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Restoring a 20th Century Terrazzo Pavement: A Conservation Study of the Floor Map of the New York State Pavilion, Queens, New York

Amel Chabbi
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Presented to the Faculties of the University of Pennsylvania in Partial Fulfillment of the Requirements for the Degree of Master of Science in Historic Preservation 2004. Advisor: Frank G. Matero

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RESTORING A 20TH CENTURY TERRAZZO PAVEMENT:
A CONSERVATION STUDY OF THE FLOOR MAP
OF THE NEW YORK STATE PAVILION
QUEENS, NEW YORK

Amel Chabbi

A THESIS

in

Historic Preservation
Presented to the Faculties of the University of Pennsylvania in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

2004

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Associate Professor of Architecture
To my mother
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CHAPTER 1
INTRODUCTION

I. Statement of Purpose

This research aims to develop methods for cleaning, consolidating and restoring the terrazzo pavement of New York State Pavilion, a showcase building erected by the architect Philip Johnson for the New York World’s Fair of 1964-65. The pavement is an immense terrazzo reproduction of a 1960’s Texaco Oil Company road map of New York State. It measures 130 by 160 feet and is comprised of 567 individual 4 by 4 foot panels that were hand crafted and laid individually. The pavement was the stage for several exhibits in the pavilion that served to educate visitors about the State of New York. Since the fair closed in 1965, inappropriate use, vandalism and weathering, largely due to the removal of the roof, have left the Pavilion and its pavement in an active state of decay.

Along with other art work by Andy Warhol and Roy Lichtenstein displayed in the complex dedicated to New York State, the pavement is one of the largest examples of American Pop Art. Although the pavilion was initially built as a temporary structure, it was decided after post-fair evaluations to retain the structure. Although one component of the Pavilion – the Theaterama – has been rehabilitated, the Tent of Tomorrow and its flooring lie unprotected from harsh environmental conditions and disuse.

II. Methodology

A detailed research program for the conservation and restoration of the pavement was conducted using archival and material analyses. This study aims at providing a conservation treatment plan to consolidate and restore the remaining pavement and formulate alternatives to fill areas of loss. Archival investigation shed light on the
Chapter 1

Introduction

history of terrazzo, its traditional methods of fabrication and the production of the specific pavement at the New York State Pavilion. The site was visited three times in order to survey its condition and to map out general deterioration patterns. From these observations, it was possible to associate the condition of the floor with original construction, and subsequent repairs and maintenance; use, reuse, and abandonment; and with environment (covered and uncovered). It was also possible to select a specific panel that was representative of the floor’s materials and conditions, presenting most of the deterioration processes for further study.

A panel of the pavement was lifted and brought back to the Architectural Conservation Laboratory of the Graduate Program in Historic Preservation of the University of Pennsylvania for close-up examination and testing. Although the choice was limited by cost and accessibility, the chosen panel presented most of the conditions observed on the entire floor, such as active friability or flaking, erosion, overpaint, microflora, corrosion, pitting, cracking, loss, and detachment. The panel was documented and its condition was recorded through rectified photography and AutoCAD delineation.

Material analysis of the panel has several goals:

- Firstly, to investigate and confirm the construction and material composition of the terrazzo mix and the various components of the panels (plastic, metal dividers and frames, pigments, terrazzo mixes).
- Secondly, to determine the physical properties of the panel and the reasons for its degradation. This provided information about how the original design, material composition and installation techniques have been affected by time and the environment.
- Thirdly, to test cleaning, stabilizing and consolidating treatments in order to

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1 The device crafted by Professor Lindsay Falck and John Hinchman to lift the panel will be described in Appendix A.
identify potential methods to be applied to the entire pavement.

Analysis of the material composition of the panel was performed using transmitted microscopy (thin section and dispersion), as well as Powder X-Ray Diffraction, Fourier Transform Infra-Red spectroscopy, microchemical spot testing, and metal detection and chemical identification. Microscopy was used specifically to measure the ratio of binder to aggregate in the terrazzo mix and to observe the causes for deterioration of the sub-surface layers (e.g., corrosion, erosion, biological intrusion, carbonation of the cement, overpaint, and cracking). Powder X-Ray diffraction was useful in determining the composition of the terrazzo paste and cement mixes while FTIR identified the plastic used as separators and symbols. Microchemical spot testing was performed to determine the panel’s metal strips.

Conservation treatments tested on the panel were chosen based on a review of literature mostly focused on the restoration and consolidation of classical mosaics, and the latest recommendations on the restoration of modern cementitious masonry systems. Recommendations were drawn from the assessment of the performance of the treatments. These treatments include cleaning overpaint and tar, and removing stains; stabilizing and consolidating areas of detachment, loss and cracks; and exploring methods of infill and replacement. Recommendations and specifications are formulated based on these tests. In situ application of compatible treatments are also included in the recommendations.

The remainder of this introduction establishes the context of the pavement for the World’s Fair. The next chapter provides a brief history of floors and a study of the evolving technology of terrazzo followed by a description of the production of the pavement at the New York State Pavilion (including labor, technique, materials, and assembly) based on documentary resources and also on the preliminary investigations done on site. Chapter 3 focuses on the condition of the pavement today with regard to general problems to the specific deterioration phenomena affecting individual panels.
Chapter 4 describes the testing program related to determine the composition of the pavement and the assessment of results. Chapter 5 consists of a literature review of conservation techniques applied to classical mosaics, historical and modern masonry floors. Chapter 6 follows with a testing program for treatment. This chapter also offers an assessment of the data gathered, draws conclusions and presents recommendations for treatments. Appendix A is the description of the removal of the sample panel. Appendix B includes the conditions glossary developed for the terrazzo pavement and the panel while Appendix C presents the data collected from the various experiments conducted to identify the material composition of the floor.

III. New York World’s Fair

The World’s Fair of 1964 was built on a large tract of marshland in Flushing Meadows, Queens. This site was originally known as the Corona Dump and was piled with tons of burnt garbage before the first New York World’s Fair of 1939 was built. As a continuation of the 1939 World’s Fair theme “The World of Tomorrow,” the Fair Corporation, presided by Fair Corporation President Robert Moses, decided that the pavilions and exhibits for the 1964 fair would be a dedication to “Man’s achievements on a shrinking globe in an expanding universe” and would follow the theme of “Peace through Understanding.” 2 The buildings and exhibits aimed to predict improvements and future developments in communication, travel and public health.

Architect Philip Johnson was selected by Governor Nelson Rockefeller to build the New York State Pavilion. His design was a reinterpretation of a previous building proposal by Frank Lloyd Wright for the Chicago Century of Progress Exposition of 1933. 3 At Rockefeller’s insistence, the pavilion was to be a superlative structure: the tallest and

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3 Ibid, p. 112.
the largest at the fair with the world’s largest two-dimensional map pavement and the largest suspension roof, complementing the largest globe (Unisphere), and the largest scale model of a city located in the New York City Pavilion.4

The New York State Pavilion was composed of the Tent of Tomorrow, three observation towers with the tallest reaching 226 feet, and the nearby Theaterama, a large cylindrical movie theater decorated on the exterior with Pop Art by artists such as Andy Warhol, Roy Lichtenstein, James Rosenquist, and Alexander Liberman. After the fair was closed, the New York State Pavilion was one of the few structures to remain standing due to the exorbitant cost necessary to demolish it. Attempts to find alternate uses for the pavilion included transforming the structure into a roller skating rink, known as the Roller Round, in the 1970s.

Figure 1 - The New York State Pavilion, 1964.
(Source: Official Postcard, Dexter Press, West Nyack, NY)

4 Ibid, p. 112.
While the Theaterama was renovated into a theater for the arts in 1972, the rest of the complex was closed and fell into disrepair. For safety reasons the suspended acrylic roofing panels were removed in 1976 exposing the pavement directly to harsh environmental conditions (e.g., rain, snow, heat, guano).
CHAPTER 2
CONSTRUCTION TECHNIQUE

I. The Terrazzo Map of the New York State Pavilion

The pavement of the New York State Pavilion was designed as a replica of Texaco’s New York State road map and the most extensive terrazzo project ever undertaken at the time. The project cost nearly $1,000,000 and was financed by Governor Nelson Rockefeller. While Rand McNally & Company supplied topographic information, Texaco provided the location of each of its gas stations in the state. A group of Yale School of Art students assisted in constructing the terrazzo map, which featured the 50,000 square miles of New York State in meticulous detail. Cities, towns, highways, roads, and Texaco stations were all accurately placed in the 22,000 square-foot design (Figure 3).

A. Design

Three quarter inch square sections of an actual Texaco road map were enlarged 64 times to create an overall map of 567 panels spanning an area of 130 feet by 166 feet. The picture of the map consisting of the roads, rivers, highways and locations of cities and towns was first projected onto paper templates. Then, Yale art students completed the map design by drawing in the symbols, letters and numbers on the paper templates. These templates were used to make plywood pattern boxes which were used as molds to cast the terrazzo. The plywood boxes were sent to a tile factory and the terrazzo mix was poured into these molds. Pigmented cement was used to depict the map features such as land

6 Ibid.
7 The construction of the map started in mid-1963, therefore a Texaco map of 1962 was probably used.
9 Documentation on the production of the pavement is very limited. A possible scenario for the use of the plywood pattern boxes may be that the boxes were assembled to create a negative imprint of the features
Figure 3: Floor Plan of Philip Johnson’s New York State Pavilion. The panel used for the study is outlined in red. Source: Johnson, 66.
(white, green, and beige), roads (black and red), rivers (blue), and lakes (blue).\textsuperscript{10} Details of the map were brightly colored in imitation of the printed Texaco road map. Red, blue, green, white and black plastic was used to depict the various topographical markers of the map. Colored plastic strips were inlaid to replicate words, numbers, and symbols and to delineate the pigmented areas. Based on the designs traced by the Yale students, the plastic insets were hand cut and then inserted into the terrazzo mix. Recent analysis has identified the different materials and techniques used for different types of insets. The cast terrazzo panels were each laid individually on a bed of sand, concrete reinforced with steel mesh, and plywood (Figures 4-5).\textsuperscript{11}

Examination of a representative panel removed for the study revealed a complex assembly. The ½ inch terrazzo topping is poured and bonded to a 1 ½ inch cementitious underbed. The lower portion of this underbed is encased in an L-shape metal frame with that were to be filled with the plastic insets. The terrazzo was poured into these molds face down, the design was then completed by inlaying the plastic pieces.

\textsuperscript{10} Identification of pigments is detailed in Chapter 4.2.

a one inch wide flange. Below the underbed are a sheet of plywood and a layer of sand. These two layers top a layer of concrete reinforced with steel mesh. Each panel consists of the terrazzo topping and the layers beneath that are contained by the metal frame (Figure 6).

Panels rest on a structural slab of concrete which was poured when the pavilion was built. The panels were manufactured at a tile company and mounted together on site.
using suction-cup lifts to move each panel in place. Metal dividers are inserted between each panel. The top portion of the panel is framed by a metal divider. Each panel weighs 400 pounds totaling a floor that weighs 114 tons.

Plastic cut to represent long lines for roads, streams and rivers (a in Figure 7: Inset) are partially hollow underneath and are fastened to zinc dividers (b) with rivets (c). These dividers outline the different pigmented terrazzo areas representing land, parks, water bodies, roads. The dividers span the terrazzo layer and extend into the terrazzo underbed where they are connected to a steel anchor (d) by a steel rivet (e). Each anchor holds the inset-zinc divider system in place and prevents it from shifting in the terrazzo layer above.

For map names of locations, the method of assembly is somewhat different. Two parallel zinc dividers are placed underneath the fully cut out letters. The dividers are also connected to metal anchors. The letters, symbols and numbers are placed in the terrazzo mix while wet.

