MORE THAN MEETS THE EYE

Evaluating Masonry Using Nondestructive and In-Place Tests

By Michael Schuller

What do you do when you need critical information on how a masonry building was constructed? In years past, you may have hired a mason contractor to begin cutting openings into the wall to expose internal conditions. Engineers can now turn to a series of nondestructive techniques that allow us to peer into walls without damage.

Figure 1: Radar scanning of an historic stone wall.

Whether for conservation of an historic building, prior to designing an addition, or as part of a forensic effort, there are many situations when designers need critical information on as-built and current conditions. Recent advances in nondestructive technology provide the engineer with a new set of tools for evaluating as-built conditions and locating deterioration within masonry walls. Other mechanical tests, unique to masonry, can measure engineering properties such as strength and stiffness in place, without removing samples for laboratory testing.

Applications

Engineers have to make a lot of decisions during the design process, and we need accurate information to back up these decisions. When dealing with existing buildings, original drawings and specifications rarely exist. One way to get simple information on how the building was constructed is to use nondestructive testing (NDT). NDT can provide answers to basic questions such as: how thick is that retaining wall, or how is that wall reinforced?

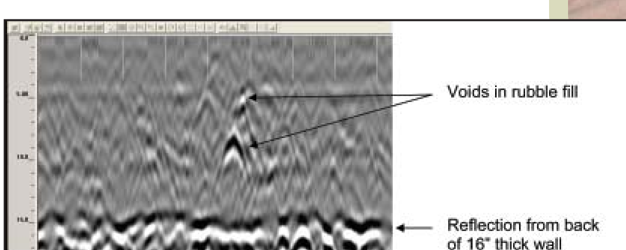

Figure 2: Radar trace showing void spaces within an historic stone wall.

Historic Construction

Old masonry walls were built to be massive, relying on sheer size to resist loads. Some wall sections were built solid, but it is common to find rubble fill and voids at the interior of walls. Through-wall pulse velocity and radar scanning are convenient methods to locate internal void spaces. The location and continuity of header courses and bond stones, used to tie walls together, is best found using impact-echo or radar. (*Figure 1 and Figure 2*)

When preserving old masonry construction, one all-too-common mistake is specifying a modern repair mortar that is much harder than the historic materials already in place. Testing the existing mortar joints with a special pendulum-type rebound hammer will give you a simple measure of mortar properties, and if the mortar hardness varies throughout the building. Results of mortar hardness tests are used to help guide the choice of appropriate repointing mortar. (*Figure 3*)

Figure 3: Pendulum rebound hammer, used for evaluating mortar hardness.

Damage

Buildings may be damaged from fire, applied loads, freezing weather or a number of other causes. Rather than wholesale replacement of building components, concentrate your repair efforts on only those areas that are damaged as defined by NDT. The extent of fire damage, for example, is often determined by a rapid series of surface hardness tests.

Cracks can be located with many of the methods discussed above, including impact-echo, pulse velocity, and microwave radar. Tomographic velocity reconstructions are often used to image the depth of crack penetration. (*Figure 4, Figure 5, Figure 6*).

Figure 4: View of stone imaged using tomographic methods; the horizontal cross section shown below is marked with masking tape on the stone.

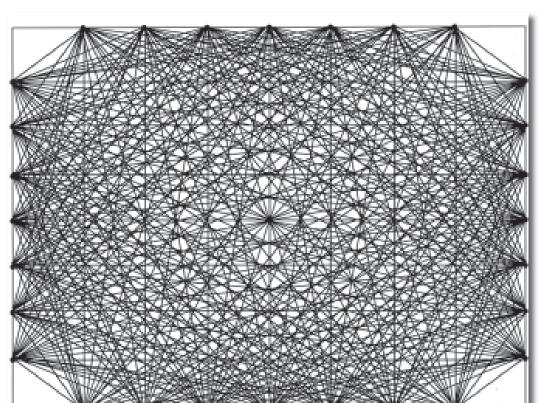

Figure 5: Diagram showing ray path configuration used to acquire data for tomographic analysis. A total of 294 ultrasonic pulse velocity readings were acquired for input.

