

Damage Assessment of RCC Bridge Deck by Impulse Response Technique

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ABSTRACT: The Impulse Response (IR) method is a non-destructive testing (NDT) technique, in which the dynamic response of an element resulting from an impact event (hammer blow) is measured with a geophone to determine element's integrity, stiffness, and/or support conditions. The method is excellent for evaluating the repair of slab subgrade support conditions by comparing the support conditions before and after repair. This paper emphasizes on case study of RCC Bridge Deck slab for detecting damage by collecting SIR data at multiple, densely spaced locations to improve the conclusions by mapping relative areas of higher and lower mobility. ASTM Standard C1740-10 prescribed set of parameters, which are computed from the 'mobility plot' which is obtained by dividing the measured bridge deck response by the measured impact force in the frequency domain.

KEYWORDS: Damage detection, RCC Bridge decks, Non Destructive Testing, Impulse Response, Mobility, Voids Index.

I. INTRODUCTION

Structural damage identification has drawn increasing academic interest, as witnessed by the number of relevant journal and conference papers, in recent past. Impulse response testing is advanced form of Non Destructive Testing. The Impulse Response (IR) method is a form of non-destructive testing (NDT) where the dynamic response of an element resulting from an impact blow is measured with a geophone or accelerometer to make conclusions about the element's integrity, stiffness, and/or support conditions. The Impulse Response (SIR) system is designed to identify subgrade voids below on-grade concrete slabs that are less than two feet thick. The SIR method cannot identify the actual depth or thickness of possible voids, but can determine the lateral extent. The SIR method can also be used on other concrete structures to quickly locate areas with delaminations or voids in the concrete. SIR can be performed on reinforced and non-reinforced concrete slabs as well as asphalt or asphalt-overlay slabs.

NDT is a wide group of analysis techniques used in science and technology industry to evaluate the properties of a material, component or system without causing damage. A Doctor testing a patient; an Engineer tests the fitness of the material. So, NDT is necessary because it does not destruct the structure while testing in any form. The need to ensure safety, NDT can be used to improve output and profitability. A structure can be tested many times using several types of tests through the complete life cycle to ensure its continued integrity. Choosing the right method and techniques is an important part of the performance of NDT.

Impulse Response Testing Method

The Impulse Response Test developed in the late 1970s in France is a surface reflection technique that relies on the identification of P-wave reflections. With advancements in computers and data acquisition systems, IR method is being used for other civil infrastructure beyond piles. Hertlein and Davis documented the first application of this method to concrete slabs in 1987 [2]. In 2004, Ottosen et al. presented the first, and as far as we are aware the only, attempt to explain the IR method on concrete plate-like structure, where an analytical solution was derived to identify the mobility of a concrete beam resting on a bed of sand. The effects of loss of support and concrete honeycombing on the mobility were derived and presented [4]. The test is executed by impacting with an impulse hammer, which induced transient

vibrations (up to 2 kHz). The impulse response function is a characteristic of a structure and it changes depending on geometry, support conditions and the existence of defects.

The Slab Impulse Response (SIR) system is designed to identify subgrade voids below slabs-on-grade less than two feet thick. In addition, the Slab IR test method can be used on other concrete structures to quickly locate areas with delaminations or voids in the concrete, if the damage is relatively shallow. Slab IR can be performed on reinforced and non-reinforced concrete slabs as well as asphalt or asphalt-overlay slabs. Figure 1 shows the picture of impulse response testing apparatus used.



Fig 1: Slab Impulse Response Testing Apparatus

Working Principle

The operating principle is based on a low strain impact produced by a hammer with a rubber tip. Stress waves sent through the tested elements. The impact causes vibrations in the element and stimulates primarily flexural form. A velocity receiver set near to the point of impact, takes the response. The load cell and the velocity receiver are connected to a laptop computer analyze the results. The function of the force in time, which is produced by the hammer and the measured velocity response, is transformed in the frequency domain using the Fast Fourier Transformation (FFT). The range of velocity response divided by the range of force and the "mobility" is shown as a function of frequency. The resulting impulse response spectrum has units of velocity/force, which is referred to as mobility. The mobility plot provides information on the dynamic stiffness of the structure. The mobility is given in units of speed per power (m / s) / N. Figure 2 below shows typical mobility plot.