![Diagram](image)

**Figure 7: Cross section (left) and side view (right) of inset system. Drawings by author.**

C. Assembly

Each metal frame possesses two pins on each side extending ⅛ inches out from the frame (Figure 6). These pins act as locks where each panel’s frame is fitted into

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12 Ibid.
the consecutive frame by interlocking each pin. The entire map is designed in this way forming a “mosaic” of panels that are interlocked with each other. The plain terrazzo area of the pavement surrounding the map are assembled in the same way; however the terrazzo mix is composed of gray aggregate in a grey matrix. Panels contiguous to the map are encased in metal frames and are assembled in the same way as depicted in Figure 6. For plain terrazzo panels outlying the map, re-bars are also present in the concrete underbed. Panels at the seam between the walls and the floor are not enclosed by a metal frame; however they are delineated by metal dividers. The plain terrazzo layer is ½” thick while the concrete under bed is 1” to 2” thick for the panels at the seam.

II. From Opus Signinum to Terrazzo

Terrazzo is a composite material poured in place or precast, which is used for floor and all treatments. It consists of marble, quartz, granite, glass or other suitable chips, sprinkled or unsprinkled, and poured with a binder that is cementitious, chemical or a combination of both. Terrazzo is cured, ground and polished to a smooth surface or otherwise finished to produce a uniformly textured surface.13

This type of flooring was introduced to the United States as early as the 1890’s and became widespread in the 1920’s. It is derived from the Roman technique of opus signinum and was developed with the Venetian tradition of pavimento alla Veneziana.14,15 A brief overview of historic composite masonry floors, especially mosaics, and their evolution will provide a better understanding of the origins of terrazzo and how it achieved its present form.

A. History and Construction of Mosaics

According to Pliny, mosaics may be considered a Hellenistic invention although

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early attempts at mosaic making have been found in Egypt and Mesopotamia.

Archaeological investigation has yielded evidence in Anatolia of pebble mosaics dated to the 8th century B.C.\textsuperscript{16} Although the first examples were small pebble bi-colored mosaics, they are still regarded as a prototype for this floor finish. Over time, pebble mosaics gave way to a different type of floor decoration made of cut or shaped pieces known as \textit{tesserae}. These \textit{tesserae} were usually made of marble, hard stone, terracotta, and later also of glass, mother-of-pearl, and enamels. The material used was indigenous to the area of mosaic production although, in some cases, where certain colors were scarce, the material was imported.\textsuperscript{17} The \textit{tesserae} were embedded in plaster or cement to hold them in place.

Floor mosaics or \textit{lithostratum} were developed extensively by the Romans. Within this category, there are three subgroups that characterize the size of the \textit{tesserae} used: \textit{opus sectile} used large interlocking plaques of stone or marble; in \textit{opus tesselatum}, \textit{tesserae} are usually uniform in size and shape and range between 0.7 cm in length and 1.7 cm in length.\textsuperscript{18} Historically, \textit{opus tesselatum} was used for small \textit{emblemata} that were made in a workshop and brought \textit{in situ}. Geometric motifs supplanted figurative scenes and began to expand and cover entire floors. Later on, figures reappeared especially in the dominant representation of mythological scenes or scenes connected to the function of the building in which the mosaic was being laid. \textit{Opus vermiculatum} involved \textit{tesserae} that are smaller than 0.7cm in length\textsuperscript{19} and was used mostly for figurative designs. \textit{Opus tesselatum} was used for both figurative and geometric forms while \textit{opus vermiculatum} was employed for figures and central components of the design.

\textsuperscript{16} Katherine M. D. Dunbabin, \textit{Mosaics of the Greek and Roman World} (Cambridge: Cambridge University Press, 1999), p. 5.


\textsuperscript{19} Ibid.
Within \textit{opus tesselatum} exist different techniques of which the three most prominent are: \textit{opus segmentatum}, \textit{opus fliginum}, and \textit{opus signinum}. The former fits together slabs of marble that are cut into random shapes. \textit{Opus fliginum} includes large ceramic sections in rows of two or three pieces forming a square pattern. \textit{Opus signinum} derives from the Punic and Roman traditions of \textit{cociopesto}, which is essentially a lime mortar made with a pozzolan (volcanic sand or crushed bricks), sand and fragments of brick or pottery.\textsuperscript{20} \textit{Cociopesto} was mostly used for utilitarian purposes as an impermeable rendering such as waterproofing walls, cisterns, and aqueducts. It was also used to face roads and pavements. \textit{Opus signinum} used this type of mortar which was also mixed with crushed marble. White \textit{tesserae} were often used to delineate or make figurative designs. \textit{Opus signinum} is one of the humblest types of mosaic floor decoration and was not only found in private dwellings but also on public pathways as can be seen in Pompeii.\textsuperscript{21}


According to Vitruvius, five layers should comprise the stratigraphy of a typical mosaic floor (see Figure 8):

- the *statumen* (1): a thick rubble bedding,
- the *rudus* (2): a 9 inch layer of coarse mortar of gravel or crushed brick and lime,
- the *nucleus* (3): a 6 inch “brown coat” of finer mortar,
- the *bedding layer* (4): a thinner, finer, and smoother layer rich in lime into which
- the *tesserae* (5) are inserted as illustrated in the following figure:

![Figure 8: Example of mosaic stratigraphy according to ancient literary sources. Source: Mosaics In Situ Project: Illustrated Glossary, 2003, http://www.getty.edu/conservation/publications/pdf_publications/mosaicglossary.pdf](image)

There are three methods of assembling a mosaic. The direct mosaic consists of placing the individual *tessera* in fresh mortar according to a pattern that was ruled, scored or painted onto the surface of the bedding layer. The indirect and reverse methods both
consist of creating a reverse image either on a sand cushion or on a cloth, and transferring this layer of inverted tesserae to the bedding layer. Traditionally, the master mosaicist created the central figures while the apprentices assisted in the repetitive geometric patterns and the background.

**B. Pavimento alla Veneziana**

During the Byzantine period, the art of mosaic reached a peak with the inclusion of mother-of-pearl, precious stones and gilding with gold or silver leaf. During the Middle Ages, mosaics were prominent in religious settings along with stained glass. During the Renaissance, *opus flignonum* was revived, which gave rise to *pavimento alla Veneziana* or *Palladiana*, where small random pieces of marble ranging between ½ inch to 2 inches were mixed with stucco or mortar, and embedded closely together in a coat of weak concrete, and finally ground and polished.\(^{22,24}\)

*Seminato* was another inexpensive technique where large marble chips (measuring 3 to 4 inches) were sprinkled onto a bed of cement; the voids between the aggregate were filled with medium and smaller chips. The whole slab was leveled and polished until a smooth finish.\(^{25}\)

Traditional terrazzo evolved from *opus sectile*, *opus signinum* and *pavimento alla Veneziana*. It was originally light weight and fairly elastic, which made it ideal for floors in Venice where buildings were built on pilasters. This type of pavement reduced the weight on the foundations of buildings. Terrazzo was durable, easy to work with and inexpensive to create. However, it was limited to small areas and seldom used in large expanses because it was prone to cracking due to shrinkage and movement.

\(^{22}\) This type of flooring finish was extensively used by Palladio.


Chapter 2

C. Technology of Terrazzo

According to the National Terrazzo and Mosaic Association (NTMA), terrazzo is a mixture “composed of two parts marble to one part Portland Cement, to which color pigments may be added and water.” The use of terrazzo spread rapidly to the rest of the world early on; in the 18th century, it reached the United States (e.g. Mount Vernon displays some early examples of terrazzo). However, modern terrazzo, as specified by the NTMA, became popular again at the end of the 19th century, especially in the United States, because of improvements in technology.

Originally, terrazzo was polished by hand with galleras, which were pumice stones attached to long wooden handles. This method was eventually replaced with electric polishers; thus greatly facilitating the finishing process. Divider strips were introduced in 1924 by L. Del Turco and Bros. to reduce cracking caused by shrinkage. These 1 ½ inch-long strips usually made of corrugated brass or zinc deflected cracks from the terrazzo topping to the joints and could also be used as guides for the workers when setting different colored terrazzo. Strips were embedded within the terrazzo and held a good grip with the underbed of cement and the terrazzo topping. With the development of these new tools and methods, terrazzo became widespread by the 1920s. This finish was very popular during the Art Deco period and is still extensively used for interiors.

(1) Terrazzo Components

There are two main components in making terrazzo: cement and marble chips. Additives such as pigments, metal strips and resins have been introduced for aesthetic and

28 Del Turco, L., and Bros., Inc., Modern Mosaic and Terrazzo Floors; a Handbook on the Improved Method of Laying Terrazzo Floors with Metal Dividers, Precast Terrazzo Base, Treads, etc., Marble Mosaic Floors; Full Size Color Samples and Floor Designs (Harrison, NJ: Del Turco, L., and Bros., Inc., 1924), pp. 6-7.
also functional reasons but are not essential to creating a solid and sound mixture.29

**Cement**

ASTM C 150 Type 1 Portland Cement is specified by the NTMA as well as other terrazzo companies and associations such as the Terrazzo, Tile and Marble Association of Canada.30 Portland cement consists of hydraulic calcium silicates. Grey or White Portland cement can be used for terrazzo although grey terrazzo does not yield as uniform a color in the dry product. In the past 25 years, resinous matrices such as epoxy resins, polyester resins, or polyacrylates have been used as substitutes for Portland cement.31 Epoxy may also be used to bond the terrazzo topping with the concrete structural slab in bonded terrazzo system. Resinous matrices are more resistant to harsher environmental conditions and are more often used when terrazzo is laid outdoors.

**Aggregate**

Marble chips are usually freshly quarried from stone selected for its strength and color. They are usually produced by crushing large slabs of marble and sifted and categorized according to size. The NTMA specifies 9 grades of marble chips ranging from 1/16 inch to 1 inch. Grades 1 (1/8 inch) and 2 (¼ inch) are most frequently used. In some case, other stones such as onyx, travertine and serpentine have come to replace marble. The traditional ratio of Portland cement to marble is 30% to 70% by volume.32

The National Bureau of Standards undertook a study in 1943 of the physical properties of the aggregates used for terrazzo based on 77 types of marbles from various quarries.33 It was found that the marbles were classified as calcites, dolomites or

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34 Ibid.
dolomitic marbles, serpentines.\textsuperscript{34} This study provided information on wear resistance, toughness, water absorption, bulk specific gravity, dust content, percentage of voids and thickness grading. The results have helped in establishing standard specifications for terrazzo use and performance.

**Pigments**

Pigments are generally selected to harmonize with the marble chips and to allow terrazzo to be designed into patterns. Alkali resistant and non fading inorganic pigments are recommended. They can either be of mineral or synthetic origin. Modern pigment specifications are based on ASTM standards.\textsuperscript{35} For example, zinc oxide, zinc sulphide, titatium oxide may be used for white pigments. Bone black, graphite, lamp black or iron oxide can be used for black. Green can be achieved with chrome green, chrome oxide green or phtalcyanine green; yellow, orange and brown from various iron oxides, ochre or sienna and molybdate orange; red from iron oxides, para or toluidine.\textsuperscript{36} Pigments should not exceed two pounds per bag of Portland cement (94 pounds) for interior terrazzo or $\frac{1}{2}$ pound of pigment per bag of Portland cement for exterior terrazzo.\textsuperscript{37}

**Divider Strips**

Dividers were introduced at the beginning of the 20th century. They are specified to be non-corrosive, made of zinc or brass, or sometimes in plastic, and measure $\frac{1}{8}$ to $\frac{1}{4}$ inch thick. Divider strips should not be laid more than six feet apart.

\textsuperscript{10} Installation

When preparing the terrazzo mix, it is essential to slowly hydrate the dry mixture with a fine mist of water until plastic to create a smooth mix free of any lumps. Terrazzo

\textsuperscript{35} ASTM, 1209, volume 06.01.
\textsuperscript{37} National Terrazzo and Mosaic Association Inc., http://www.ntma.com/02_matrix_data.php.
panels should not exceed 12 square feet to avoid shrinkage. Joints within the panel should correspond to joints in the structural slab below. When laying the terrazzo topping or its underbed, it is essential that the structural slab be rough or scratched to allow the mixture to key in and bond.

Polishing should occur before the terrazzo is entirely dry. Grinding occurs in two phases. The first phase uses a Carborundum brick or disk and water. The floor is then washed. Voids are filled with a fine slurry of Portland cement. The second phase involves grinding with a disk or stone of finer grain. Once the floor is polished, a solvent type sealer is now recommended.