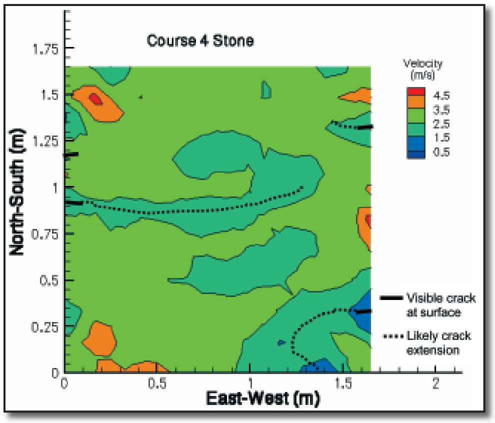

Figure 6: Velocity profile through the imaged stone, calculated using tomographic analysis software. The approximate locations of surface-breaking cracks are shown as dotted lines.

Reinforced Masonry

Nondestructive testing also has a role in evaluating new construction. For example, if the inspector missed a day on the job site, NDT is a convenient way to conduct follow-up quality assurance tests. On other occasions, you may have questions about exactly where the reinforcement and grout was placed. Locate the reinforcement first using pachometer or radar scanning, then check for grout continuity along the rebar. Grouted cells can sometimes be located by sounding with a hammer, but sophisticated techniques such as impact-echo, pulse velocity testing, and radar are more precise. If temperature conditions are correct, infrared thermography is a great choice for rapidly evaluating grout presence over large areas. (*Figure 7*) Careful analysis of radar or pachometer data can sometimes identify lap splices, but X-ray approaches remain the best option for accurately locating reinforcement splices within walls.

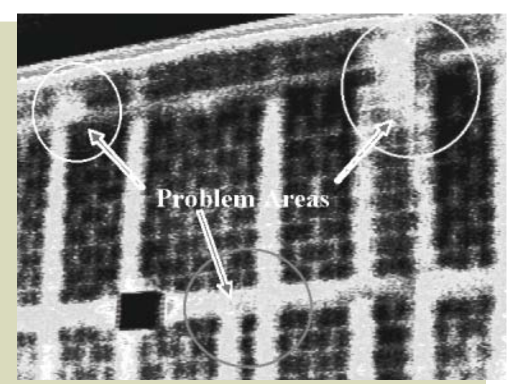

Figure 7: This infrared scan of a reinforced concrete masonry wall shows surface temperature as gray-scale variations. Grouted cells transfer heat through the wall better than empty cells, showing as light strips, and discontinuities show up clearly in the image. (Image courtesy of Trey Hamilton).

Controlling Repairs

Designers spend a lot of effort specifying repair materials and special procedures. However, short of full-time inspection, it is difficult to tell if repairs were carried out properly. Nondestructive methods are an effective means to provide quality assurance on repair projects, to check bond of repair materials, solidity of areas repaired by injection, and repointing mortar hardness. Pulse velocity, impact-echo, radar, and infrared thermography have all been used successfully to qualify repairs.

Engineering properties

Engineering design begins with defining basic masonry properties such as compression and shear strength. Nondestructive methods do not provide a direct measure of material properties, and we have to turn to a series of in place, or *in situ*, tests to define these properties. Flatjack methods are especially useful for in-place testing. The existing state of compression stress within veneers, walls, or columns can be measured using a single flatjack in a process of stress relief (described by ASTM C 1196); the double-flatjack test described in ASTM C 1197 provides a means to measure masonry deformability properties in place. (*Figure 8 and Figure 9*)

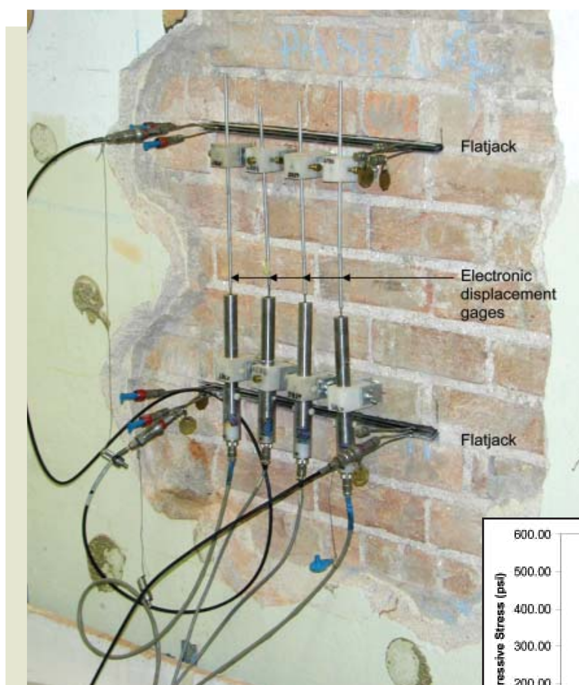

Figure 8: Masonry compression response is measured by pressurizing two flatjacks, placed one above another into slots cut into the wall. Surface strains are measured using electronic or mechanical gages and results are shown as a familiar stress-strain curve.

