Nondestructive Testing Verifies Quality of Repair

by Malcolm K. Lim, George W. Seegebrecht, and Honggang Cao

Nondestructive testing (NDT) has become an important tool in evaluating questionable structures or individual building components. The information gained from NDT is critical for determining the extent and severity of construction defects or making damage assessments. It provides a basis for assessing the condition of columns, beams, foundations, walls, etc., and helps in developing a sound corrective response.

Advancements in personal computing have made the PC a vital tool of the nondestructive testing industry. A PC increases the flexibility and speed with which NDT crews can gather data, which allows them to examine more areas in less time for less cost. These factors have made NDT more valuable to owners, engineers, and contractors who need to correct construction problems quickly.

When building components exhibit problems such as low strength, excessive voiding, improper cover over reinforcing steel, or damage due to fire, investigators commonly take material samples for analysis. Extracted samples, such as concrete cores or reinforcing steel specimens, are very useful, but extracting samples is destructive and may create a need to repair sampled areas. This is why fewer samples are often taken than ACI and ASTM guidelines recommend. When a testing program includes both destructive samples and NDT, far fewer samples generally will be required. This saves time and results in less damage to the structure, while actually covering a much greater portion of the structure. In summary, combining NDT with the testing of actual material samples in a properly executed test program and engineering review is the best way to assess the causes, and not just symptoms, of a structural defect. It offers the best basis for developing a repair approach to correct defects.

Overall view of garage wall at entrance. Debris is still in place at the time of the site visit, preventing visual inspection of exterior surfaces of lower panels. However, NDT proceeded as planned from the interior surfaces

Assessing a Fire-Damaged Garage

CTLGroup recently evaluated a parking garage that was severely damaged by fire. In the evaluation program, nondestructive testing provided information on changes in precast panel stiffness and mobility as a result of the fire damage. This information was used in conjunction with the testing of concrete cores and steel reinforcement specimens as a basis for the owner's repair approach. A follow-up test program was also conducted after completion of all repairs to assess the improvement in panel performance after application of a silica fume repair material.

The garage was approximately 120 x 260 ft (37.5 x 73 m) in plan and contained six levels of parking. The garage walls consisted of 8 in.-thick (20 cm) precast concrete panels. The garage was surrounded by wood-framed condominiums that were still under construction when the fire occurred. The fire resulted in considerable cracking and spalling of the concrete at the exterior face of the precast panels.

The panels were precast of normalweight concrete about 2 to 3 months before the fire. At this early age, the panels still retained considerable internal moisture, and this moisture, when exposed to the fire's intensity and speed, contributed to the severe spalling exhibited by the structure. The garage walls were two panels high. The lower-level panels were reinforced with two layers of 4 x 4 in. (10 x 10 cm) W3/W3 WWF, and the upper level panels were reinforced with one layer of 12 x 6 in. (30 x 15 cm) W3/W5 WWF. The reinforcing bars were 60 ksi (414 MPa) grade bar.

The NDT team evaluated the condition of the garage panels after the fire and again following the repair. Investigators used Impulse-Response (I-R) test methods in the testing program (see sidebar). All panels that had been exposed to the detrimental effect of the fire were tested. Severely damaged panels that the owner had immediately designated for replacement were sampled to identify a "worst case" test signature. Fire-induced spalling of the exterior faces caused section loss in the panels. Therefore, investigators tested the panels from their interior faces to evaluate the resulting reduction in stiffness and increase in mobility.

The NDT program covered most of the exposed surface area of the precast panels. A grid pattern was established to test the panels at 2 x 2 ft (0.6 x 0.6 m) intervals both vertically and horizontally. In addition, cores were extracted from almost every panel to determine compressive strength, measure loss of panel thickness due to spalling, determine modulus of elasticity, and perform petrographic examinations. Finally, mechanical properties of the reinforcing steel were tested in accordance with ASTM A 370 "Standard Test Methods and Definitions for Mechanical Testing of Steel Products." The combination of NDT and destructive laboratory testing yielded enough information for the team to develop the repair approach with full confidence. The repair plan addressed the need for surface preparation, removal of reinforcing steel in heavily spalled areas, and procedures to achieve adequate bond of the shotcrete repair material.