There are three major types of terrazzo installation. Monolithic terrazzo, bonded terrazzo and sand cushioned terrazzo.

**Monolithic Terrazzo**

![Figure 9: Monolithic terrazzo.](image)

*Source: NTMA, Specifications and Technical Data, 4b.*

Monolithic terrazzo is the simplest and cheapest installation technique. The terrazzo layer may measure between ½ to 5/8 inch and is poured directly on a subfloor structural concrete slab. It is similar to bonded terrazzo; however, the absence of a bonding agent (such as an underbed of cement and sand) between the two layers increases the effects of shrinkage or shock. Dividers are sawn into the concrete slab at the joints.38

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**Chapter 2  Construction Technique**

**Bonded Terrazzo**

This installation involves three layers: a weak concrete mixture of sand and cement acts as a bonding agent between the 5/8 inch terrazzo layer and the structural slab. In some cases, epoxy resins may be used instead of sand and cement.\(^{39}\)

![Figure 10: Bonded terrazzo.](image)

Source: NTMA, Specifications and Technical Data, 1b.

The underbed is laid on the concrete slab which has been hydrated with a fresh layer of cement. This increases the bonding reaction. While the underbed is still wet, divider strips are placed and then the terrazzo topping is poured. This system is usually 2 inches in thickness; additional reinforcement such as iron mesh may be added if necessary.

**Unbonded or Sand-Cushioned Terrazzo**

This last installation type is the one used at the New York State Pavilion. It is recommended by NTMA to prevent structural

![Figure 11: Sand-cushioned terrazzo](image)

Source: NTMA, Specifications and Technical Data, 1c.

\(^{39}\) National Terrazzo Mosaic Association, Inc., Specifications and Technical Data, pp. 1b, 1c.
movement through shrinkage, expansion, settlement, or vibration. Unbonded or sand-cushioned cementitious terrazzo is a multiple layer system where the terrazzo topping and cement underbed are separated from the structural slab with a layer of sand and a waterproof membrane.\textsuperscript{40} The sand layer (1/4” thick) acts as an insulator: it absorbs shock and movement between the subfloor and the topping, reducing the effects of expansion, cracking and the overall thickness of floor ranges between 7/8 to 1 inch. The underbed is usually reinforced with a metal wire (galvanized iron mesh). Divider strips are also suggested to reduce cracks and are inserted while the underbed is still fresh and before the terrazzo is poured.

**Other Systems**

If the slab is made of metal, the system is a “cementitious terrazzo over metal deck” where the metal subfloor measures 2 1/2 inches thick. Other materials used as the subfloor lead to the appellation of “structural cementitious terrazzo.” Other methods are possible such as Venetian terrazzo, terrazzo over wood, outdoor terrazzo or abrasive terrazzo. In each case, the thickness of the underbed and terrazzo topping vary as well as the specifications for the terrazzo mixture.

(3) **Maintenance**

It is recommended not to use oil, waxes or sand for cleaning. Cleaners such as detergents and water should have a neutral pH. Acidic and caustic cleaners as well as floor stripping agents can cause etching or pitting as these chemicals may disintegrate the bonding agent from the aggregate. Stains should be removed with a poultice or a dissolving agent.

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\textsuperscript{40} In the case of the New York State Pavilion, the plywood sheet was used as a waterproofing membrane.
CHAPTER 3
CURRENT CONDITIONS

As “documentation and recording are the cornerstones of conservation practice,” these two steps should be the preamble to any testing procedure. Because of limitations of time and site access, recording the pavement conditions required a broad overall survey through on-site visual observation coupled with a detailed examination of one of the 567 panels. This approach was sufficient enough to gain an approximate understanding of the major deterioration phenomena and to evaluate the treatments most needed for stabilizing and consolidating the floor. To adequately select a representative panel, the condition of the pavement was broadly assessed to understand the major trends in deterioration processes. A panel representing most of the conditions surveyed was selected and lifted from the site. The panel was closely observed and micro-deterioration processes were identified and recorded using a conditions glossary developed specifically for the project (see Appendix B).

I. Entire Pavement
   A. Survey

The ultimate goal of surveying the entire pavement was to understand the relationship between conditions and environment, pavement design, construction technology, past and current uses, and maintenance.

A Texaco map of New York Sate published in 1964 for the World’s Fair was acquired.

42 Accurate measurements should be undertaken if the pavement were subject to a full conservation plan.
to facilitate recording the conditions. Minor discrepancies were observed between the
design of the pavement and the published map, especially in the location of certain
symbols and the addition of the Texaco logo indicating Texaco gas stations.

The published map was scanned and reproduced to record conditions during
subsequent survey trips. The conditions observed on site were divided into four broad
categories: friability, which was associated with friability, flaking and cracking, plant
intrusion, overpaint, and fills. These conditions were recorded for the northern half of
the pavement (which represents the eastern half of New York State); the southern half
of the pavement was obstructed by the presence of a dumpster, debris, and vegetation.
Approximate areas were estimated by correlating the road and city markers on the
pavement with those on the map. The data collected was then transcribed digitally. With
AutoCAD® (by AutoDesk©), the conditions were drawn onto a rasterized copy of the
Texaco printed map. The extent of each condition was calculated as a ratio between the
area covered by a specific condition and the area surveyed.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Area of Coverage</th>
<th>Percent of Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Map Pavement</td>
<td>7300 square feet</td>
<td></td>
</tr>
<tr>
<td>Surveyed Pavement</td>
<td>3340 square feet</td>
<td>46% of total Map Pavement</td>
</tr>
<tr>
<td>Overpaint</td>
<td>1020 square feet</td>
<td>31% of Surveyed Area</td>
</tr>
<tr>
<td>Fills</td>
<td>250 square feet</td>
<td>7.5% of Surveyed Area</td>
</tr>
<tr>
<td>Vegetation</td>
<td>250 square feet</td>
<td>7.5% of Surveyed Area</td>
</tr>
<tr>
<td>Friability</td>
<td>63 square feet</td>
<td>2% of Surveyed Area</td>
</tr>
</tbody>
</table>

Table 1 - Area of Coverage of Conditions for Pavement Conditions Assessment

43 It is important to stress that the survey yielded general results and recording was done without precise
measurements: approximate areas of coverage by a specific condition were recorded on the map. Using
a total station and measuring distances by triangulation would have yielded much more accurate results;
however for our purposes, i.e. determining trends in deterioration and areas of greater damage, a broad
survey was considered sufficient.

44 This ratio was computed with ArcMap® (ArcView© by ESRI).
Figure 12: Conditions assessment of New York State Pavilion pavement.
Plant Intrusion

Plant intrusion describes the colonization of macroflora and microflora. Higher plants are found predominantly near the center of the pavement especially underneath the central ring where the suspension cables converge. Growth extends to the peripheral areas especially along the panel seams (Figure 13).

![Figure 13: Plant intrusion throughout the eastern half of the state of New York. Photograph by author, November 2003.]

Overpaint (Figure 14)

Large areas of overpaint, mostly grey and pink near the north entrance, obscure the terrazzo pavement. Underneath are also traces of tar and other paint spatter. The tar is most probably due to the frequent passage of cars and trucks used to haul supplies from the pavilion to the theater. The paint is due to the current use of the pavilion as a stage set preparation area for the Queens Theater. Furthermore, during the time when the pavilion was used as a skating rink, the pavement was “plastic coated for protection from the skaters.”

Figure 14: Overpaint.
Left: residue of red plastic coating. Right: overpaint from stage set preparation
Photographs by author and John Hinchman, October 2003.

Figure 15: Friability and cracking.
Photograph by author, November 2003.
Friability and Cracking (Figure 15)

Flaking and cracking were grouped under the same condition for the pavement conditions assessment\textsuperscript{46}. For panels where plant intrusion was pervasive, network cracking was important. Network cracking was also associated with friable and flaking terrazzo. The pavement had crumbled into $\frac{1}{2}$" to 4" wide fragments bound into discreet segments by the inserts. These areas are also associated with partial loss due to their instability. The plastic inserts also have loosened and have been displaced leaving shallow depressions for water intrusion.

Fills (Figure 16)

Areas of total loss have been filled with grey concrete by the New York City Department of Parks and Recreation over the years since 1965. These fills are prevalent in the southern part of the map. Full panels that were lost were replaced in form and fit into the metal frames. For half panels, the concrete was poured and consolidated the friable edges.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{image.png}
\caption{Concrete in-fill for half of panel. Photograph by author, November 2003.}
\end{figure}

\textsuperscript{46} For the panel conditions assessment, these conditions were each observed individually.
B. Discussion of results

The area surveyed presented more varied conditions than the rest of the pavement. This is probably due to the fact that this area is closest to the main entrance which is still in use today by the Queens Theater.

Plant Intrusion

The prominent area of plant intrusion lies underneath the central ring of the roof. This ring served for drainage purposes when the acrylic panels were still in place. Today, it serves as a roosting area for birds and also channels water onto the center of the pavement. Both guano deposits and concentrated water provide the necessary requirements for localized plant growth (Figure 17).

Fills

The concrete fills can be seen as an attempt to stabilize the floor; however, cracks have formed parallel to the boundary between concrete fills and the terrazzo probably because of shrinkage and differential thermal movement. Once cracked, dissolution, salts and freeze-thaw action have caused further damage.

Overpaint

The Queens Theater has used the premises of the pavilion for storage and also to prepare its stage backdrops since 1994.\textsuperscript{47} The areas with paint layers are often associated

with backdrop remnants that have also left imprints in the paint patterns. Furthermore, tar stains were found near the north and east entrances that are used for vehicular traffic. The area surveyed represents the portion of the pavement that is currently in use today. The pavilion is accessed through the north entrance rather than the east or west entrances. Utility vehicles use the secondary accesses for trash removal and also for loading. The pavement is strewn with trash especially near the west entrance. A large dumpster is situated over “Long Island” while a smaller trash can sits in the middle of the pavement. Trash from the Queens Theater, such as backdrop remains, tarps, and metal barricades are scattered throughout the site (Figure 18). Metallic objects have caused some corrosion stains on the terrazzo.

Figure 18: Trash and dumpster over Long Island section of terrazzo. Photograph by author, October 2003.
Friability and Cracking

Past uses are also responsible for the present condition of the pavements. From 1970 to 1974, the pavilion was used as a roller skating rink, known as the Roller Round. Roller skaters caused much abrasion which in turn may have contributed to the friability of the pavement. The Roller Round came to an end because of poor maintenance. Moreover, vandals, throughout the years, removed parts of the pavement specifically around New York City and Long Island.48

Differential settlement has caused the pavement to slope. This is most apparent during rainy weather where water accumulates in the recessed areas, which aids in the growth of plants. In 1977, the suspension roof was acutely deteriorated; wind blew the fiberglass tiles off and some fell onto the pavement. The tiles were removed for safety exposing the floor to severe weather conditions and bird guano.

The plain terrazzo panels that are not part of the map present parallel cracks as seen

in Figure 19. This is probably due to the fact that the pavement lacks zinc dividers. The vibrations due to the unstable building foundations are not diverted toward the dividers but rather span the width of the panel.

The sand cushion and steel mesh, which is present in the sand-cushion cementitious terrazzo used for the map, should have isolated the terrazzo from shock and from rising damp and salts. When excavating a plain terrazzo panel, the plywood was found to be extremely damp and compressed to nearly 1/8 inch in thickness. The failure of the plywood greatly undermined the soundness of the terrazzo topping by allowing the ingress and rise of water. Consequently the sand cushion was wet as well. The hydration of the sand reduced its capacity as a shock insulator. This contributed to the network cracking in the map terrazzo.

II. Panel

A. Selecting a panel

From the site analysis, it was established that two areas held all of the major conditions assessed in the field: the area around Rochester and the area of Niagara County, near the city of Buffalo. However because each panel is interlocked with its neighbor on each side except for the panels on the outskirts of the map, it was decided to remove one of the extremity panels to reduce damage. Our choice was limited to the first panel of the map representing the south western tip of New York State. This panel includes pigmented terrazzo mix (white and black), plain terrazzo mix (grey), plastic inserts of various colors (green, white and black) and presents many subtle micro conditions not clearly visible when observing the entire pavement.

