TECHNICALBULLETIN #12

TERRA COTTA

INTRODUCTION

Architectural terra cotta is used for facing walls, ceilings and domes of buildings. Structural terra cotta, another form of the material, is used in structural or fireproofing applications. All terra cotta is made of clay molded, extruded or sculpted into shape and then fired to over 2000 degrees Fahrenheit in a kiln. Terra cotta is available in a wide range of shapes, textures, colors and finishes. Some finishes are designed to replicate natural stone such as limestone, sandstone, and granite. Ceramic glaze coatings are often applied to its surface.

The most widespread use of terra cotta in North America was between 1870 and 1930. Catalogues of standard shapes and profiles were available to building designers. At the turn of the century more than 200 manufacturers were in business. Today, only a few terra cotta manufacturers are in business. Their work is largely custom made for restoration, additions, or new construction.

FEATURES AND BENEFITS

Terra cotta is a durable, weather resistant and fire resistant material. Among its excellent qualities are:

1. Weather resistance
2. Fire resistance
3. Ability to color through glaze coatings
4. Low maintenance requirements

Often used as a substitute for carved stone, terra cotta has several advantages:

5. Lighter weight
6. Lower cost
7. Faster production time, particularly in extrudable shapes

The walls of a terra cotta block are typically 1" to 1 ½" thick with transverse web walls, which help keep the stones shape and also to distribute loads placed on them.

Terra cotta was traditionally set with mortar joints, filled from behind with mortar and brick and tuck pointed with a special mortar after the wall was constructed.

Restoration Investigation Considerations

The prerequisite to any restoration project on an existing terra cotta building is a thorough identification investigation of the conditions causing the problems. These conditions could include manufacturing problems, structural issues resulting in overstress, corrosion of anchorage, and water infiltration. Documentation of building construction should also be researched, including archival sources for original drawings and detailing.

Investigation of terra cotta problems is best conducted by a licensed architect or engineer with experience in the specific problems associated with terra cotta and terra cotta assemblies. A thorough examination of the building exterior reduces the possibility of uncovering additional problems during restoration. It is difficult to evaluate any but the most obvious problems by visual survey. Close-up examination from scaffolding is the preferred method.

Tools commonly used in field and laboratory evaluation processes include the following:

1. Sounding – tapping with a wooden, rubber, or acrylic-headed mallet with unhealthy terra cotta returning a dull, hollow thud.
2. Borescope – optical fiber instrument inserted into hole drilled into wall, to allow examination of buried structural elements. This equipment is limited to hollow core terra cotta.
3. Strain gauges – measuring the extent of compression within the terra cotta veneer through electrical instrumentation.
4. Destructive testing – exploratory openings or probe openings, i.e. removal of veneer stones to allow examination of buried structural or waterproofing elements.
5. Physical testing - of veneer terra cotta samples for absorption rates, compressive strength, and shear strength.

Site documentation commonly includes annotated drawings and photographs. After developing a cataloguing methodology to identify individual stones, prepare elevation drawings noting deteriorated conditions, such as cracking, spalling, displacement, etc.

Manufacturing Problems:

Many current failures on buildings can be traced to the original manufacturing process. Types of manufacturing problems include:

1. Shrinkage poorly controlled during firing, resulting in deformed or improperly sized block. Terra cotta shrinks approximately ¾" per foot during firing, so the block in its green state must be oversized properly to allow for shrinkage and result in a properly-sized finished product.
2. Surface crazing is often the result of swelling of the bisque, which is absorbent. As the bisque grows, the hard but brittle glaze can fracture.
3. Cool cracking – surface cracks can develop when the block is cooled too rapidly after firing.
4. Contamination – blocks and/or glaze can fail due to impurities in the clay, causing cracking and spalling.

Installation Problems

1. Failure to accommodate differential movement or expansion by inserting joints through the massive solid wall construction.

2. Failure to accommodate shrinkage of the structural frame through the massive dead load of the veneer and back-up masonry. In high-rise construction, a terra cotta veneer is often placed in severe compression by dead load compaction of the structural frame.

3. Failure to protect anchors securing the blocks to the back-up masonry or structural frame. These anchors and the structural frame are usually mild steel, which corrodes easily.

4. Failure to properly protect the supporting structural steel members from corrosion.

5. Poor workmanship that causes irregular movement of water or stress in the terra cotta. Examples include wood shims left in joints between blocks, careless back-pointing of mortar joints, and head joints too thin to allow proper mortar installation.

Maintenance Problems

1. Lack of periodic inspection to catch potentially destructive deterioration at an early and manageable stage.

2. Improper use of repair materials. Pointing or patching mortars with high compressive strength and density can cause spalling or cracking of the repaired blocks. Coatings that entrap moisture can cause surface failure of adjacent glaze and/or clay body.

