Use of Infrared Thermography as a Standard in the Quality Assurance and Quality Control of Grouted Masonry Construction

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ABSTRACT

Current Building Codes and Standards specify the requirements for design and construction of masonry walls. These codes also include requirements for different levels of masonry inspection. In spite of the fact that these Codes and Standards set forth strict guidelines for the design of masonry walls, testing of materials, and periodic inspection procedures, construction defects may occur and remain undetected. In particular, voids may be created in the grouted cells of reinforced concrete masonry from obstructions, material deficiencies or incorrect placement procedures. These flaws can significantly reduce the strength and water penetration resistance of the masonry wall.

These voids are typically the result of poor construction practices and are not visible to the naked eye. Infrared Thermography (IRT) may be used by the inspector to distinguish the difference between hollow (or voided) and grouted cells. Corrective action can then be taken to adjust the materials or the methods of construction and to repair the voided masonry prior to the building's occupancy.

This paper addresses how infrared thermography or thermal imaging can be used in detecting flaws that may occur in reinforced masonry wall construction. Basic thermodynamic concepts are briefly discussed to describe the applicability of IRT for masonry. A case history of successful implementation of IRT in new construction inspection is presented. Limitations of this method are discussed to help prevent misinterpretation of test data. Recommendations for implementation of infrared thermography as part of a standard inspection or quality assurance program are discussed along with a sample framework for its organization.

Keywords: infrared, thermography, masonry, grout, void, inspection, quality assurance, repair

1. INTRODUCTION

Masonry is one of the most commonly used building materials in building construction. Virtually any building erected today utilizes either clay or concrete masonry to form the foundations, walls, columns, or cladding systems in some area of the structure. Masonry, when properly constructed, is a robust, versatile, and cost effective material that effectively resists most loads commonly encountered in building construction. However, masonry must be assembled by skilled tradesmen, and like many other building construction materials, errors and defects may result from poor construction practices or material deficiencies.

Although many building materials can be visually inspected after construction to determine if the system was installed in accordance with the design specifications, some components of masonry construction are not visible to the naked eye. Grout is used in masonry construction to fill annular spaces inside concrete masonry units (CMU) or between masonry wythes (parallel walls). If discontinuities or voids are present in the grout, they can reduce the structural capacity of the system and, in the case of reinforced masonry, can limit the effectiveness of the steel reinforcement and reduce the out-of-plane resistance to the lateral design loads. These voids can also collect water leading to interior damage and corrosion of reinforcement.

Often, masonry is limited to periodic inspection as it is being constructed. However, as the masonry is constantly erected in the field, it is difficult with periodic inspection to verify that mortar and grout are being properly placed. Depending on the size of the project, it could require constant supervision of individual masons and laborers as the project proceeds, which can be cost prohibitive for some owners. The industry as a whole recognizes the importance of quality assurance in masonry construction and has modified the industry code requirements to reflect the need for inspection that is both stringent enough to assure quality construction and varied enough to accommodate both critical structures and non-structural masonry systems.

The Masonry Standards Joint Committee (MSJC) is responsible for the development of the Building Code Requirements as well as the Specifications for Masonry Structures. This committee is comprised of representatives from the American Concrete Institute (ACI), The American Society of Civil Engineers (ASCE), and The Masonry Society (TMS). The 2002 Building Code Requirements for Masonry Structures (ACI 530-02/ASCE 5-02/TMS 402-02) provides minimum tests and submittals and minimum inspection requirements for three distinct levels of quality assurance. The necessary level of quality assurance is dependant on the design methods used by the engineer and the classification of the facility as either an essential or a non-essential structure. A part of the Level 3 inspection protocol (most stringent requirements for engineered masonry of essential facilities) requires verification of compliance with the contract documents for the placement of grout continuously during the construction. The purpose of this paper is to present an industry standard method to supplement continuous monitoring of the grouting operations by using infrared thermography as a quality assurance tool during construction. The use of infrared thermography will permit testing agencies, engineers and contractors to rapidly and effectively scan newly constructed masonry systems to identify voids in the construction and thereby enhance the quality of the product provided to the owner at completion of the project.