B. Condition of Panel

The panel selected was removed with part of its metal frame. It measures 16
square feet. Although two thirds of the panel are plain terrazzo, the panel as a whole presents most of the conditions assessed for the entire pavement, e.g. overpaint, loss, cracking and friability. Intrusive vegetation is not present; however, there are traces of microflora. Closer study and accurate measurements were taken of the panel and its original installation. This resulted in measured drawings in section and elevation views of the panel and of the mounted inserts. Observation under low magnification revealed additional deterioration patterns at the microscopic level. These conditions are detailed in the conditions glossary found in Appendix B.
CHAPTER 4
MATERIAL ANALYSIS

The purpose of the analyses was to characterize the terrazzo in order to determine its constituent makeup. The lack of documentation on the production of the pavement made the identification of these components essential in selecting appropriate treatments and documenting the fabric of the floor. Although the main components of terrazzo are specified by the NTMA, some constituents such as the pigments and metal dividers were left up to the choice of the manufacturer. It was important to characterize the binder, aggregate and additives of the terrazzo, and identify the plastics and metals used for insets in order to select compatible treatments.

The chosen analytical methods produced the desired information and were also feasible. Time and availability of analytical instruments were the main constraints. Optical microscopy (petrography) with thin sections and XRD were chosen as the primary methods. FTIR was chosen to identify the plastics, and chemical spot testing for metals. The information gathered was mostly qualitative. The data requiring quantification—aggregate to binder ratio and porosity—was determined by optical microscopy.

I. Bedding composition

A. Microscopy

Thin section microscopy was used to determine the material composition of the terrazzo topping and the underbed for both the plain and map terrazzo. Microscopy also yielded more information on the deterioration mechanisms especially at the surface of the terrazzo. The thin sections were prepared by embedding the samples in an epoxy resin
on a glass slide and grinding them down to a thickness of 30μm. A dye added to the resin was useful in highlighting porosity.\textsuperscript{49} Both thin sections were observed at 50X, 100X and 200X magnification under reflected and transmitted, plane and cross polar light.

(1) Plain Terrazzo

**Micromorphology using reflected light**\textsuperscript{50}

The original sample contained two layers: the top terrazzo layer with large grey marble aggregate (1 in Figure 20) in a grey pigmented matrix (2) and the bottom cement (6) and sand-based mortar (4) underbed with corroded iron mesh reinforcement (5). When observed in cross section, the surface of the sample presents signs of pitting and deep erosion of the paste (3). Black and brown corrosion particles as well as paint residues are also clearly visible. The sample is not friable however.

The mortar layer is much more friable and is of 120-grit texture.\textsuperscript{51} The aggregate is more uniformly distributed throughout the rather coarse paste. The aggregate ranges from a medium to fine sand and sub-angular to angular in shape. The mortar appears white to slightly cream in color (10YR 7/3 on the Munsell scale). Some corrosion particles from the iron mesh are embedded in various areas of the mortar.

**Transmitted Light Microscopy**

Observation of the samples with transmitted light\textsuperscript{52} allowed identification of the components of the terrazzo mix and underbed. UV light provided more information on the deterioration phenomena.\textsuperscript{53}

The top terrazzo layer clearly displayed marble as its aggregate. The large sub-angular particles measure on average 6mm by 2mm and were large composite...
Chapter 4

Material Analysis

Figure 20: Plain terrazzo and underbed.
Reflected light, 0.8x magnification.

Figure 21: Surface erosion and soiling of paste, plain terrazzo (upper layer).
Plane polarized light, 4x magnification.
metamorphic aggregate with many anistropic and highly bi-refringent calcite grains. The paste is made of fine particles. The layer is quite dense with a few small interconnected pores between the aggregate. Adobe Photoshop© was used to calculate the percent porosity\textsuperscript{54} and the binder-to-aggregate ratio\textsuperscript{55} based on pixel differentials. The porosity for the top layer was calculated at 8% while the paste-to-aggregate ratio is 1 to 3.5 (the marble aggregate comprises nearly 70% of the terrazzo layer).

Physical deterioration can be seen in transmitted light: microcracks within the paste were on average 25μm wide and 1mm long. Cracks present in the paste ran along the boundaries of the aggregate (Figure 22). In a few cases, cracks were found within the aggregate and measured 25μm wide and 1.5mm long on average.

The erosion of the surface was more visible under higher magnification (Figure 23). The paste is clearly recessed compared to the surface of the aggregate. In some cases, the aggregate presents rounder edges and shows signs of abrasion. It was possible to measure the degree of erosion. Assuming that the original polished surface of the aggregate corresponds to the top of the present aggregate, the amount of paste eroded can be measured between the top of the aggregate and the top of the paste. The rate of erosion can be calculated as the ratio between the amount of paste eroded and the span of time since the floor was laid. For the gray terrazzo, the rate of erosion was calculated over the whole surface of the sample and was found to be on average 0.08mm\textsuperscript{2}/year. The overall effect is a rougher, coarser texture and color shift to grayer and more opaque material as more surface area of the aggregate becomes visible.

The surface of the paste is darker in some areas due to soiling. Under UV light, this

\textsuperscript{53} UV microscope used was a Nikon Alphaphot-2 YS2 model.
\textsuperscript{54} The percent porosity was calculated as the ratio between the pixels associated with voids in the matrix as evidenced by the thin section resin and the total number of pixels corresponding to the top terrazzo layer of the sample.
\textsuperscript{55} The binder-to-aggregate ratio was calculated as the ratio between the pixels associated with the binder and the pixels associated with the aggregate.
Figure 22: Microcracks in gray cementitious paste, plain terrazzo.
Plane polarized light, 10x magnification.

Figure 23:
Bottom: underbed with isotropic quartzite particles.
Top: cementitious paste of plain terrazzo.
Cross polars with accessory plate, 4x magnification.
area fluoresces green and may represent organic residual coatings known to have been applied when the pavement was used as a roller skating rink.

The underbed is made of quartz particles (sand) and cement paste (Figure 24). The particles of sand range between 250μm and 1mm. They are very heterogeneous in size distribution and more angular than the marble aggregate above. The paste has nearly the same porosity (9%) and the ratio of binder-to-aggregate is 3 to 4. There is large agglomeration of fractured cement paste in the bottom of the thin section. Also, part of the iron mesh can be seen in section in the bottom of the mortar section. Corrosion staining is present in this area of the thin section (Figure 24).

Figure 24: Iron mesh reinforcement in underbed, plain terrazzo. Plane polarized light, 4x magnification.

(2) Map Terrazzo

The sample was taken directly from the panel with a Dremel micro tool. The lack of flexibility of the instrument required chiseling the sample away from the underbed. The vibrations caused the sample to crack in half however both halves were embedded into the resin for the thin section.

56 A Dremel micro tool allowed to saw a small ½ inch square sample from the panel.
The sample only presents one layer: the top layer of terrazzo. The aggregate and paste are lighter gray in transmitted light but white in reflected light. The aggregate is marble with anisotropic calcitic crystals. Grains are sub-rounded to sub-angular and on average 3mm to 4mm in diameter. The cementitious paste is compact and devoid of large pores. The porosity is 7% while the aggregate represents 60% of the mixture.

The surface is much more eroded than in the plain gray terrazzo: here, all the aggregate is exposed (Figure 25). This is not only due to polishing after the pavement was installed but also due to weathering and abrasion. The rate of erosion is calculated over the length of the surface of the sample and was found to be 0.18mm²/year. This rate is much larger than the rate calculated for the plain terrazzo (0.08mm²/year). One reason for this may be due to the location of the sample on the panel. Indeed, the sample was taken from an area of the panel that was subject to substantial loss. This area lay alongside a divider strip which acted as a channel for shocks and vibrations within the panel. Therefore, the area around the divider strip presents many microcracks and network cracking. The cracks are generally 50μm wide and run within the marble
aggregate. Cracks are also present along boundaries of marble grains and join to form networks within the paste (Figure 26). Erosion and loss is usually due to these network cracks along the boundaries of the aggregate which cause the cementitious paste to detach. Calcite grains experience unequal anisotropic movement along two crystal axes; this may account for the cracks at the interface of the paste.

A small amount of biological growth fluoresced under UV light. Below this layer, the remaining paste between the aggregate is darker due to trapped soiling and penetration of previous coatings. Under UV light, there is a clear distinction between the accumulation of dirt and superficial coating and the original sealant of the pavement.

B. X-Ray Diffraction

X-ray diffraction (XRD) is an instrumental analytical technique that can identify a wide variety of crystalline compounds. The technique is based on Bragg’s Law of light diffraction: crystalline compounds will refract light in unique patterns when exposed to an X-ray beam whose angle of incidence changes over time. Each crystalline solid
differfracts X-rays in a unique way because each crystalline plane diffracts the X-ray at a certain angle. A graph can be generated that indicates both the plane of diffraction and its intensity. This unique fingerprint can be compared to XRD fingerprints from other known samples in order to come up with a match.

XRD is mostly used for qualitative characterization of crystalline compounds. Approximate quantitative ratios can be deduced from the spectrographs but more accurate quantitative analytical methods should be used. Its limitations are that it cannot detect minerals that are present at less than 2% of the mixture. Furthermore, complex compounds can yield complex graphs that are difficult to interpret.

XRD is efficient in determining mortar composition in order to determine various mineral phases present. This technique was chosen to identify the mineralogical composition of the gray terrazzo, its underbed (fines and coarse aggregate) and the colored map terrazzo for the New York State Pavilion’s pavement. Each sample was ground to a fine powder and prepared for XRD analysis. The ground sample of the underbed was sieved through a sieve stack. The fines (collected in sieve no. 75 and higher) were tested separately from the coarse particles.

For the sample of gray terrazzo, the XRD pattern revealed 78.5% calcite (calcium carbonate), 10.3% portlandite (calcium hydroxide), 3.7% hatrurite (calcium silicate), and 2.6% dolomite (calcium magnesium carbonate oxide). Calcite and portlandite are main components of Portland cement which was used as the matrix for the terrazzo topping. Hatrurite is a tri-calcium silicate comparable to alite which is also commonly found in Portland cement. This compound is hydrated to produce calcium silicate hydrates and lime during the cement production process. The presence of hatrurite is residual from the hydration process of cement. Dolomite and calcite are minerals found in marble which is
the aggregate in the terrazzo mix.

Silicon oxide (quartz) and calcite were the main components for the underbed fines and coarse particles. A small amount of sodium aluminum silicate (albite) was found in the coarse particles. Albite is a plagioclase feldspar mineral that may be found in certain types of sands. Albite was included in the sand used to make the mortar for the underbed.

A portion of the terrazzo layer of the panel that had broken off while lifting it from the pavement was used as a sample for XRD. The sample contained 78.5% calcite, 10.3% portlandite and 3.6% zinc silicate (Willemite). Willemite is a rare zinc mineral that is found in abundance in Franklin, New Jersey. It is usually associated with calcite and zincite (zinc oxide). Considering the small amount of this compound, the presence of Willemite may be an error in interpretation of the XRD pattern.

C. Pigment Identification

Pigments used for the production of the sample panel were determined using microscopy. Small samples of black terrazzo paste and white terrazzo paste were taken and mounted into dispersions. Using polarized light microscopy, it was possible to identify the black pigment used for the road symbols as bone black. The particles were opaque, black, isotropic and with a refractive index superior to 1.66. Using the McCrone Particle Atlas, these characteristics were matched with bone black, an organic pigment made of very little carbon and calcium carbonate and mostly of calcium phosphate.