3. Destructive cleaning and/or surface preparation processes can abrade the surface and expose the bisque to greater water penetration

4. Improper sealant specification and application can allow excess moisture to penetrate the assembly.

5. Biological growth (i.e. ivy and mosses) feed off the lime in the mortar joints, can allow excess moisture to penetrate the open joints, and maintain a moist environment for ongoing decay.

Weather Problems

1. Freeze-thaw action in colder climates, where penetrated water expands in volume upon freezing. This can cause overstress spalling and cracking.

2. Thermal shock in warmer climates, where sudden cooling by rain on hot days results in rapid shrinkage. This can also cause overstress spalling and cracking.

3. Acid rain can cause erosion of glaze coating and block surface.

4. Humid environments can promote biological growth.

5. Airborne pollutants such as salts in coastal areas can damage through re-crystallization.

6. Glaze spalling can also be caused by soluble salts from other elements of construction (i.e. brick, concrete, mortar, etc) migrating to the surface and crystallizing under the glaze.

Restoration Design Considerations

After gathering the investigation information, a restoration design is developed. This design is based on correcting the sources of deterioration discovered during the investigation. As these are restoration repairs, always consider the least intrusive methods that will effectively correct the source of the damage.

A common first step is performing at least some cleaning of the terra cotta, either to test the viability of general cleaning or to uncover additional deterioration hidden under soiling.

Cleaning

The purpose of cleaning is to remove soiling material, yet not damage the terra cotta. Many cleaning agents contain hydrofluoric acid that can damage terra cotta and, noticeably, highly vitrified glazes. However if used under strict supervision, following careful trials, they can also be effective in removing heavy dirt deposits. Their use is often following the use of alkaline cleaners.

Considerations include:

1. The cleaning process is affected by many variables; surface and air temperatures, concentration, wind, dew point, dwell time, etc.

2. Perform cleaning samples to determine the best method and to use as quality control.

3. Always start with the least aggressive methodology that gives the required results, following any applicable historic preservation guidelines.

Cleaning methods to consider:

- Low pressure water
- Tri-Sodium Phosphate solutions
- Diluted ammonium bifluoride solutions
- Diluted mild anionic detergents
- Gentle hand-cleaning using above solutions and soft bristle brushes

Cleaning methods to avoid:

- Steam cleaning
- High pressure water
- Abrasive cleaning
- Acidic cleaning solutions
- Gentle hand-cleaning using above solutions and soft bristle brushes

Pointing

Mortar joints between terra cotta blocks transfer stress and moisture through the wall. Deteriorated pointing causes moisture and stress to concentrate unevenly, often resulting in cracking or spalling. Relief of compression within terra cotta veneer blocks can be affected to a large degree through pointing of the mortar joints. In many cases, removal of the original mortar material between blocks and replacement with a softer mortar mix allows at least some of the compressive stresses to dissipate.

Considerations regarding pointing include:

1. A qualified professional should specify the mortar component mix, generally based on physical test samples taken during the project investigation.

2. Care must be shown during removal of existing mortar material, to avoid damage to glazed surfaces that extends over the return edge of the terra cotta and into the mortar joint. Tooling, color and profile of pointing mortar should match original. For additional information refer to SWR Institute Technical Bulletins #3 and 4.

3. Movement/expansion joints, and joints exposed to severe weathering (e.g. cross joints at projecting water tables, cornices and sills) should be sealed with a proper joint sealant. Lead "T" joints can be used in conjunction with sealant in larger joints of this type.

Patching

There is no definitive text or agreement on which materials should be used for patching repair of terra cotta. Proprietary products have been developed for terra cotta patches. These repair materials should be compatible with these areas of terra cotta in terms of shrinkage rate, modules of elasticity, linear coefficient of thermal expansion, moisture and vapor permeability.

Patching repair considerations include:

1. Bond strength of the patch to the substrate is the single most important issue.

2. Terra cotta has much lower linear coefficient and thermal expansion than other building materials, therefore patches particularly large and deep patches must have similar characteristics.

3. Materials used in concrete repairs are generally not appropriate for terra cotta repairs.

4. Reinforcing of the patch using non-corrosive armatures may be needed for very deep or projecting repairs.

Glaze Repairs

Glaze spalls are often the result of freezing moisture, salts or algae growth, and should be rectified as part of the repair process. Loss of glaze material leaves the bisque of the block vulnerable to water infiltration. Permanent repair of vitreous glaze material is beyond the current state of restoration science, but temporary repairs are possible.

