Rapid non-destructive test method at the Taiwan High-Speed Rail project

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In 2002, Construction Technology Laboratories Inc participated in a program to evaluate concrete placement in samples of post-tensioned box girder sections at an early stage of the Taiwan High-Speed Rail (THSR) project. Impulse Response testing was used to locate and quantify noted and potential deficiencies in the girder concrete such as poor compaction and delamination, as well as loss of post-tensioning caused by patching of partial exposures after post-tensioning and formwork stripping. NDT was able to help in assessing and quantifying these early concrete placement difficulties, both for cast-in-place and full-span precast systems. This article presents the Impulse Response non-destructive stress-wave test method for evaluation of concrete conditions in prestressed and post-tensioned bridge units.

The Taiwan High-Speed Rail (THSR) project, between Taipei in the North and Kaohsiung in the South of the island, comprises a total length of 345 km, 70 percent of which is on viaducts and bridges. With the exception of a few, isolated, long span steel structures, the viaducts and bridges are concrete box girders using a variety of construction techniques. These include full span precast, cast-in-place on advancing shoring, cast-in place on fixed shoring, cantilever segmental and incremental launching construction methods. The structures are designed for a life of 100 years.

Figures 1 to 4 show general views of viaduct girder construction, as well as details of one of the post-tensioning systems used. Typical concreting deficiencies appeared on some girders in the early stages of construction (both precast and cast-in-place), primarily in a single section of the project. These problem areas included incomplete consolidation (compacting) of concrete cold joints, low concrete cover over em-

Fig. 1 General View of Elevated Girder Section

Fig. 2 Cast-in-Place Girders Under Construction.

Fig. 3 Box Girder Internal View.

bedded reinforcement, debris present in the body of the concrete, and questionable concrete repairs (Figure 5). Incomplete consolidation of concrete resulted in areas of segregation, honeycombing, and voids. Large quantities of steel reinforcement at girder end diaphragms, plus box girder webs with either large-diameter post-tensioning ducts (in cast-in-place sections) or large numbers of prestressing strands (in precast sections), complicated concrete placement. Other factors were initial problems in using new, specially designed formwork for cast-in-place girders and refinement of concrete placement techniques.

Fig. 4 Post-Tensioning Details at Diaphragm.

Fig. 5 Repair Patching.

Construction problems

Surface deficiencies became apparent immediately after stripping girder formwork, suggesting the need for some form of non-destructive testing to determine the nature and extent of deficiencies in the web and diaphragm concrete. Construction Technology Laboratories, Inc. (CTL), of Chicago, USA., has developed an evaluation approach built around the non-destructive, Impulse Response (IR) test method. It was asked by the owner, the Taiwan High Speed Rail Corporation, to demonstrate the suitability of this approach in a pilot test program on selected girders on the THSR to support the owner's strict quality assurance program. CTL recommended this test methodology for the following reasons:

- CTL's experience on other similar projects had shown that the IR method could detect the nature and quantifies the severity of defects typically observed in these girders (e.g., poor concrete consolidation, voids, and repair patch debonding).
- The close spacing of reinforcing steel in the girders *(Figure 6)* ruled out other non-destructive methods.
- The IR test can rapidly cover the large areas to be tested.
- A trained engineer can quickly assess the test results onsite. Test results are obtained by a field computer and processed immediately.

For prestressed/post-tensioned box girders of the types found in this project, the IR test method is used only to detect voiding and poor concrete consolidation in original concrete and repair patches, as well as the possible debonding of repairs. In addition, some information is obtained about the difference in stress levels between original prestressed/post-tensioned concrete and unstressed patch repairs.

Fig. 6 Density of Steel Reinforcement.

The Impulse Response Test Method

The IR test is also used to assess the quality of deep foundation construction, where it is more commonly known as a bored pile integrity test (Ref. 1). The method applied to concrete structures has been developed relatively recently, and is fully described in Reference 2. A low-strain impact is used to send stress waves through the tested element. The impactor is usually a 1-kg sledgehammer with a load cell built into the hammerhead.

The maximum compressive stress at the impact point in concrete is directly related to the elastic properties of the hammer tip. Response to the input stress is normally measured using a velocity transducer (geophone). Both the hammer and the geophone are linked to a portable field computer that acquires and stores data (Figure 7). Both the time records for the hammer force and the geophone velocity response are processed in the field computer using the Fast Fourier Transform (FFT) algorithm.

The resulting velocity spectrum is divided by the force spectrum to obtain a transfer function, referred to as the mobility of the element under test. The test graph of mobility plotted against frequency from 0 to 800 Hz contains information on the condition and the integrity of the concrete in the tested elements. A typical test output is given in Figure 8.