The particles found in the pigment used for coloring the white surfaces of the terrazzo were transparent under reflected light, anistropic showing uniaxial (-) interference pattern. Microchemical spot testing was performed on the particles. The pigment used for the white terrazzo was identified as whiting or calcium carbonate. According to the

57 Rutherford J. Gettens and George L. Stout. “The Stage Microscopy in the Routine Examination of Painting” reprinted from Technical Studies, Vol. IV, No. 4 (April 1936), pp. 217. A drop of nitric acid caused the sample to effervesce and dissolve. The drop did not dry completely and no crystalline residue formed. A drop of water and a small drop of dilute sulfuric acid were added and small needle-like crystals of calcium sulphate formed.
McCrone Particle Atlas, the particles were associated with aragonite. Other colors used in the map terrazzo were not present on the sample panel for testing.

II. Insets

A. Identification of Metal Dividers and Supporting Frame

Because metals possess distinct chemical and physical properties resulting from their composition, it was possible to identify the architectural metals used for the metal frame, the metal support for the insets, and the metal dividers by examining visual and physical properties and by conducting chemical spot tests.

(1) Visual Examination

The metal frame is heavily corroded by reddish brittle corrosion and incrusted with dirt. The original color of the metal is not observable because of the great accumulation of corrosion. The metal has a rather high density, is stiff even though it is highly corroded and is magnetic. The inset metal support and the metal divider have the same physical property: they are apparently white metals, with a dark layer of oxidation that is removable by scratching the surface. The samples are very stiff but of low density (7.3g/cm³).

(2) Spot Tests

The specifications given by the NTMA and L. del Turco & Bros, Inc state that dividers should be made of zinc or brass; therefore, the series of spot tests served to identify white metals and also copper. The samples were tested for lead, iron, zinc, tin, and aluminum.

The following table presents the results found from the chemical spot tests. It was

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58 It was not possible to calculate the density of the sample due to the size of the frame. Because of its stiffness, samples were scraped off the surface for chemical spot testing and identification.

found that the metal frame was steel coated by tin while the divider was made of zinc coated in tin. The tin acted as an anti-corroding agent although tin itself corrodes rapidly in an alkali and acidic environment.\(^{60}\)

<table>
<thead>
<tr>
<th>Test</th>
<th>Sample</th>
<th>Divider</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRRON</td>
<td>Potassium Ferrocyanide</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Ammonium Thiocyanate</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>TIN</td>
<td>Phosphomolybdic Acid</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>ZINC</td>
<td>Potassium Mercuric Thiocyanate</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Zinc</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>LEAD</td>
<td>Potassium Iodide</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ALUMINIUM</td>
<td>Aluminion Solution</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>COPPER</td>
<td>Ammonium Hydroxide</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Rubeanic Acid</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2: Matrix of metal identification for frame and divider strip.

**B. Identification of Plastic Insets**

Fourier Transform Infrared (FTIR) Spectrometry uses transmitted infrared light to characterize phases within a sample. Different chemical groups present in the sample absorb or emit different amounts of energy as they are excited by incident infrared radiation. FTIR records the changes in the absorption and reflectance of infrared radiation and creates an absorption or transmittance spectrum which ranges 4000 to 500 wavenumbers (cm\(^{-1}\)).

Each chemical compound generates a unique spectral fingerprint which is generated from the various groups of atoms present in the sample. For instance, methyl (CH$_3$) groups, carboxyl groups (CO-OH), and carbonates (CO$_3$), all generate unique variations in the spectral output generated by the FTIR instrument. Typically each group of atoms will generate various wavenumbers, intensities, and shapes. This unique fingerprint can be read and interpreted to deduce the chemical components present in the sample.$^{61}$ FTIR spectroscopy is best used to for qualitative analysis for organic and inorganic materials. The simpler the compound, the easier it is to identify the fingerprint of the compound. Organic examples include carbohydrates, colorants, natural resins (can be hard to differentiate), oils and fats, proteins (another difficult case), synthetic resins, and waxes. Inorganic examples include corrosion products, minerals, pigments, fillers, stone, glass, and ceramics.

FTIR was used on four samples of the inset. Sample 1 was a section of black symbol inset; sample 2 was a section of red strip inset as a road; sample 3 was a section of green strip inset as a road; sample 4 was a section of black letter inset. Samples 1 and 4 were found to be polymethyl methacrylate. Samples 2 and 3 were cellulose acetate butyrate.

(3) Samples 1 and 4 – Polymethyl Methacrylate

Polymethyl methacrylate has four characteristic bands (see Appendix C for spectra):

- 3030-2930 cm$^{-1}$ indicates the aliphatic stretches for C-H bonds,
- 1730 cm$^{-1}$ peak indicates the carbonyl bond of the ester,
- 1500-1440 cm$^{-1}$ stretch shows the methyl group deformations,
- the region between 1195-1140 cm$^{-1}$ indicates the C-O-C stretch of the ester.

The specific absorption region that distinguishes polymethyl methacrylate from other

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Acrylates is the double peak in the methyl group deformation stretch.

Polymethyl methacrylate is known as acrylic and also under its tradenames such as Perspex, Lucite, Plexiglas, and Diakon. It was synthesized in the early 1930s and manufactured as cast sheet material. It was fabricated into various shapes by thermoforming, machining and engraving. This polymer is extremely resistant to moisture, light, and biological growth and is, therefore, recommended for exterior uses. It may undergo stress crazing as a reaction to certain chemicals; it is resistant to ethanol and isopropyl alcohol.62

(2) Samples 2 and – Cellulose Acetate Butyrate (CAB)

The FTIR spectra for both samples were matched with CAB standard. The characteristic bands of absorption are:

- 3490 cm\(^{-1}\) for the \(-\text{OH}\) stretch,
- 3000-2850 cm\(^{-1}\) for the aliphatic \(-\text{CH}\) stretch,
- 1750 cm\(^{-1}\) for the carbonyl stretch,
- 1500-1350 cm\(^{-1}\) for the \(-\text{CH}\) bond deformation,
- 1250-1050 cm\(^{-1}\) for the C—O—C stretches.

The spectrum for CAB is distinct from cellulose acetate due to the double peak in the \(-\text{CH}\) bond deformation stretch and the broad peaks in the C—O—C stretch.

CAB like cellulose acetate is a thermoplastic resin known also as butyrate. It is a modified version of its predecessor cellulose acetate. Unlike acetate, CAB is tougher, resistant to UV rays, and has better weathering characteristics. It has a glossy appearance and is transparent. However, it is dissolved by chlorinated solvents, aromatic hydrocarbons, alcohols and ketones. CAB is generally used for tubing because it is

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malleable and formable. Its glossiness, clarity, and workability make it an ideal product for decoration.

In the case of the New York State Pavilion, CAB was preferred to represent long linear elements because CAB can be easily adapted to curves. Because methyl methacrylate is more prevalent as stiff sheets, it was easier to cut symbols and letters.

The material analysis confirmed the composition of both terrazzo samples. Bone black and whiting were identified using microscopy. Bone black was used even though NTMA specifications recommend the use of mineral pigments. Bone black is a pigment that is comprised of 10% carbon content and 90% phosphorus. Although it is sometimes grouped with organic pigments, black bone retains many of the characteristics associated with mineral pigments due to its high phosphorus content. Identification of the metals concurred with the NTMA specifications. The identification of the plastic inset was essential in determining the appropriate treatments. The thermoplastics used have very different properties, including reactivity to various solvents.

The identification of the materials used for the production of the pavement allowed for the selection of suitable treatments to apply to restore the floor, keeping in mind the various properties of these materials.
CHAPTER 5
LITERATURE REVIEW OF TREATMENTS

This chapter is a summary literature review of works published on the conservation of mosaics and related floor materials during the past 20 years. The same treatments have been applied throughout this period and there is a general consensus among mosaic conservators on the appropriate treatments. This chapter also includes a review of concrete restoration techniques. Restoration of concrete masonry has been the subject of recent publications. Specifications for the treatment of terrazzo were derived from maintenance manuals provided by the National Terrazzo and Mosaic Association and various journal articles. There is very little work published on the conservation of terrazzo by professional conservators.

I. Cleaning

A. Initial Cleaning

For mosaics, a water/alcohol mixture or a neutral surfactant with water are efficient in removing superficial dirt and concretions using brushes, dental picks, scalpels and spatulas. Non-ionic detergents such as Synperonic N® by Uniqema remove atmospheric dirt. A tension-active quaternary ammonium salt, such as Desogen® by Ciba-Geigy, can be used to clean superficial biological growth.

65 Note that Synperonic N which is similar to Triton X-100 is a carcinogen. Both are no longer recommended. Synperonic A7 and Triton XL-80N have replaced these products.
67 Luca Demitry, “Misure Preventive di Conservazione in Situ di Mosaici Pavimentali,” in Mosaics no. 5, p. 65.
The NTMA specifies neutral cleaners (between pH 7-10) and ample water to remove superficial dirt and dust. It is important to keep the floor wet during the entire cleaning procedure to avoid incrustation of more dirt. Soft brushes, mops, and sponges are recommended. For terrazzo with Portland cement paste, all-purpose cleaners or soaps containing water soluble, inorganic, crystallizing salts, or harmful alkali or acids should not be used. Highly basic or acidic products may cause the paste and the aggregate to dissolve. Oily soaps should not be used as oil and waxes may cause a discoloration of the terrazzo and trap more dirt. Surfactants should not emulsify too much as this will cause the floor to be slippery.\textsuperscript{68}

**B. Stains**

Staining is the result of the introduction of foreign materials into a substrate. Removing stains necessitates the identification of the composition of the staining agent in order to apply the appropriate stain remover. For terrazzo, water-based stains can be removed with custom made removers; oil-based stains are removed with a cotton cloth and soap; tobacco with trisodium phosphate, chlorinated lime and a tale poultice; ink with sodium perborate and water.\textsuperscript{69}

**C. Salts**

Rising salts and carbonaceous deposits may form a film on the surface of calcareous pavements. For mosaics, poulticing is generally recommended by specialists. The poultice may include cellulose pulp, clays (sepiolite), carton pulp, and weak solvents. If such poultices are not effective, micro-abrasion can be performed.\textsuperscript{70,71}

\textsuperscript{69} Johnson, “Terrazzo,” p. 239.
\textsuperscript{71} If preliminary consolidation is required, 1-5% consolidant may be added to the poultice according to Paolo Mora, “Conservation of excavated intonaco, stucco, and mosaics” in *Conservation of Archaeological Excavations: with particular reference to the Mediterranean Sea* (ed. Stanley Price, Rome: ICCROM, 1984), p. 100.
For concrete based pavement, the carbonation of the pavement and the attack of chloride ions may form a white incrustation on the surface and increase the rate of corrosion of the steel reinforcement (this will be discussed in a subsequent section). Carbonation occurs when carbon dioxide reacts with the calcium hydroxide and calcium silicate hydrates present in the concrete to form calcium carbonate. Chloride ions infiltrate concrete in aqueous solutes by diffusing through the pores of the substrate. Both phenomena cause the metal reinforcement in the concrete to corrode: carbonation lowers the alkali environment that protects the metal from corroding and induces chloride ions to attack the steel. Traditionally, removal of contaminated concrete has been preferred; however, when aesthetics and design are important, it is possible to resolve this problem with cathodic protection, chloride extraction and/or realkalization of the concrete.72

Cathodic protection occurs when a small current generated by a sacrificial material that will corrode easily is applied to an anodic site such as a metal like steel in reinforced concrete. Realkalization can occur without removing the superficial carbonated concrete layer and is an application of electrolysis. A current is applied between a temporary mesh that is placed at the surface and the reinforcement within the concrete. This allows water to migrate through the capillaries and restore an alkali environment around the steel. Chloride extraction is also based on electrochemistry and aims to attract the chloride ions to the surface of the concrete.

D. Biocides

The selection of a biocide is specific to the composition of the substrate. The biocide will have different effects on the substrate depending on its mineralogy and the environment.73 Herbicides may deeply affect the color and surface of the substrate.