Glaze repair considerations include:

1. Vapor transmission rate of repair material, particularly in comparison with original glaze.

2. Expected performance history of glaze repair material.

3. Extent of surface preparation required. Some products may require removal of additional bisque material.

4. Color and gloss requirements to match surrounding terra cotta, both when wet and when dry.

Stabilization

Cracks and minor displacement are generally the direct result of overstress, and the first consideration must be the stability of each individual block. If the investigation conclusively indicates that a block does not require replacement, a stabilization repair can be considered.

Stabilization repair considerations include:

1. Determination of the type of substrate material behind the damaged terra cotta block, and the condition and stability of that substrate material. This can often be performed by borescope or other non-destructive means. The intention is to evaluate the suitability of the substrate to resist the loading applied by stabilization anchors.

2. Number, sizing, location, and embedment depth of non-corrosive stabilization pins.

3. Possibility of injecting adhesive material (either grout or resin) into cracks.

4. Material characteristics of adhesives should be selected to reduce possible stress concentrations.

Replacement of Terra Cotta

The ultimate repair is replacement of the terra cotta block. Restoration philosophy requires careful evaluation prior to recommending replacement, but when the stability of a block is in question, or when all other repair possibilities have been exhausted, the block must be replaced.

Considerations regarding replacement materials include:

1. Understanding the likely reason for the original damage, and eliminating (or reducing to the greatest extent possible) the source of that damage.

2. Physical properties of potential replacement materials. For instance, denser materials should not be considered if overstress caused the original failure. Also, some replacement materials are non-load-bearing (or flammable), and unsuited for applications requiring load-bearing capacity (or inflammability).

3. Historic/regulatory requirements. In some cases, replacement with matching terra cotta may be the only possibility.

4. Cost of replacement materials.

5. Availability (including fabrication schedule) of replacement materials

6. Durability of replacement materials, including color fading, susceptibility to impact damage, and ability to clean in future.

Alternate materials such as stone, brick, FRP, GFRP, GFRC, concrete (cast stone), EIFS, and sheet metal have been used successfully to varying degrees, and may be considered.

Removal of Terra Cotta Blocks

Terra cotta walls are often in a compressive state. Care should be taken when removing stones to minimize residual damage to surrounding areas. Cutting back of mortar should be performed incrementally to allow the built up stresses to be relieved gradually.

Removal of terra cotta or adjacent masonry can cause an imbalance, and the loading geometry needs to be understood prior to removal (and during design of replacement blocks).

Anchors

Replacement anchorage should be non-corrosive (i.e. stainless steel), and special designs may be required to accommodate eccentric fits, coursing and bund sets Structural steel components should be replaced or reinforced as necessary, and protected by waterproof coatings and/or flashings for corrosion resistance. It may also be necessary to install additional anchorage to comply with new building codes for seismic and wind pressures. Terra cotta cornices often incorporate small steel members that are simply embedded into back-up masonry and should be considered carefully when reused. It is often necessary for new terra cotta to be installed with different anchoring design than original. In general, terra cotta should be anchored to a structural member or directly to adequate back-up and not to adjacent stones.

Flashings
The purpose of flashing is to protect embedded ferrous metals and to control moisture when it penetrates by guiding it back to the exterior of the wall. Replacement of terra cotta blocks should be viewed as an opportunity to install additional flashing at particularly vulnerable locations, even when such flashing was not included in the original design.

Shop Drawings and Submittals
When blocks are to be replaced, shop drawings are typically prepared to indicate the relevant details of each individual stone or area to be replaced. Terra cotta manufacturers often need access to document stones on the building wall before the stones are removed. Shop drawings are organized to describe and identify each individual block by its location, dimension, color, glaze, and texture. Anchorage detailing is often indicated or suggested.

Additional Sources of Information:
Preservation Brief 7 from the U.S. Department of Interior, National Park Service.

DEFINITIONS

Bisque: Fired clay material beneath the surface glaze, forming the central volume of the terra cotta block.

Grog: Previously-fired clay materials, ground to various consistencies and added to the pre-fired clay material to regulate shrinkage, stiffness and other physical properties.

Glaze: Vitreous coating applied to the surface of the terra cotta block. When fired, glaze coatings become hard and water-resistant, and can be either glossy or matte in appearance.

Polychrome: Having more than one color of surface glaze on an individual terra cotta block. Also known as "faience".

Crazing: Cracking of surface glaze material, often exhibiting a "spider web" pattern.

Spalling: Loss of surface material due to water infiltration, overstress or defects within the block, or surface impact.

Firing: Heating process whereby the clay material (and any applied coatings) is fused into a hard material.

Green state: Initial point in fabrication process in which the clay material is soft and workable. It is at this point that shaping, sculpting and tooling is performed.

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