecofriendly Characteristics:

High vapour exchange qualities
Produced with lower energy than cementitious mixes
Re-absorption of CO2 in curing
Will not deteriorate timber
Possibility of recycling the materials used in building
Elimination of painted finishes

Mechanical Characteristics

		Ecomortar G
Dry bulk density	lbs/ft^3 (kg/m^3)	84.3 (1350)
Compressive strength		
7 days	Psi (n/mm^2)	174 (1.2)
28 days		275.5 (1.9)
90 days		522 (3.6)
Elasticity Moduli	Psi (Mpa)	725.000 (5000)
Vapour Permeability Gr. Air x m^2 x hour		0.85

Granulometry: **G** granulometry from #6 (3mm) to #23 (0.08mm) for masonry, pointing, dubbing out, first and main coats on renders and rough finishing coats.

Packing: 35 kg. (77 lbs.) and 25 kg. (55 lbs.) bags.
Consumption: (See - Ecomortar G - Consumption Chart)
Preparation: in ordinary drum mixers (mix for about 5 minutes)

Water Addition:
EcoMortar **G** 1 gallon (4.0 litres) – 1.2 gallons (4.5 liters) per bag of 77 lbs. (35 kg)

Application:
On clean and dry background not water proofed. Dampen adequately dry or high suction surfaces. Do not apply at temperatures below 40°F (5°C) or above 85°C (30°C). Protect

against strong rain, frost, drying wind or direct strong sun until sufficient hardening has occurred.

The above details are given for information purposes only. Final dosages and application should be checked with our technicians. The Factory reserves the right to alter specifications.

Ecomortar F - Ready-Mix

Premixed pure & natural hydraulic lime and sand mortars for plastering & finishing in a variety of colors

The absence of cement, ashes, gypsum and other pozzolanic additions together with its other qualities, make Ecomortar F highly suitable for repair and conservation work on traditional, vernacular and historic buildings. In new build the properties of Ecomortar F will allow joint free construction, dispersion of condensation and will accommodate small settlement movements.

Ecofriendly Characteristics:

High vapour exchange qualities
Produced with lower energy than cementitious mixes
Re-absorption of CO^2 in curing
Will not deteriorate timber
Possibility of recycling the material used in building
Elimination of painted finishes

Mechanical Characteristics

		Ecomortar F
Dry bulk density	lbs/ft^3 (kg/m^3)	87.4 (1400)
Compressive strength		
7 days	Psi (n/mm^2)	145 (1.0)
28 days		217.5 (1.5)
90 days		435 (3.0)
Elasticity Moduli	Psi (Mpa)	580.000 (4000)
Vapour Permeability Gr. Air x m^2 x hour		0.89

Granulometry: **F** granulometry from #16 (1.18mm) to #23 (0.08mm) for fine joint work. Available in a wide range of colors.

Packing: 35 kg. (77 lbs.)
Consumption: (See Ecomortar F - Consumption Chart)
Preparation: in ordinary drum mixers (mix for about 5 minutes)

Water Addition:
EcoMortar **F** 1.2 gallons (4.5 litres) – 1.3 gallons (5.0 liters) per bag of 77 lbs. (35 kg.)

Application:
On clean and dry background not water proofed. Dampen adequately dry or high suction surfaces. Do not apply at temperatures below 40°F (5°C) or above 85°C (30°C). Protect

against strong rain, frost, drying wind or direct strong sun until sufficient hardening has occurred.

Application by Spray Gun:
Possible. Please consult us.

The above details are given for information purposes only. Final dosages and application should be checked with our technicians. The Factory reserves the right to alter specifications.