NONDESTRUCTIVE EVALUATION AND REPAIR OF CONCRETE MASONRY UNIT WALLS

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Concrete masonry units (CMUs) are used for interior and exterior walls, partitions, retaining walls, and other enclosures. CMUs have become a standard building material due to their structural advantages, energy efficiency, durability, fire-resistant quality, economics, and minimal maintenance. In reinforced CMU wall construction, grout is always placed in the cells containing reinforcing steel. In seismic regions, it is customary to grout all the cells, including those without reinforcing steel. Important factors that contribute to the strength of the CMU wall include:

- Strengths of the CMU, grout, and mortar;
- Horizontal and vertical spacing of reinforcing steel; and
- Consolidation and bond of the grout.

Oftentimes, full-time, on-site inspection is not provided during construction of the CMU walls; therefore, verification of the placement of reinforcing steel and grout cannot be made unless additional testing is performed. Most specifications require drilling and removing cores from the cells to determine the quality of the grout. Nondestructive techniques can also be used to determine the presence of steel and grout and the consolidation and bond quality of the grout in the CMU walls.

OVERVIEW OF NONDESTRUCTIVE TESTING (NDT) METHODS

The most applicable methods to test the walls for grout condition include pulse velocity, impact echo, impulse response, radar, infrared thermography, and X-rays. These methods have been extensively discussed in the literature; hence, their details are not provided in this article. Pulse velocity is based on the sound propagation through the material and needs access from both sides of the wall. Impact echo is based on the principle of the propagation of stress waves through the material and needs access from only one side.

In the impulse response method, the "mobility" of the structural member under investigation is determined. Mobility is a complex ratio of particle velocity and the applied force. The test involves striking the surface of the CMU cell with an instrumented hammer and measuring the vibration response of the CMU. The mobility of the member is obtained by calculating the transfer function of particle velocity and the applied force. The value of the mobility is used to determine whether the cell is grouted or not.

Pulse velocity, impact echo, and impulse response are all "local" tests. The result is obtained only where the test is conducted; therefore, multiple tests need to be conducted within the cell area.

Electronic metal detectors and radar can be used to detect reinforcing steel in the CMU wall. Radar is also very helpful to cover the large areas of the wall; however, detecting the lapped lengths of the reinforcing steel and the quality of the grout can be a challenge.

Infrared cameras detect temperature and hence heat energy. Because grouted cells are higher in mass, they absorb and release heat slower than the ungrouted cells. Depending on the daily conditions (such as cloudy, overcast, or sunny), infrared images can be captured to detect grouted and ungrouted cells of the CMU wall. It is a faster method to capture large areas. Naturally, it is difficult to test the interior walls with solar energy. Small areas can be tested using heat lamps.

X-rays can be used to precisely determine the lapped lengths of the reinforcing steel in the CMU wall; however, this is an expensive option. This method also needs access from opposite sides and therefore cannot be used on retaining walls.

A CASE HISTORY

A one-story building using the CMU walls was under construction (Fig. 1). As part of the quality assurance program, four cores were removed by the testing agency to observe the condition of the grout from a completed CMU wall of the building. Two of the cores showed unacceptable quality of the grout (Fig. 2); hence, questions were raised regarding the quality of the grout in the rest of the masonry units of the wall. The wall was built with a standard 12 in. (305 mm) CMU and the construction, including placement of the grout, was observed by the testing agency. So, in this case, the existence of the grout was not in doubt but the quality of the grout was questionable. Based on experience, the impact-echo method was chosen to determine the condition of the grout.

Each cell of approximately 800 ft^2 (74 m^2) of the exterior CMU wall was tested from the interior of the building. As viewed from the interior, there were two small rooms—one on each side of the main wall. In the two rooms, nine courses of the CMU from the bottom were tested for the entire length of the rooms (19 ft [5.8 m] long x 6 ft [1.8 m] high). The main wall was tested at accessible locations for its entire length, except for the top three courses (approximately 47 ft [14.3 m] long x 13 ft [4.0 m] high).

TEST RESULTS

For each test, the amplitude ratio versus frequency graph was monitored using the impact-echo equipment. Results were classified based on the quality and repeatability of the obtained signals. Figure 3 shows the representative graph of amplitude versus frequency, where the grout in the cavity was well consolidated and bonded. A frequency of 6000 Hz corresponds to a thickness of 12 in. (305 mm) based on a propagation velocity of 12,000 ft/s (3658 m/s). In theory, the test response obtained should be identical for all the well-grouted cells. Significant deviation from the "normal" response indicates an anomaly, such as a void or debonding of the grout. Figure 4 shows a graph with a primary frequency of 4444 Hz, indicating an anomaly.