Chapter 5

Treatment Literature Review

One of the first steps in choosing a biocide is to determine the type of biological growth that is present on the substrate (algae, fungi, bacteria, lichen, etc…). Each treatment will target a specific type of organism. Commercial products such as Lito 3® (Ciba-Geigy) and Karmex® (Du Pont) were used as mild herbicides that are efficient on bacteria and lichen but left white residues on the substrate. Peptide 5® (Patent N.1134 by the Consiglio Nazionale delle Ricerche, Italy) and Velpar® (Du Pont) were more efficient on photosynthezing organisms.74

A study on the effects of glyphosate based herbicides such as Round Up® (Monsanto) was performed on various types of stone and brick masonry.75 Glyphosate is one of the most commonly used herbicides in the United States. It is a weak organic acid with low vapor pressure and high solubility in water, and is non-selective (i.e. is reactive on all types of plants) and post-emergent (i.e. can be planted after a plant sprouts). Acidic glyphosate has extremely adverse effects on calcareous stones and mortars causing carbonation, chromatic changes, surface loss, formation of insoluble salts and salt deposits.76 As a result of Dewey’s study, it was found that mechanical removal of plants before they reach maturity was the best option to avoid roots damaging masonry units.

II. Consolidation

Mora in his article on the conservation of wall paintings and mosaics provides several guidelines for consolidation. Consolidants must have a deep penetration into a substrate.77 The consolidating mixture needs to have good evaporation rate. When the substrate is saturated with water, it is important to use water immiscible solvents such as xylene or chlorothene. The concentration of consolidant should not exceed 10%. The

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74 Isotta Roncuzzi Fiorentini, “Nettoyage et consolidation des mosaïques de pavements” in Mosaics no. 4, p. 208-9.
applications should be repeated at low concentration rather than a single application at a higher concentration.

A. Consolidation of Friable Edges

In mosaic conservation, the general trend for consolidation of friable edges of lacunae was typically done with an acrylic resin such as Paraloid B72® in an organic solvent (e.g. Chlorothene) or Primal AC33®. Presently, consolidation of outdoor mosaics is shifting away from these acrylic resins. In some cases, other types of consolidants have been used such as lime mortars, vinyl resins, or silanes. Consolidants should allow proper water vapor transmission through the substrate and should increase the mechanical strength of the substrate; however, they should not have excessive mechanical strength.

B. Grouting

Grouting is used to provide adhesive and cohesive properties to a substrate. An appropriate grout should be identified based on its injectability (viscosity), its mechanical strength, porosity, shrinkage rate and the amount of soluble salts it carries. Grouting can be used for either structural repairs, filling small voids, or for reattachment.

From the literature reviewed for grouting in the conservation of mosaics, there seems to be a shift from the use of cement-based grouts to lime-based grouts that are more compatible with the lime-based nucleus. Cement was not found to be compatible with the original because it is mechanically too strong and too impermeable. Epoxy resins

78 Paraloid B72® is known as Acryloid in the United States. Primal AC33® is known as Rohplex AC-33 but has been replaced by a similar acrylic emulsion by Rohm and Haas.
are not recommended for consolidating mosaics with a lime nucleus because of their hydrophobic qualities and their excessive mechanical strength when compared to lime mortars. New grout systems were formulated such as lime/casein, lime/synthetic resin emulsion, synthetic resin emulsions, and thermosetting synthetic resins. Synthetic resin emulsion such as polyvinyl acetate or acrylic co-polymers provide adhesive strength to the substrate but may form impermeable layers. Formulations that are more compatible with the substrate include hydraulic lime with added pozzolana such as diatomaceous earth or brick powder and a fluidizer.

Epoxy resins and Portland cement seem to be compatible in the case of terrazzo where the substrate is cementitious. Formulations that combine cement with added polymers can achieve better cohesion especially within the smaller voids of the substrate in the case of structural grouts.

NTMA recommends using sealants to consolidate cracks. Cracks may also be filled with polyester resin.

III. Compensation

Lacunae are usually filled with material compatible with the rest of the substrate. The in-fill mortar is matched in composition to ensure that porosity and water vapor transmission are not significantly altered. In some cases, the mortar is pigmented to match the area that it is integrating. Where there is incompleteness in design, the infill

85 Ibid.
88 See section V on sealants.
89 Frederick M. Hueston, Caring for your Terrazzo (Longwood, FL: National Training Company, 1997), p. 45.
is kept white and the design is painted on or *tesserae* are loosely placed to complete the form.\(^{90}\) When original loose *tesserae* have been found, they are placed back in context on a new bed of mortar. It is possible to find that the *tesserae* are carved into the in-fill and then painted over to match the colors around it.\(^{91}\) Reattachment of large sections of *tesserae* still attached to the *nucleus* may be done with adhesives such as vinyl resins or epoxy resins in small quantities.

In the case of terrazzo, it is usually advised to replace whole segments contained between dividers with new in-fill terrazzo that is matched in composition with the original terrazzo.\(^{92}\)

### IV. Concrete Reinforcements

As mentioned previously, cathodic protection, realkalization and chloride extraction are efficient in protecting concrete reinforcements from corrosion. Other methods are possible such as the use of corrosion inhibitors. These inhibitors are admixtures that can be applied to the concrete and infiltrate the substrate or can be injected by grouting. Admixtures such as calcium nitrite form stable passive films on the reinforcement, protecting it from further chloride ion attack.\(^{93}\) The use of such inhibitors is fairly new and the performance of the concrete after treatment with these admixtures has not yet been studied. This method seems to be less expensive than the electrochemical methods, retards ingress of further corroding agents, and protects the steel reinforcement.\(^{94}\)

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\(^{92}\) Johnson, “Terrazzo,” p. 239.


V. Sealants and Water Repellents

Sealants are generally not recommended for mosaics as they would interfere with the permeability of the substrate and also darken the tesserae. In the case of newly poured terrazzo, it is essential to coat the surface with a sealant to in-fill voids between the aggregate and protect the carbonaceous paste from weathering or being attacked by a highly acidic or alkali environment.

In the case of concrete based materials, continuous coatings can put a barrier between the substrate and harsh environmental conditions and reduce the ingress of corroding or damaging agents. Sealants will also retain vivid colors in the case of pigmented terrazzo.\textsuperscript{95} Coatings in general, although cheap and easily applied, can change the appearance of the terrazzo by giving it a waxy appearance, or being subject to UV degradation. Strippable coatings such as acrylics, styrenes and polyethylene may damage the terrazzo in the long term as their removable with chemical agents may etch or harm the terrazzo topping. Permanent coatings such as epoxies, polyurethanes, bituminous systems are effective water repellents but are not recommended for terrazzo as they are difficult to remove.\textsuperscript{96} Penetrating sealers are good hydrophobic sealants. Silicon-based water repellents are most effective. Silanes and siloxanes are finer than other silicone resins and penetrate the substrate deeper. These repellents must be applied on a dry, alkali substrate.\textsuperscript{97} Penetrating sealers require few applications and are durable and resistant; however most of them are toxic and hazardous for the environment.\textsuperscript{98} Waxes, laquers, shellacs and varnishes should not be applied.\textsuperscript{99}

From this literature review, it is possible to see how conservation treatments applied

\textsuperscript{95} NTMA, \textit{Specifications and Technical Data}, p. 5d.
\textsuperscript{96} Hueston, \textit{Caring for your Terrazzo}, p. 32-3.
\textsuperscript{97} Ibid.
\textsuperscript{98} Hueston, \textit{Caring for your Terrazzo}, p. 36-7.
\textsuperscript{99} NTMA, \textit{Specifications and Technical Data}, 5d.
to classical mosaics can be adapted to the cleaning, stabilization and consolidation of the terrazzo pavement at the New York State Pavilion. Based on the identification of the materials used for the construction of the floor and the products and techniques used for the restoration of mosaics as well as the new techniques developed for the restoration of concrete, informed decisions were made to select the appropriate treatments to apply to the pavement.
CHAPTER 6
TESTING PROGRAM

To provide a better understanding of the extent of the treatments, the panel was divided in half. The left side, which was mostly plain terrazzo, was left untouched. The testing program was performed on the right side of the panel which contained plain and map terrazzo.

I. Dirt Removal

This first step took place in two phases. The panel was first swept clean of loose dirt with stencil brushes. Large incrustations, especially accumulated in the cracks and areas of loss, were loosened with a dental pick and scalpel. Water was not sufficient in removing some of the incrusted dirt; therefore a 10% Triton X-100 solution was prepared to remove these tenacious areas. Triton X-100 is a non-ionic surfactant that forms reactive micelles that are readily able to pick up dirt particles. A rigid stencil brush was used to apply and manipulate the solution as a wet foam. Minimal water was used to rinse the solution from the surface to avoid exposing the divider strips to moisture.

The results were successful as the dirt was entirely removed and the Triton solution did not react with the plastic insets.

II. Paint Removal

A. Solvent testing

Several layers of red and gray overpaint cover nearly 95% of the panel. To identify

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100 Triton X-100 is potentially a health hazard as it contains octyphenol, which is an xenoestrogen and interfere with the body’s endocrine system. Triton XL-80N is a good alternative to Triton X-100. It is a non-ionic surfactant made from a primary alcohol alkoxylate.
the solubility parameters of the overpaint and dry susceptibility of the plastic insets to organic solvents and alkaline reagents, testing was conducted with solvents from a wide range of chemical groups to identify which type would be successful in dissolving the paint. Methanol, ethanol, isopropyl alcohol, acetone, methyl-ethyl ketone, xylene, toluene, mineral spirits, and ammonium hydroxide were tested on 1 square inch sections of the panel. It was found that acetone, methyl-ethyl ketone, methanol and ethanol removed the overpaint successfully. Xylene and toluene were partially successful while mineral spirits and ammonium hydroxide did not swell or dissolve the paints (Figure 27). Upon testing these solvents on the white, black and green plastic insets, it was found that methyl-ethyl ketone and ethanol did not affect the plastic; methanol partially dissolved the cellulose acetate butyrate while acetone reacted greatly with the inset. Reactions included color bleeding and softening of the plastic.

From these tests it was concluded that methyl-ethyl ketone and ethanol were suitable solvents to be used to remove the overpaint safely. Methanol was also acceptable.

Figure 27: Solubility test.
B. Commercial Paint Strippers

Several criteria were established when searching for commercial paint strippers. The stripper needed to be a poultice with methyl-ethyl ketone or ethanol as a base solvent. It was important that the paint strippers were not acidic or alkaline as this would harm the terrazzo surface. Finally, the use of water as a rinsing agent was to be minimal to avoid further corrosion of the metal dividers.

Prosoco Sure Klean Fast Acting Paint Stripper® and Peel Away 7® by Dumond Chemicals were selected as compatible with our search criteria. Prosoco’s product is a thixotropic stripping agent designed to remove paint coatings, graffiti and epoxies from terrazzo floors and other masonry surfaces. It is of a neutral pH and requires minimal rinsing. Its reactive components are methanol, dichloromethane, amine, xylene and alcohol. Peel Away 7® was selected because of its easy application as a gel that is covered with a fiber cloth, and because it did not present methylene chloride or alkali substances. Furthermore, it is recommended for masonry surfaces coated with epoxies and paint. The recommended dwell time for Prosoco’s product was 15 minutes, whereas that of Peel Away ranged between 2 and 24/48 hours.

Both products were tested on 2 areas of the panel. Peel Away 7® was tested on four areas where plastic insets were present: one area of red paint for 90 minutes, one area of red paint and one of gray paint for 24 hours; and one area of gray paint for 90 minutes. Prosoco was tested on an area of red and gray paint for 15 minutes and on another area of red and gray paint for 45 minutes.101

When removing the paint strippers it was apparent that both products removed the paint successfully. However, Peal Away 7® was too aggressive on the plastic insets.

101 These dwelling times were based on the specifications given by the manufacturer and on observations of the on-going reaction while testing.
Where the emulsion had stood for 90 minutes, the CAB was deformed such that the metal divider was now apparent, and the green plastic was discolored to black. Where this same product was left on the surface for 24 hours, the plastic dissolved (Figures 28-29). The Prosoco Sure Klean Fast Acting Stripper® was far gentler with the plastic insets. The plastic was intact where the stripper had a dwell time of 15 minutes (Figure 30). Based on this test, it was decided to use Prosoco Sure Klean Fast Acting Stripper® on the remainder of the pavement. This stripper is also marketed as environmentally safe.