The IR method is a point test, with the hammer influencing a circle on the tested element with a radius of approximately 600 mm around the impact point. Test points are normally laid out on a grid between 450 and 600 mm, depending on the element tested (diaphragm or web).

The hammer blow depth of influence on plate structures of this type is 500 to 600 mm, which incorporates the full depth of the girder webs in most cases. The diaphragms are thicker than this zone of influence, and, consequently, only the outer 500 mm can be assessed with this method.

When the mobility of a sound concrete plate element (such as the web of a girder) is compared with that of concrete with voids or honeycombing, the latter shows increasing mobility with increasing frequency, whereas the former maintains a relatively constant mobility over the same frequency range. This IR parameter is referred to as the mobility slope. Figure 8 shows different values for mobility slope, and when this parameter >4, it indicates poor consolidation.

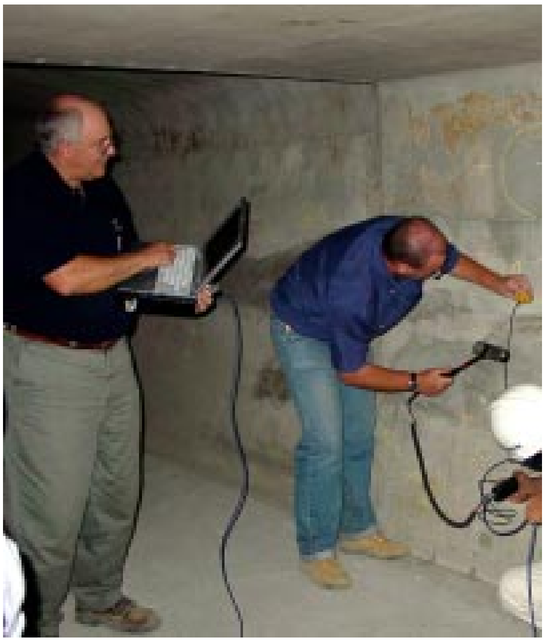


Fig. 7 Impulse Response Equipment.

The severity of internal voiding increases with increasing mobility slope. This applies to voiding within the original concrete, as well as voiding in or beneath repair patches.

If repair patches are debonded or adhere poorly to the substrate, then the IR test shows an increase in a parameter referred to as the voids ratio (ratio of peak mobility from 0-100 Hz to the average mobility between 100 and 800 Hz). When the voids ratio exceeds 2, patch debonding is probable.

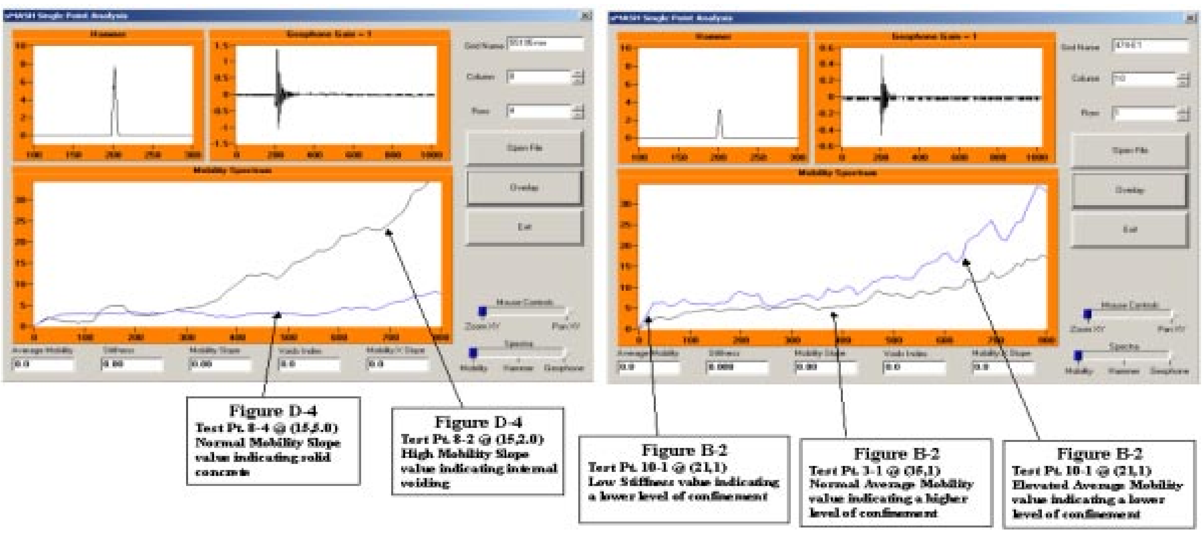


Fig. 8 Examples of IR Test Output.