The post-repair impulse-response test was performed after the repairs to the panels were completed. The impulse-response test was performed at the same test point locations of the previous test so as to compare the pre- and post-repair results. The post-repair results showed that the high mobility values recorded before the repairs (areas noted in yellow, orange and red on the pre-repair plot) were

Overall view of portion of the garage where damage was severe and many panels were replaced. Only limited testing was conducted on these panels

Overall view of typical interior panel faces. Core holes are visible. The inside faces of the panels were generally unaffected by the fire and provided an excellent surface to send and receive impulse signals

Common degree of damage suffered at the precast panel exterior face due to fire. Spall depths of up to 2-1/2 in. (6 cm) exposing steel were not uncommon

Impulse-Response testing on the inside surface of the panel no longer present, indicating that the repairs were satisfactory. The two I-R plots depict the mobility of the wall before and after the repairs.

Nondestructive testing can be used both as a tool to verify problems and also as a quality assurance tool. Testing can be performed quickly and cost-effectively as demonstrated by this case study. As a quality assurance tool, nondestructive testing can be used to demonstrate to the owner that the repairs are properly installed.

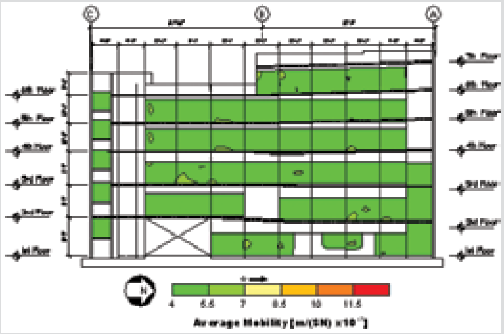
Impulse-Response (I-R) Testing

The I-R method uses a low-strain impact to send a stress wave through the tested element. The impactor is usually a 2.2 lb (1 kg) sledgehammer with a built-in load cell in the hammerhead. The response to the input stress is normally measured by a velocity transducer (geophone). Both the records for the hammer force and the geophone velocity response are processed in the field computer to obtain a transfer function, referred to as the mobility of the element under test. The test graph of mobility plotted against frequency over the 0 to 1 kHz range contains information on the condition and the integrity of the concrete in the tested elements.

Sound concrete in plate-like structures such as slabs, walls, and bridge decks typically gives a constant value of I-R average mobility, which is inversely proportional to the concrete element thickness. Poor concrete compaction and honeycombing cause the value for average concrete element mobility to increase, usually accompanied by a rising mobility value with increasing frequency. A reduction in dynamic stiffness is often present too. Delamination of concrete along reinforcing bar planes is registered in the I-R test by a significant increase in average mobility, accompanied by a large reduction in dynamic stiffness and a high mobility at low frequencies.

The I-R test produces a principal parameter, "average mobility," which is defined as the result of structural surface velocity responding to the impact divided by the force input ($(\mathrm{m/s})/\mathrm{N} \times 10^{-7}$). The mean mobility value over the 0.1 to 1 kHz range is directly related to the modulus, density, and thickness of a plate element, for example. In general, the presence of any internally delaminated layer, weakened layer, cracking, unconsolidated concrete, or reduced effective thickness will result in an increased average mobility value. Conversely, a sound concrete element without distress will have a low average mobility value.

I-R plot of panels showing numerous areas of distress (yellow, orange, and red). Testing was performed on the inside surface prior to any repairs



I-R plot of the panels after the repairs were performed. Plot showed uniform average mobility values. The high mobility values recorded before the repairs were no longer present, indicating that the repairs were satisfactory

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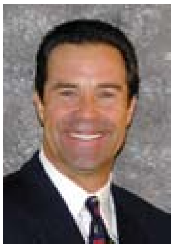

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