2. APPLICATION OF INFRARED THERMOGRAPHY TO MASONRY WALLS

Infrared thermography of masonry utilizes principals of infrared energy, thermodynamics and heat transfer to distinguish between grouted and hollow cells. Because heat energy is transferred and emitted differently through solid masonry cells and hollow masonry cells, an infrared camera also known as a thermal imager can be used to detect the relative thermal differences between the two different conditions. A nominal amount of infrared energy is reflected from masonry and can be reasonably neglected.

In new construction, masonry walls are often the first elements constructed because they frequently support roof components or are necessary to “close in” construction so that other work can proceed without delay from foul weather. However, building heat or cooling is not present at this stage in construction, so infrared thermography must be implemented based on principals of “thermal lag”. A schematic of the “thermal lag” method is shown in **Figure 1.**

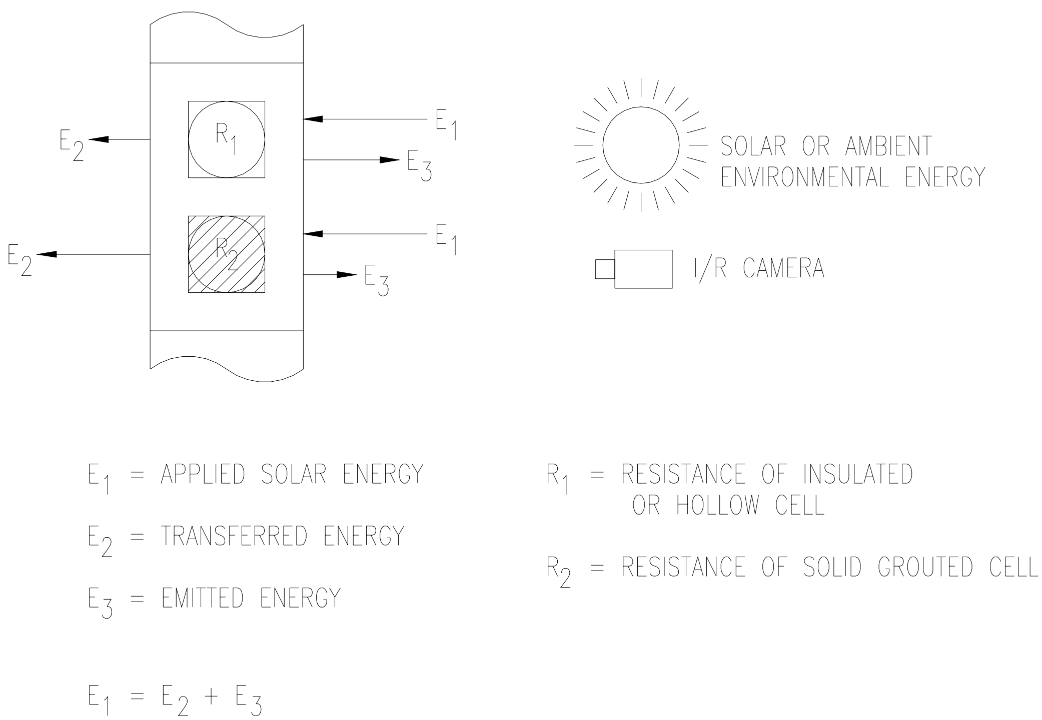

Figure 1 – Principals of the “Thermal Lag” Method

The principals of "thermal lag" rely upon materials of differing construction (solid or voided masonry units) absorbing and emitting either solar or ambient environmental energy at differing rates. Early in the morning, when the ambient temperature is low and prior to the onset of solar loading, masonry walls will typically seek thermal equilibrium. As the morning temperatures rise and/or solar energy strikes the wall surface, the thermal energy is absorbed by the masonry. Hollow or insulated cells create a thermal break (or barrier) within the cell causing the exterior face shell to heat more rapidly than the solidly grouted cells. Conversely, the solid cells transfer the infrared energy away from the surface and into the grout. As a result, the emitted energy of the exterior surface of the solid cells "lags" behind those of voided cells and this emitted energy pattern is normally visible with an infrared camera. In the evening, as temperatures drop, a reversal in the IR pattern occurs, offering a second thermal window for the thermographer to collect data.