Fig. 9 IR Test on Girder Web.

One major advantage of the IR test method is the relative ease with which it allows the technician to detect anomalies.

As individual tests are compared with other test results, anomalous results that indicate likely defects quickly become apparent. The use of these IR test parameters for defect detection is summarised in Table 1 below.

Defect	Mobility	Stiffness	Mobility Slope	Voids Ratio
Voiding/Poor consolidation (Original and repair concrete)	x		xx	
Debonded repair patches	x	xx		xx
Loss of stress in repair patches	xx	x		

xx - Strong indicator x - Moderate indicator

Table 1: IR Parameters for Defect Detection.

At the same time, debonding reduces the dynamic stiffness. The mobility and stiffness of concrete with locked-in stresses (such as those created by prestressing/post-tensioning) are different from those for the same concrete with no applied stresses (such as repair patches after post-tensioning). The mobility is discernibly higher and the stiffness lower in the latter case.

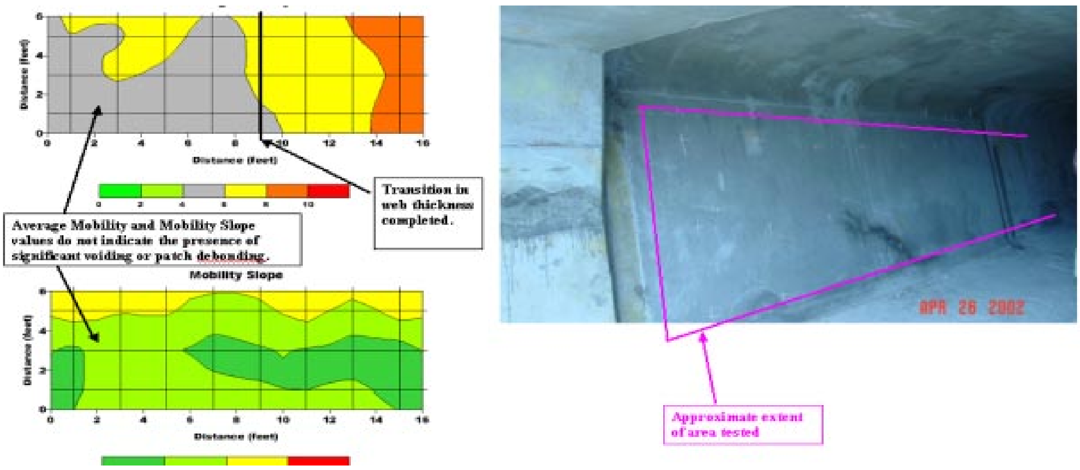
THSRC Girder Results

Figure 9 shows an IR test being performed inside a girder web. The demonstration project included IR testing on girders in three separate contract sections; two with cast-in-place and one with precast construction techniques. Any visible surface concrete deficiencies had been cleaned and patched prior to testing.

Figures 10 to 13 are IR test contour plots adjacent to photographs of the tested areas in the plots. Figure 10 (B-1a) shows a patched area with no concrete deficiencies; however, the increasing mobility values from right to left indicate the web thickness decreasing from 750 mm to 500 mm.

The high mobility values in the vicinity of the full-depth patch repair in Figure 11 (B-2a) indicate that the patching is not integral with the surrounding concrete, but also that no voiding remains within or around the patch (normal mobility slope values). Figure 12 (D-4a) confirms the presence of localised internal voiding behind the patch, indicated by high values for both mobility and mobility slope. Figure 13 (B-4) is a contour plot of web stiffness, showing the effect of the post-tensioning stress pattern in the web.

Fig 10.



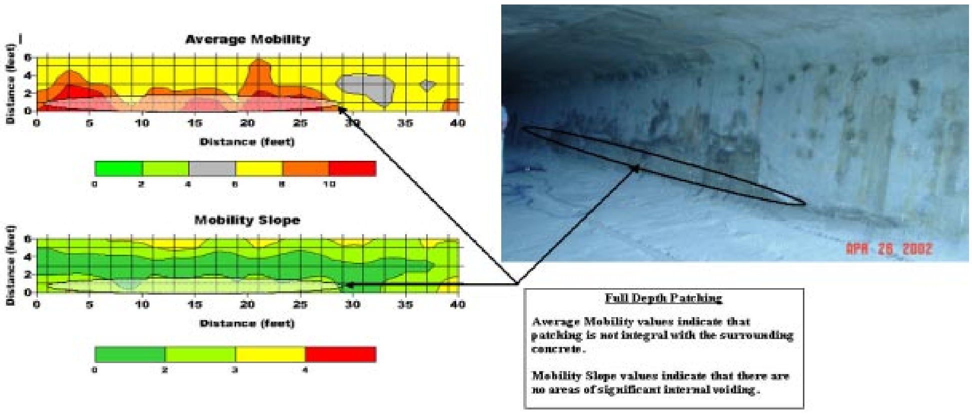


Fig 11.