The impact-echo testing indicated responses representing honeycombing and debonding at the interface of the CMU and the grout. Sometimes the debonding was at the interior face or at the exterior face or sometimes at both faces. At some locations, results were nonrepeatable within the surface area of each cell, indicating a variation from the normal response. Locations with potential anomalies and inconclusive results were identified on the wall for further evaluation. Most of the significant anomalies were detected between the fourth and sixth courses from the top in the middle and right portions of the main wall, as viewed from the interior. Details of the grout placement were not available for review to determine the cause(s). No significant anomalies were detected in the two rooms at the tested locations.

CORE REMOVAL

To confirm the test results, two cores were removed from the cells with potential anomalies. The cores and their respective core holes showed cracked grout and a delamination at the interface of the CMU and the grout (Fig. 5 and 6). A partial depth core was removed from the cell to observe the grout condition around the reinforcing steel. At the partial depth core, the exterior face of the CMU was delaminated, but the grout around the vertical reinforcing bar was

Fig. 1: Exterior view of the CMU wall

Fig. 2: View of the core hole showing honeycombing of the grout on the upper portion

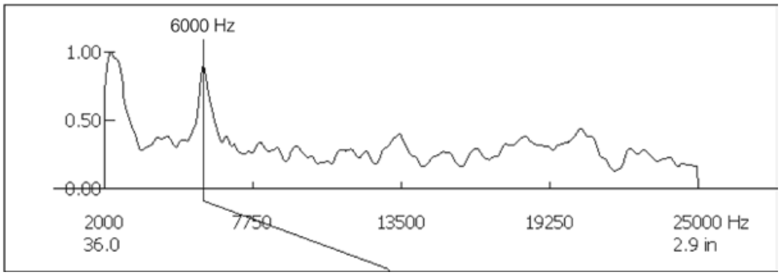


Fig. 3: Impact-echo test result indicating acceptable grout condition

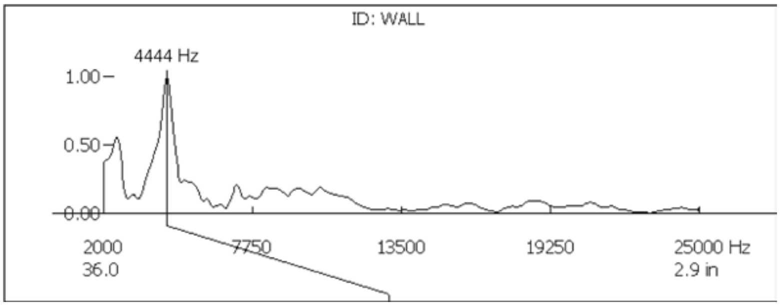


Fig. 4: Impact-echo test result indicating unacceptable grout condition

bonded adequately (Fig. 7). In addition, a core was drilled and removed from the cell where the impact-echo testing showed acceptable grout condition. The core showed well-consolidated and bonded grout, thus confirming the test results.

RECOMMENDATION AND REPAIR

Based on the impact-echo test results and observations of the cores, the recommended repair method included epoxy injection of the grout in the suspected areas. The repair material chosen was a two-component epoxy adhesive with low viscosity and minimal heat generation during curing. Because there was a possibility of debonding of the grout at both the exterior and interior interfaces, it was necessary to inject the repair material by drilling holes in each cell from both sides. It was also necessary to identify the cells with reinforcing steel prior to drilling of the holes. The method allowed not only the achievement of good distribution of the repair material, but also the avoidance of damaging buildup of internal pressure. As a precaution, epoxy injection was first performed in a trial area to ensure the proper operation of the system and to ensure that not too much of the repair material was getting absorbed by the CMU to cause bleeding and discoloration.

Quality control procedures included testing of the samples taken from the injection dispenser at regular intervals for setting rate and hardness. After the repairs were completed, impact-echo testing was again performed to confirm the integrity of the grout.

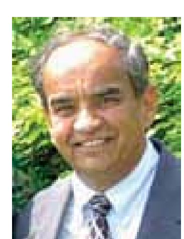
Fig. 5: The core with a crack in the grout

Fig. 6: Core showing the debonding of the grout at the interface of the CMU and grout

Fig. 7: Partial depth core showing good bond around the reinforcing steel

NDT SUCCESS

Impact echo, an NDT technique, was successfully employed to determine the condition of the grout. The results were verified by drilling and removing the cores. The integrity of the grout was achieved by injecting the epoxy adhesive. Engineers normally recommend full-time, on-site observations to confirm the placement of the reinforcing steel and grout. But as the case history illustrated, on-site observations are not a guarantee to achieve the required strength and integrity of the wall. NDT of CMU walls should be recommended prior to drilling and removing the cores.



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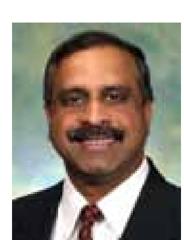

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