Other paint removal methods including micro-abrasive cleaning were considered but could not be tested during the time allotted. Micro-abrasive would be more useful as it will not alter the plastics chemically.

Figure 28: Peal Away®7 applied to red overpaint. Left: 90 minute dwell time; Right: 24 hour dwell time.
Figure 29: Peal Away® 7 on gray overpaint.
Left: 90 minutes dwell time; Right: 24 hours dwell time.

Figure 30: Prosoco Sure Klean Fast Acting Stripper® on gray and red overpaint.
Left: 45 minutes dwell time; Right: 15 minute dwell time.
C. **Overpaint Removal** (Figure 31)

Based on the preliminary tests, the Prosoco Sure Klean Fast Acting Stripper® was applied to the panel. A first application resulted in most of the overpaint being removed. However there was some residue especially in areas where the cementitious paste had eroded and the paint was trapped in the interstices of the aggregate. The paint stripper was applied a second time. A stencil brush was used to force the gel into these interstices and activate the reaction. A solution of 50% ethanol-50% deionized water was used to clear the stripper away. After this second application, white tenacious residues were still visible on the plastic insets. A second solvent test as performed above identified methyl-ethyl ketone as the only solvent capable of removing these white residues. Although methyl-ethyl ketone is not recommended for CAB, it was efficient in removing the residues. However, several hours after the application of methyl-ethyl ketone, a chromatic change occurred on the CAB green insets resulting in the plastic to turn dark green-black. The polymethyl acrylate insets were cleaned successfully without any adverse effects.

![Figure 31: Results of paint stripping.](image)

White residue on plastic inset. Overall good removal of paint from terrazzo.
D. Final Cleaning

A solution of 2% Orvus® by Ivesco in a 50% ethanol-50% deionized water solution was used to remove dirt that had been trapped between the overpaint and the surface as well as residues from the paint removal. The solution was applied with a stencil brush and manipulated as a wet foam. Nebulized deionized water was used to wash off the solution.

III. Compensation

Based on the literature and on the nature of the substrate, a cement based mortar was chosen to fill areas of loss on the panel. Based on the conditions assessment map done in AutoCAD®, areas of moderate loss (i.e. that are equal or superior to 1/8 inch) were to be filled with mortar. Areas of partial loss (especially near the plastic insets) were to be consolidated with fill mortar.

The product selected to prepare the mortar was Jahn Restoration Mortar M90® (Cathedral Stone® Products, Inc.), which is recommended for horizontal and vertical concrete repairs. This mortar is cementitious and mineral based. It is vapor permeable, of a neutral pH, and is resistant to carbonation and salt crystallization. The active ingredients for this mortar are: calcium oxide, tricalcium and dicalcium silicates, tricalcium aluminate, and silicon dioxide. It is white to pastel in color and the aggregate is fine.

A. Mortar Formulations

Three types of fills were identified:

- areas of moderate loss in the white pigmented terrazzo,
- areas of partial loss in the white pigmented terrazzo,
- areas of moderate loss in the black pigmented terrazzo.

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102 Orvus® is a gentle soap with a pH of 7-8.
The color of the M90 mortar was lighter than the color of the terrazzo. A sand filler was chosen from the sand library of the Architectural Conservation Lab (ACL) at University of Pennsylvania to pigment the mortar and match its grain to the exposed coarse aggregate of the terrazzo. The filler chosen was WR Regional Mining Division, New White Sand, S19. A sand filler was chosen rather than marble aggregate because the aggregate would have been too large and made the mortar too weak. The filler contained pebbles and was therefore sieved to separate the very coarse aggregate (superior to 2.35 mm retained in the #8 mesh) from the finer particles. The finer particles were kept to add to the mortar formulation. The finer particles gave a yellow and warmer hue to the mortar. Removal of the large aggregate ensured better cohesion of the mortar with the terrazzo substrate. This also changed the binder-to-aggregate ratio of the Jahn mortar by making it weaker. The ratios matched the ratios found through material analysis.

For the black area of moderate loss, bone black was use to pigment the mortar. Sand from the Martin Inc. stone quarries was selected from the ACL sand library and used as a filler. This sand was dark grey and generally fine with little coarse material.

Two mortar formulations were prepared for the white terrazzo (see Table 3). Mortar A was used for areas of moderate loss more than 1 square inch in coverage. Mortar B was applied to areas of moderate loss covering less than 1 square inch in coverage and areas of partial loss. Mortar C was prepared to match the black terrazzo.

| MORTAR A        | 1 part Jahn M90  
|                 | 2 parts New White Sand, S19 (< 1.18mm) |
| MORTAR B        | 1 part Jahn M90 fines (< 600μm)  
|                 | 3 parts New White Sand, S19 (< 600μm) |
| MORTAR C        | 2 parts Jahn M90  
|                 | 1 part Martin Inc. stone quarries sand  
|                 | ½ part Bone Black |

Table 3: Mortar formulations for fills\textsuperscript{103}

\textsuperscript{103} Note that Jahn M90 is partly comprised of sand; therefore, the effective ratio of mortar A is 1 part cement to 3 parts sand and of Mortar C is 2 parts cement for 3 parts sand. In mortar B, the sand was sieved and collected in mesh #16 and #30, therefore the effective ratio is 1 part cement to 2 parts sand.
B. **Application** (Figure 32)

Areas to be filled were dampened with nebulized water to clean and reduce surface suction. The mortar was applied using a microspatula and a wooden swab. For areas of moderate loss only, the fills of mortar A were leveled with the surface of the terrazzo. Small gaps between the plastic insets and the substrate (marked as areas of partial loss) were packed with Mortar B. Areas of partial loss were considered to shallow and were, therefore, not filled as the mortar would have spalled from the surface of the terrazzo. For areas of overlap between moderate and partial loss, it was important not to feather the edges of the fill in order to increase the adhesion of the mortar to the substrate. Mortar A was used to fill the deeper areas of recess. After the mortar was applied, the terrazzo

![Figure 32: Examples of mortar application.](image-url)
was misted with water and tented. Misting was repeated every 24 hours while the mortar cured for 72 hours. Once the mortar cured, a second layer of fine Mortar B was added to areas of overlap between moderate and partial loss. These recesses were hence leveled with the surface of the terrazzo.

Once cured, a light film of mortar residue formed on the plastic insets (mostly on the polymethyl methacrylate) because the mortar was not properly washed off before curing. A solution of 5% glacial acetic acid partially removed this residue.

IV. Adhesive Repairs

A. Reattachment

The upper right corner of the panel presented two cases of detachment. In one case, a portion of the terrazzo with the underbed was detached at the level of the plywood. In the second case, several fragments of the terrazzo bedding had fractured at the surface of the underbed. In both cases, Sikadur® 31, Hi-Mod Gel was used for reattachment. Sikadur® 31 is a low viscosity, high modulus, high strength and moisture tolerant epoxy adhesive whose active ingredients are epoxy resin, calcium carbonate, silica, nonyl

![Figure 33: Two different cases of reattachment using Sikadur®31 Hi Mod Gel](image)
phenol, benzyl alcohol, aromatic hydrocarbon blend, cyclic and aliphatic amines. It
is recommended for adhesion to concrete, masonry, metals, wood and most structural
materials. Both products were chosen based on their specifications, composition and easy
application.

In the first case of reattachment, Sikadur 31® was applied to the exposed plywood
to create a rough surface to anchor the detached fragment. Once the resin had set, a slurry
of mortar B was applied and left to cure for 24 hours. After this, the resin was applied a
second time to the fresh mortar as well as the sides of the detached fragment which was
set onto the resin for adhesion (Figure 33).

In the second case, the resin was applied to the underbed substrate and the underside
of the terrazzo fragments. The pieces were set onto the bed of resin and left to set
(Figures 34-35).

B. Grouting

Because the cracks identified on the surface of the terrazzo are less than ¼”, it
was important to select a very low viscosity and high-strength grout. Sikadur® 52 is a
moisture tolerant epoxy injection adhesive that is used for injection. Its active ingredients
are epoxy resins, nonyl phenol, aromatic hydrocarbons and aliphatic amines. Its
200 cps viscosity makes it ideal to consolidate the cracks present in the panel. The grout
was applied using a syringe and 1 ½mm size needle into major cracks (indicated in the
conditions assessment in Appendix B), areas of deep loss where the green plastic inset
that acts as boundary between the plain terrazzo and the map terrazzo has disappeared.
Where the second case of reattachment was done previously, Sikadur® 52 was injected to
fill the cracks between the fragments of superficial terrazzo. The fragment were therefore
not only reattached to the underbed substrate but were now bonded to each other. The
Sikadur® 52 injection grout did not bleed or leave any traces on the terrazzo.
Figure 34: Reattachment of three terrazzo fragments with Sikadur®31 hi-mod gel injection.

Figure 35: Grouting of cracks between reattached fragments and panel, followed by fills with Mortar A.
### Chapter 6

**Testing Program**

#### V. Summary of Results

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Products used</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superficial Cleaning</td>
<td>Triton® X-100 (Sigma chemicals)</td>
<td>Positive. Product is a health hazard. Triton®XL-80N is a good replacement (Dow Chemicals).</td>
</tr>
<tr>
<td></td>
<td>Orvus® (Ivesco)</td>
<td>Positive. Neutral, non-ionic surfactant can also be used instead of Triton® products.</td>
</tr>
<tr>
<td>Paint Removal</td>
<td>Peal Away® 7 (Dumond Chemicals).</td>
<td>Good stripping power. Not sensitive to plastic insets. Long dwelling time: minimum 90 minutes.</td>
</tr>
<tr>
<td></td>
<td>Sure Klean® Fast Acting Stripper (Prosoco)</td>
<td>Requires 2 applications for total paint removal. Sensitive to plastic insets Need to increase dwelling time to 30 minutes.</td>
</tr>
<tr>
<td>Adhesive repairs by grouting</td>
<td>Sikadur® 52 (Sika Corporation)</td>
<td>Very low viscosity, Clear liquid, high strength, quick set. Penetrates deep into substrate and into very fine cracks.</td>
</tr>
<tr>
<td>Compensation</td>
<td>Jahn M90 (Cathedral Stone)</td>
<td>Good adhesion and compatible bonding strength with substrate. Formulations established in Table 3 should be used unless a custom made mortar is made to match pigment of substrate. May discolor plastic inset if not properly cleared.</td>
</tr>
<tr>
<td>Reattachment</td>
<td>Sikadur®31 Hi-Mod (Sika Corporation)</td>
<td>Color of resin may not be adequate, however because areas of attachment are usually concealed, this may not be a problem. Product has very high bonding strength, is quick setting and can be applied to the various materials present in the panel.</td>
</tr>
</tbody>
</table>

*Table 4: Results of testing program.*
Chapter 6

Testing Program

VII. Recommendations

Based on the literature review and the treatment program performed, the following recommendations can be made.

First and foremost, detailed documentation of the site should be undertaken next. In the event the site is not subject to a full conservation plan, documenting the pavement will be key in attesting to the cultural significance of the site as an outstanding example of Pop Art. ¹⁰⁴

If funds are unavailable, temporary stabilization and protection of the site are imperative. The active state of decay of the pavement due to constant exposure to inclement weather must be reduced. A temporary shelter such as the ones constructed in Petra or in Paphos should be considered. According to the reports written on these sites, these structures are light, cheap, and resistant to light and rain. Another solution would be to bury the pavement until proper care is possible. The metal components of the pavement may be sensitive to reburial and corrosion may be accelerated. Burial would follow the backfilling techniques employed by mosaic and wall painting conservators, which involve the use of water vapor permeable materials such as geotextile, ¹⁰⁵ and insulating salt free soil or sand. ¹⁰⁶ Burial will protect the pavement from the weather, vandalism, and more damage from the current users of the site.

In the case that the pavement can be fully treated, lifting the floor panel by panel should be considered. Rising damp and water infiltration have contributed to the rotting

of the plywood, the dampening of the sand and the corrosion of the metal elements. The introduction of a new support such as aluminum alloy honeycomb panels\textsuperscript{107} will arrest the rising damp and create a better structural support for the pavement.