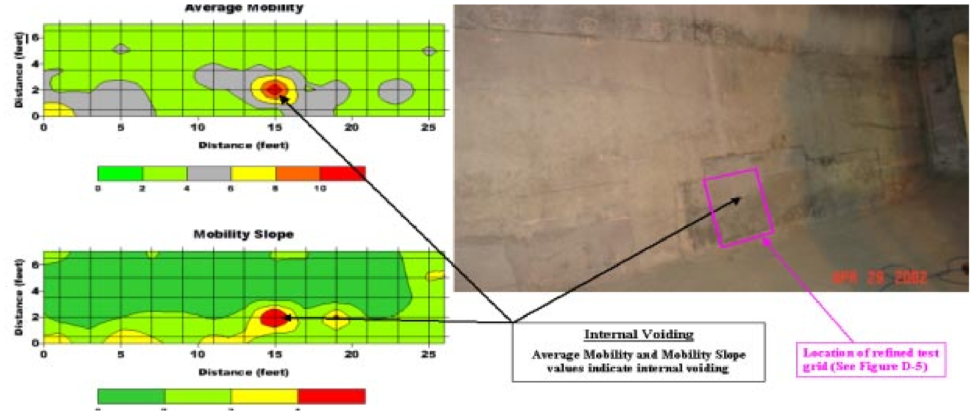


Fig 12.

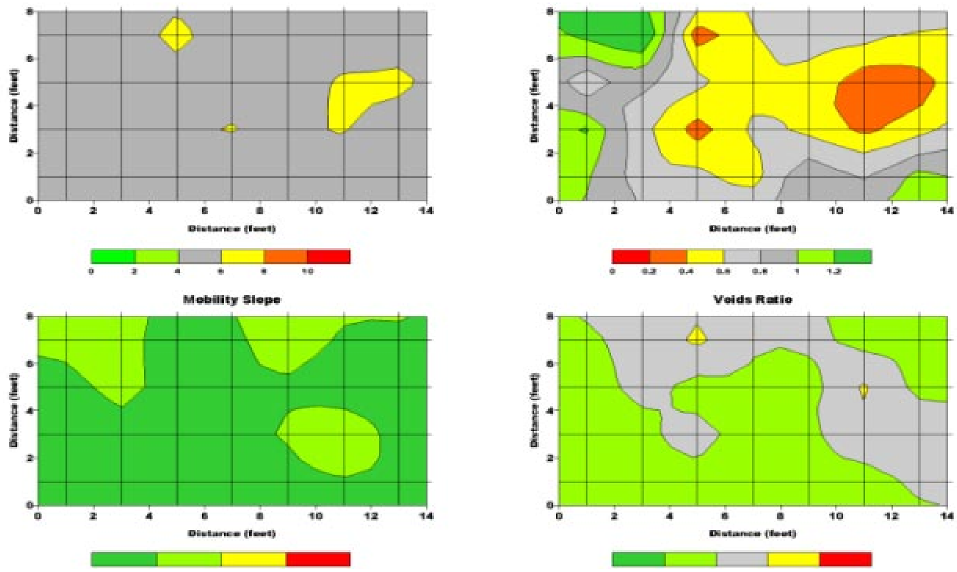


Fig 13.

Conclusion

To fully evaluate the extent and possible implications of the early concreting problems noted within the girder webs and diaphragms, and to gauge the effectiveness of repairs, non-destructive Impulse Response testing was demonstrated on selected precast and post-tensioned girders.

Despite the density of reinforcing steel and the thickness of webs and diaphragms, the testing verified and quantified deficiencies such as incomplete consolidation of concrete and honeycombs, debonded repair patches, and incompletely filled areas of voids.

The IR method is very fast, allowing more than 300 sq m of web and diaphragm to be tested during the 3-day demonstration. This output can be easily increased to 300 – 400 sq m per day for a 2-person testing team. The method also lends itself to rapid interpretation onsite, thereby facilitating repair decisions early during construction.

References

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2. Davis, A.G., 2003. "The Nondestructive Impulse Response Test in North America: 1985-2001". NDT & E International (Elsevier Science), Vol. 36, 185-193.