3. LIMITATIONS OF INFRARED THERMOGRAPHY IN NEW CONSTRUCTION

There are several distinct disadvantages to employing infrared thermography in new construction. Environmental conditions, which are relied upon to provide the data needed to properly assess the construction, vary considerably between regions and projects. Architectural features and the normal surrounding construction operations can also interfere with the results. Therefore, it is important to list some of the factors that can substantially alter the conditions during the infrared survey:

- Temperature gradient – In some climates, at certain times of the year, temperatures do not vary substantially from day to night. Based on previous experience, it is necessary to have roughly a 10 F change in a 4-hour period to effectively evaluate most common masonry systems. It is imperative the thermographer recognize when the optimum analysis period will be and to collect the data quickly and efficiently so as not to lose the thermal window.

- Moisture – Moisture is often present on new construction sites. Evening rain showers, morning condensation and periodic wash-downs of masonry walls are commonplace on most projects. Free moisture on masonry will substantially alter the results due to the evaporative cooling effect on the porous surface.

- Wind – Many times, masonry is directly exposed to differing wind velocities over its surface. Convection losses can substantially alter the infrared images, particularly at building corners and portals.

- Solar Discrepancies – Often, portions of individual walls will receive higher solar exposure than other walls. Other times solar energy is introduced into the back face of walls while thermographers take data on the front. It is the responsibility of the thermographer to accurately record any differences in solar loading between thermal scans.

- Obstructions – A construction site is typically very active during most operational hours. Staging, construction vehicles or ongoing construction, both inside and out, can obscure portions of the thermal target. The thermographer must record all obstructed masonry surfaces during the survey. It is of the utmost importance that the thermographer be aware of the construction schedule in order to sequence the acquisition of the data.

- Architectural Features – Architectural features such as metallic flashings, parapet caps and window extrusions reflect the majority of infrared energy and can affect the thermographic images of the masonry systems surrounding them. The plans, details and specifications of the project should be reviewed to identify conditions which may interfere with the infrared scans.

- Age of Construction – The curing of portland cement grouts and mortars is an exothermic process by which the grout emits substantial chemical thermal energy as it hydrates and hardens. The concrete masonry units are highly porous and absorb significant volumes of water from the grout at placement, which affect the data. Knowing the age of the construction in question is critical to the thermographer to properly evaluate the scans.

4. TYPICAL EXAMPLE OF INFRARED QUALITY ASURRANCE OF MASONRY DURING CONSTRUCTION

A high school gymnasium addition in the eastern United States was inspected during construction and is presented as a successful example of infrared thermography quality assurance. A portion of the north wall was scanned using a commercially available hand held IR camera. The wall system was constructed of 10" and 12" concrete masonry backup with a clay brick veneer. Scans were conducted of the backup wall during the winter months in the evening after a typical construction day. The inspector was an ASNT Certified Level 1 thermographer familiar with the construction requirements of the project. During the inspection, the technician made specific notes regarding joint locations and coursing conditions, locations of obstructions, distances to known landmarks (such as door jambs and control joints) and the height of the wall visible within the scan area. Data was taken only on the inside of the wall as the brick masonry veneer had already been installed on the opposite face.

Figure 2 is an thermal image of a portion of the masonry wall surveyed. The grout within the wall is characterized by the lighter vertical patterns regularly spaced intermittently across the wall. The voided areas can be clearly seen as a break in the vertical pattern. Also of interest is the change in the vertical pattern at the approximate mid height of the wall. This pattern was created by a change in the type of masonry unit from the lower level to the upper level as well as a change in the spacing pattern of the vertically grouted cells.

The data acquired in the field was recorded on digital videotape format and recreated in the office on a CAD drawing to produce an as-built rendering of the field conditions. **Figure 3** depicts the translated thermal image produced. This information was provided to the contractor to assist the masons in correcting the observed problems.