Figure 10: An in-place shear test, conducted here using a small flatjack inserted into a cleared head joint. The force required to displace the test brick (thus shearing the mortar joints above and below) is used to calculate masonry shear strength.

Shear tests are often required as part of seismic retrofit projects, but are also used as a general indicator of mortar competency. First described in the *Uniform Code for Building Conservation* (UCBC), ASTM C 1531 now lists several alternative procedures for measuring mortar-unit shear bond strength. The *International Existing Building Code* contains requirements for calculating masonry shear strength based on results of shear tests. (*Figure 10*)

Standardized Methods

Standardized methods for evaluating masonry have been developed since the late 1980's. Some of the more common evaluation approaches have been standardized by ASTM (**www.astm.org**), including the two flatjack test methods in ASTM C 1196 and C 1197, and the in-place shear test in ASTM C 1531. There are many other general NDT methods developed by ASTM that have some applications to masonry, including radar, infrared, and ultrasonic velocity techniques. The International Union of Laboratories and Experts in Construction Materials, Systems, and Structures (RILEM) has also been developing standardized methodologies for many of the masonry evaluation methods discussed here. Visit the RILEM web site at **www.rilem.org** for more information, or to obtain RILEM publications.

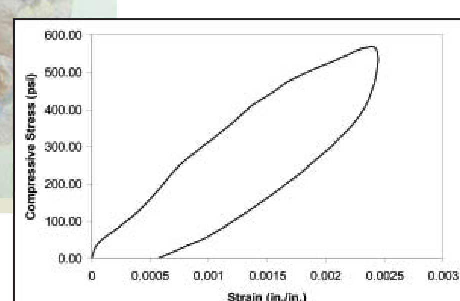

Figure 9: (Companion data plot to the previous image.)

Conclusions

When setting up an investigative program, remember that there is no single technique that works best for all situations. Use complementary tests to verify results and reduce the likelihood of false readings. Masonry is especially difficult to evaluate because of the many mortar joints and varying internal conditions that complicate NDT results. A good deal of experience is needed to interpret nondestructive test data, but, in the right hands, these methods provide information critical to the design process. Even though some of these approaches can be expensive, remember… *when the designer gets good information, you will save money in the long run: engineers that have confidence in their information are more likely to design cost-effective solutions.*■

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Common Methods for Investigating Masonry

Surface Hardness – Rebound of a mass from the surface of a unit or mortar joint provides a relative indication of material hardness for identifying general property variations.

Pulse Velocity – Stress wave velocity is dependent on material density, stiffness, and the presence of flaws such as cracks or voids. Ultrasonic waves generated with piezoelectric crystals are used with modern solid masonry and short path lengths. Low frequency sonic waves, generated by impacting with an instrumented hammer, have greater energy to travel over long path lengths through irregular masonry.

Impact-echo – Stress waves reflected from internal discontinuities are analyzed in the frequency domain to determine the depth of voids, cracks, or other flaws within walls.

Infrared Thermography – Sensitive infrared cameras record thermal patterns on wall surfaces that are caused by variations in heat transfer within the wall section. Care must be taken not to confuse patterns resulting from differences in surface texture, emissivity, or moisture with varying internal conditions.

Microwave Radar – Microwave energy is reflected at boundaries between materials with different dielectric constants, such as between masonry units and soil, grout, metal, or air voids. Microwave energy travels well through air spaces and the approach can often provide information beyond an initial boundary.

Metal Detection – Electronic devices, often called "pachometers," use eddy current principles to detect all types of conductive metals such as reinforcement, stone anchors, and veneer ties. Special search heads may be required to detect reinforcement embedded deep in masonry walls.

Tomographic Imaging – Data from pulse velocity or radar investigations is used to reconstruct 2- and 3-dimensional velocity distributions using tomographic analysis software. Large data sets are required to accurately size and locate anomalies within a cross-section.

X-Radiography – X-ray images have traditionally been made by exposing special film in the presence of an X-ray source; new technology with portable electronic detectors

and safer low-power sources looks promising for evaluating wall sections up to 8 inches thick.

Flatjack Testing – Flatjacks are hydraulic load cells, manufactured to be thin enough to fit into joints cleared of mortar. When pressurized, the jacks impose stress on the surrounding masonry. Used primarily for evaluating historic solid-unit masonry construction.

Shear Testing – Often called the "shove" or "push" test, shear tests are conducted in-place by displacing a brick with a hydraulic ram.