Once removed, the panel should undergo light cleaning with a neutral, non-ionic surfactant such as it is described in the literature and performed on the sample panel for this project. Removal of overpaint should either be done with a custom-made chemical stripper or by micro-abrasion. Because of the presence and the sensitivity of the plastic insets, a customized chemical stripper should follow the solvent tests performed in this study. Micro-abrasives should be tested on the insets and the terrazzo as the plastic will probably scratch if the hardness of the abrasive is too high on Mohs’ scale. Micro-abrasion should be considered because it is less expensive than using a chemical stripper.

Traditional herbicides containing glyphosates such as Round-Up\textsuperscript{®} should not be considered as the cementitious nature of the floor is too sensitive to these chemical. Higher plants with deep roots should not be removed mechanically as this will cause more damage to the terrazzo. Shallow root bearing plants should be removed mechanically. Biocides such as D/2\textsuperscript{®} or BioWash\textsuperscript{®} by Prosoco are quaternary ammonium salts that can be used to remove algae and lichens instead of Desogen\textsuperscript{®}, which has been discontinued. Further study should be done to identify the types of organisms that are present on the pavement in order to select an appropriate biocide.

To remedy to corrosion problems, two of the methods presented by Kevin Davies seem to be appropriate. The first includes making tradition mortar repairs followed by electro-chemical realkalization with a coating. This repair option is anticipated to be maintenance-free for 20 years. It retards the ingress of salts and acidic solutions that

contribute to the carbonation and salt incrustation in concrete. Sealants will not alter the visual appearance of the floor and will reduce friability of the substrate surface.\textsuperscript{108} The second method, which is also less expensive but has not been fully researched, consists in making traditional repairs followed by a corrosion-inhibiting coating or migrating inhibitors. The coatings will not alter the appearance of the floor; they will however affect the reapplication of the inhibitor which should occur every 10 to 15 years.\textsuperscript{109}

For compensations, a cementitious mortar such as Jahn M90 should be formulated according to the depth of the area of loss. In the case of shallow fills, a fine mortar should be used. For deep fills, a coarser mortar with aggregate ranging between 1.2mm and 600\( \mu \)m is adequate. It is important not to apply too much mortar and not to feather the edges of the fill as the mortar will spall after curing. Further study will identify the other pigments used and will therefore be added to Mortar C instead of bone black. Where areas of loss have been filled with concrete, removal of these fills should be considered.

New techniques for cutting concrete such as laser cutting can be useful in removing these fills without damaging the rest of the pavement. Laser cutting can also be used in replicating areas of the map that have been lost including those that were filled with concrete. Laser light may be used to cut and score a wide variety of materials based on drawings rendered with AutoCAD\textsuperscript{®}. The design should be based on a Texaco road map of 1963 that was used to produce the pavement. Based on the material analysis performed in this study, it is possible to replicate the terrazzo mixture and insert the same plastic insets to replicate symbols, letters and numbers. Subtle variations in the replacement panels could achieve visual and structural unity without falsification.

Adhesive repairs should follow the testing program established in this project. The

\textsuperscript{108} Davies, “Conserving Concrete,” p. 136.
\textsuperscript{109} Davies, “Conserving Concrete,” p. 138.
use of epoxy resin is indeed recommended for high bonding strength substrates such as concrete. The Sika Corporation products are excellent products to use for grouting and attachments. The specifications for the products are straight-forward and application is easy and quick. The low viscosity of the grout (Sikadur® 52) is highly suitable for the types of cracks and small interstices found in the terrazzo. The adhesive epoxy resin has a great modulus and bond strength that ensure strong adhesion without compromising the structural strength of the terrazzo.

A water vapor permeable sealant should be applied as specified by the NTMA. This sealant will stop the ingress of water, consolidate friable areas and cracks, fill the vulnerable interstices between the aggregate and reduce surface soiling. As detailed in the literature, penetrating sealers are recommended in the case of terrazzo. Siloxanes and silanes are the most appropriate because of their deep penetrating properties, high vapor permeability, and matte appearance.

VII. Conclusions

This research project has provided a better understanding of the history and significance of the terrazzo map pavement of the New York State Pavilion. Although the historical sources regarding the manufacture of the pavement are scarce and incomplete, close observation, material analysis and condition assessment of the current state of the pavement correlated with an overview of historic masonry floors has provided a clearer understanding of the building construction and deterioration mechanisms affecting the terrazzo floor.

The results obtained from the tests that were run are positive overall. The most challenging aspect in selecting appropriate chemical cleaning methods is to choose products that are sensitive to the plastic insets and the terrazzo. Products should be
custom formulated to take into account the variance in the properties of these materials. In the case of overpaint removal, mechanical cleaning with micro-abrasives should be tested as this technique might reduce the risks of altering the plastic. The reattachment and compensation treatments were successful.

The treatment program established for the terrazzo pavement of the New York State Pavilion offers immediate stabilization and consolidation options for the safeguard of this major work of Pop Art from the 1960s.
BIBLIOGRAPHY

New York State Pavilion


Mosaics and Historic Pavements

*History*


*Treatments*


Bibliography


Terrazzo and Concrete Finishes

*History*


Treatments


References


APPENDIX A
LIFTING THE PANEL
Phase 1

The plain terrazzo around the selected panel was cleared using jigsaws.

Phase 2

Separating panel edges from the rest of the pavement. A piece of angled iron was hammered between two metal dividers on the top face of the panel to create a space between two consecutive panels.
Phase 3

A giant rake-like instrument was assembled prior to the lifting: five long strips of iron were bolted onto on a main horizontal strip. Their ends converged to the same point and were bolted to a handle that could be attached to a utility vehicle. The main strip was angled and fit into the space created between the two consecutive panels (top figure).

The rake was attached to a utility vehicle and pulled away from the rest of the map terrazzo.
Phase 4

The area around the panel was cleared of terrazzo debris (top figure). A sheet of plywood was placed in the cleared area. The panel was pulled away from the rest of the pavement onto to the plywood (bottom figure). The plywood and panel system was lifted with a mechanical lift into a car to transport to the Architectural Conservation Laboratory.

All pictures taken by John Hinchman, January 2004.
APPENDIX B

CONDITIONS ASSESSMENT AND GLOSSARY

## I. CONDITIONS GLOSSARY FOR PAVEMENT

<table>
<thead>
<tr>
<th><strong>PLANT INTRUSION</strong></th>
<th>![Image of plant intrusion]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher vegetation and its associated root systems which are present under, within, or atop the terrazzo.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>FRIABILITY/CrackING</strong></th>
<th>![Image of cracking]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dislodging of discreet segments of terrazzo due to active disaggregation of the terrazzo. This has led to partial loss of 1/8” (3mm) or less in depth of the superficial surface of the pigmented terrazzo.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>OVERPAINT</strong></th>
<th>![Image of overpaint]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discoloration of surface of terrazzo due to accretion of layers of paint and tar.</td>
<td></td>
</tr>
<tr>
<td>FILLS</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>Areas where the original terrazzo is missing and where the resulting void has been subsequently filled with concrete.</td>
<td></td>
</tr>
</tbody>
</table>

![Image of Fills](image-url)
II. CONDITIONS GLOSSARY FOR INDIVIDUAL PANEL

**CRACKS**
Linear fractures of variable width and depth visible at the surface of the terrazzo, which may also penetrate into its lower layers. There are three types of cracks observed in the panel:

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Major</strong></td>
<td>Cracks larger than 1/8” (3mm) in width occurring on the surface of terrazzo, usually extending through the entire upper layer of pigmented terrazzo.</td>
</tr>
<tr>
<td><strong>Hairline</strong></td>
<td>Cracks less than 1/8” (3mm) in width occurring on the surface of terrazzo and rarely extending down through the upper layer of pigmented terrazzo.</td>
</tr>
<tr>
<td><strong>Network</strong></td>
<td>A patterned network of fine superficial cracks occurring on the surface of terrazzo often in association with friability.</td>
</tr>
<tr>
<td>DETACHMENT</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>---------------------------------------------------------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Movement or separation of discreet segments of terrazzo or insets.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EROSION</th>
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</thead>
<tbody>
<tr>
<td>Pronounced surface exposure of aggregate due to differential paste loss.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FRIABILITY or FLAKING</th>
<th><img src="image3.png" alt="Image" /></th>
</tr>
</thead>
<tbody>
<tr>
<td>Active fragmentation of the terrazzo that dislodges under finger pressure (usually associated with areas of network cracking).</td>
<td></td>
</tr>
<tr>
<td><strong>METALLIC STAINING</strong></td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>-----------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Brown discoloration resulting from the corrosion of zinc metal dividers and steel frame.</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>MICROFLORA</strong></th>
<th><img src="image2.png" alt="Image" /></th>
</tr>
</thead>
<tbody>
<tr>
<td>Areas of algae, fungi, or lichen growth visible as black or greenish discoloration.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>OVERPAINT</strong></th>
<th><img src="image3.png" alt="Image" /></th>
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</thead>
<tbody>
<tr>
<td>Masking of the original surface of the terrazzo resulting from residual overpaint, tar and coatings.</td>
<td></td>
</tr>
</tbody>
</table>
**LOSS**

Areas of the panel where sections of the terrazzo and/or the insets are missing. This condition can be classified according to depth and surface lost:

- **Partial**
  
  Loss less than 1/8” (3mm) in depth measured in plane with panel surface.

- **Substantial**
  
  Loss of 1/8” (3mm) or more in depth measured in plane with the terrazzo surface.

- **Total**
  
  Complete loss of an individual section or insert leaving an incompleteness of form.

---

![Diagram of Loss Conditions](image)

**Partial Loss**  **Substantial Loss**  **Total Loss e.g. Inset**
<table>
<thead>
<tr>
<th>PITTING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Areas of numerous small, rounded cavities on surface.</td>
</tr>
</tbody>
</table>

![Image of pitting](image.png)
APPENDIX C

EXPERIMENTAL DATA FROM MATERIAL ANALYSIS
Appendix C

Experimental Data

I. X-Ray Diffraction Data
### Appendix C

### Experimental Data

**Input Pattern**

**HSPV AMEL GRAY TERRAZZO**

**NYSP**

Peak search on 29-MAR-0414:59:07

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28 lines in pattern.

**Identified Phases:**

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**Summary Report:**

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**Appendix C**  
**Experimental Data**

**Peak search on 29-MAR-0411:29:55**

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- 5-0586* 113 11/0 77 *Calcium Carbonate / Calcite, syn = CaCO3
  - Ierr:100,200  derr:2.5  Bground:4.2  dmax/min:29.41/1.343

- 74-1811C 12 2/2 94 Silicon Oxide / Quartz alpha = SiO2
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- 13-0192D 20 3/1 7.0 Calcium Carbonate / Vaterite, syn = CaCO3
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* = Obscured  <..<> = Missing  [..] = Previously Removed
Appendix C

Experimental Data

**Appendix C**

Experimental Data

**Input Pattern**

HSPV AMEL UNDERBED COARSE NY
Peak search on 29-Mar-014:31:59

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23 lines in pattern.

Identified Phases:

JCPDS# | SI | ML/X | At% | Identity
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| Ierr:50.150 | derr:2.0 | Bgroun:1.7 | dmax/min:29.41/1.343 |
72-0156C | 37 | 3/0 | 7.3 | Calcium Hydroxide / Portlandite, syn = Ca(OH)2
| Ierr:50.150 | derr:2.0 | Bgroun:1.7 | dmax/min:29.41/1.343 |
37-1485* | 6 | 3/3 | 4.6 | *Zinc Silicate / Willemite, syn = Zn2SiO4
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II. FTIR Data

[Graph showing FTIR data with peaks at different wavenumbers.]
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Appendix C

Experimental Data
Appendix C

Experimental Data

Search results for: PML/A5457 New York State Pavilion, Flushing Meadows, NY sample# 4, black letter inset, scrapings on dc
Date: Tue Apr 13 18:06:54 2004
Search algorithm: Correlation
Regions searched: 3495.26-802.68

---

[Graph showing spectral analysis with peaks and wavelengths]
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