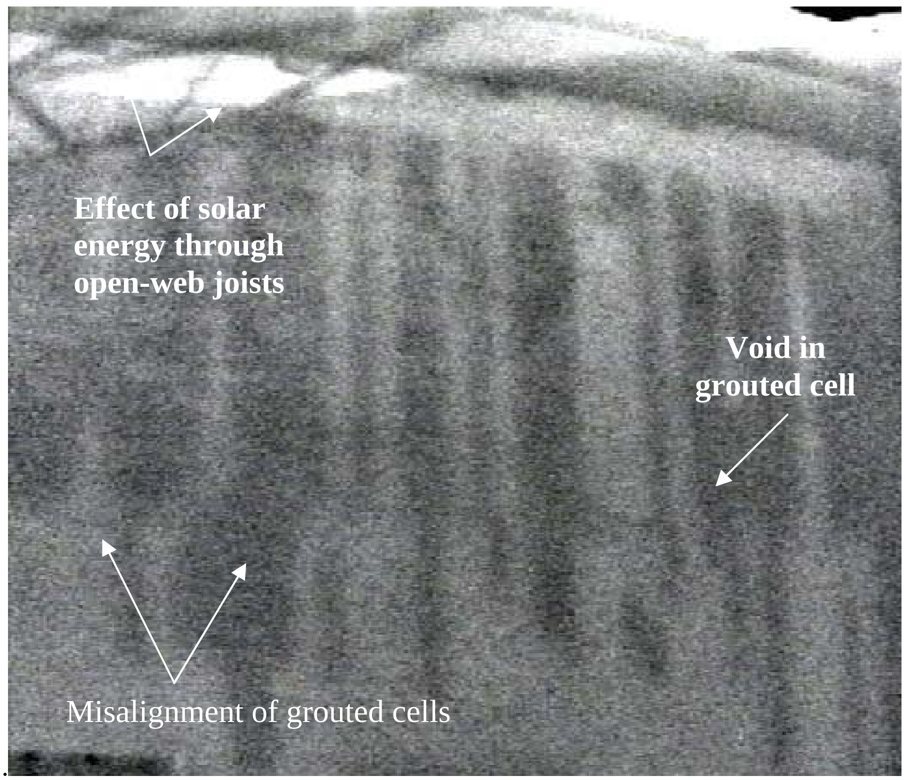

Figure 2 – Infrared Image of a Partially Grouted Concrete Masonry Wall.

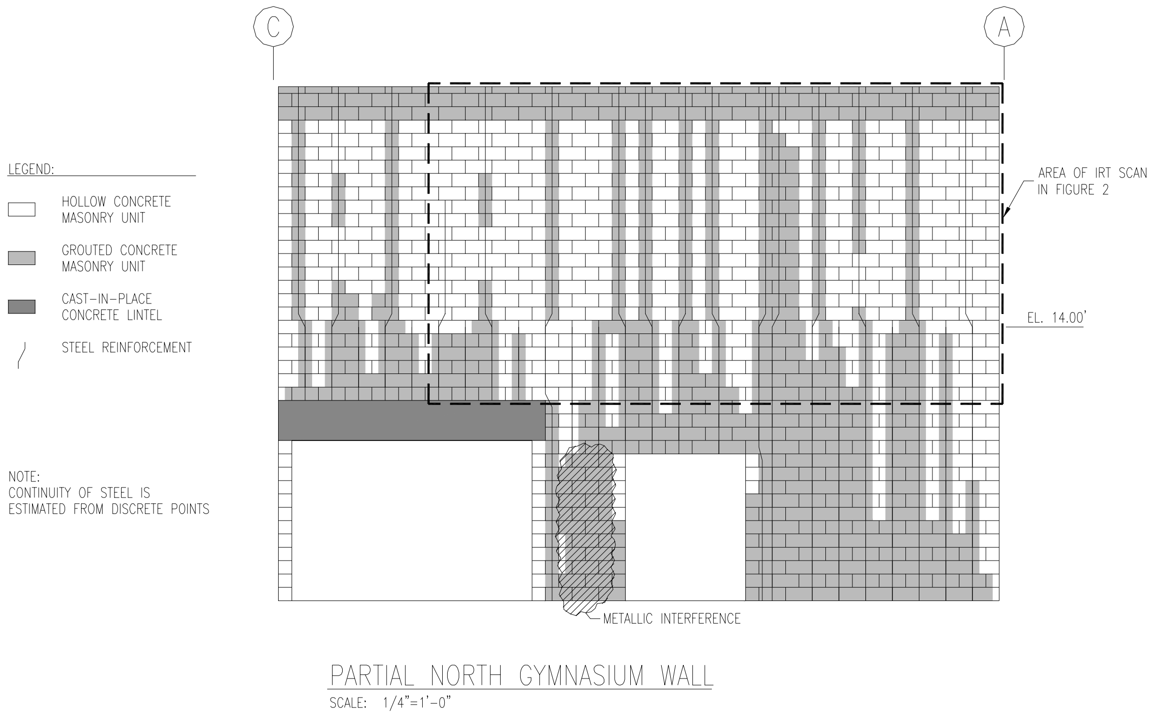

Figure 3 – CADD Drawing Illustrating Interpretation of Infrared Image for the Partially Grouted Concrete Masonry Wall. Note: Dashed box represents the area of IRT scan in Figure 2.

5. RECOMMEDATIONS FOR DEVELOPMENT OF A GROUT INSPECTION STANDARD FOR GROUTED MASONRY WALLS.

As mentioned, the masonry industry could benefit from a reliable, non-destructive method to assess the grout conditions during new construction. While thermal imaging is not considered to be a replacement to periodic on-site inspections of on-going construction by a qualified testing agency, it would be an effective supplemental tool to assist inspectors with locating defects. In turn, building owners would receive a constructed product with a higher degree of compliance to the project design. The authors are currently developing a standard that could be implemented by testing agencies to provide consistent and reliable assessment of grouted masonry. The standard will serve as a guideline to assist the certified thermographer in acquiring the most well defined data and properly interpreting the data to delineate the grout defects. The standard has been initially organized into ASTM format for future use as a potential ASTM Standard Test Method. The following summarizes the framework for the organization of this standard to date.

1. Scope:

Initially the scope will be limited to assessing grouted conditions of single wythe concrete masonry walls between 4” and 12” thick.

2. Referenced Documents:

Information relative to IR application

3. Terminology:

Standard terminology will developed using information provided by TMS and ASTM

4. Summary of the Test Method:

This test method consists of using a commercially available thermal imaging camera during periods of ambient temperature variation to identify locations of missing or inadequately consolidated grout in concrete masonry walls

5. Significance and Use:

Section will discuss the aforementioned limitations of the instrument (weather, temperature, obstructions, etc.) as well as supplemental inspection procedures such as additional non-destructive testing and/or destructive verification

6. Apparatus:

Section will cover requirements for the camera type and construction such as wavelength sensitivity, minimum distinguishable temperature difference and focal length of camera lens

7. Hazards:

Hazards would include access requirements and necessary protection during normal construction operations

8. Information Required:

Would include data required from specifier regarding masonry wall construction and requirements for grouted cells

9. Examination of Test Specimens:

Would identify surface irregularities, moisture conditions, age of construction, and environmental conditions including temperature variation, wind velocity and direction, and exposure to solar energy or other heat sources

10. Preparation of Test Specimen:

Includes standard methods for identifying landmarks in the thermal image scan and recording test specimen and surrounding obstructions

11. Calibration:

Establishes ranges for thermal levels and gain resolution

12. Procedure:

Defines requirements for field of view, rate and direction of scan, distance restrictions, etc.

13. Report:

Discusses necessary presentation requirements for report including, but not limited to; specimen description, drawings, acquisition procedures, specimen parameters, environmental conditions, test results and compliance statement

14. Precision and Bias:

No statement regarding precision or bias is necessary as results merely indicate conformance or non-conformance

15. Keywords:

To Be Determined

6. CONCLUSIONS

Masonry is a popular material used in new building construction. Flaws occurring during construction can compromise the structural integrity of the masonry wall. Tremendous refinements have been made in infrared thermography over the last decade. Improvements in the accuracy, portability and affordability of modern infrared cameras have made IRT a rapid, accurate, and safe non-destructive tool for assisting inspectors in assessing the grouted conditions of masonry walls. IRT has been successfully implemented on several masonry construction projects in the United States. The development of a standard for IRT of masonry will reduce the likelihood of misinterpretation of the data and aid inspectors in improving the quality of new masonry construction projects