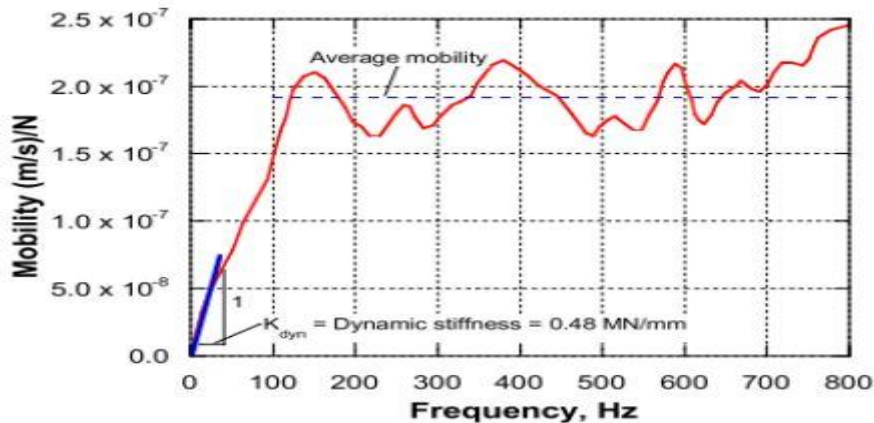


Fig 2: Typical Graph of Mobility vs. Frequency

ASTM Standard C1740-10 [1] entitled Standard Practice for Evaluating the Condition of Concrete Plates Using the Impulse-Response Method is the current test standard used in practice for condition assessment of concrete plates using the IR method. This standard recommends performing IR tests and estimating the mobility at each point of interest. The parameters used in the Slab IR data interpretation of the mobility plot used for assessing integrity are:

- i. The dynamic stiffness: The inverse of initial slope of the mobility plot from 0 to 40 Hz. The standard correlates this parameter to the elastic modulus, thickness, support conditions, and presence of internal defects.
- ii. The average mobility (lined bar): The average mobility between 100 – 500 Hz is related directly to density, elastic modulus, and thickness of the plate element. A reduction in the plate thickness results in an increase in mean mobility. Cracking or honeycombing in the concrete will reduce rigidity thus an increase in mean mobility. Peak to Mean Mobility Ratio: This ratio is the indication of voids, when this value exceeds 2.5.

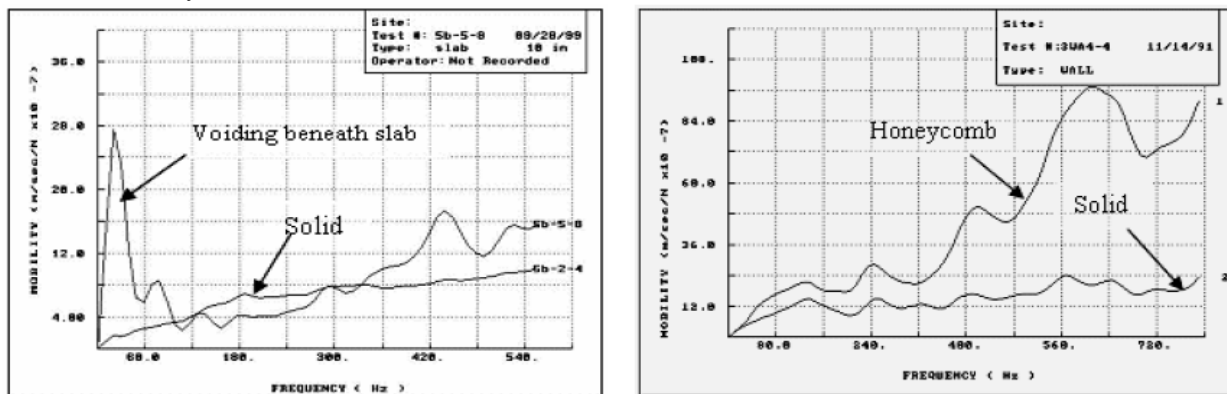


Fig 3: Typical response due to flaws compared with sound responses. If a delamination or void is present under a structure, a high mobility is measured at low frequencies (left figure). If honeycomb in concrete is present, an increasing slope in the mobility plot is seen (right figure).

- iii. The mobility slope: Mobility Slope is determined by a best-fit line to fit the mobility within the frequency range of 100 to 800 Hz.[5] The mobility of honeycomb concrete shows increasing mobility with increasing frequency over the frequency range of 100 – 800 Hz whereas solid concrete shows a relatively constant mobility over the same frequency range. This parameter is used mainly to detect areas of poorly consolidated concrete.
- iv. The voids index: The ratio of the maximum initial mobility to the average mobility. If delaminations are present or there is a lack of support of the structure, the peak mobility below 100 Hz is much higher than the average mobility (See the left side of Figure 3). If the value of the Voids Index is larger than 2-4 it's an indication of an area with a potentially poor condition (delamination or no support).[9]

II. MOTIVATION FOR CURRENT RESEARCH

The strengths of the IR method following the aforementioned ASTM Standard lie in its inherent simplicity: only one actuator (hammer) and one sensor (geophone) are used, in conjunction with, typically, a laptop computer with a basic DAQ system. The method is thus relatively inexpensive in application, fast, and flexible. First, experimental IR data from a number of real measurements for damage assessment from a bridge are presented. Data are collected over sound and delaminated areas. Next, suggestions & results are given.

III. THE PEDHI RIVER BRIDGE : CASE STUDY



Fig 4: Photograph of Pedhi river bridge site

The Pedhi river bridge was constructed on October, 1883. The Pedhi River, a tributary of Purna River, falls under Tapi River basin. The Pedhi flows in a general south-easterly course passing by Walgaon and Bhatkuli. The bridge has moderate traffic during the day, but severe while peak hours. The bridge deck is made up of RCC and the piers and abutments are of coarsed rubble masonry. The bridge consists of 18 piers of length and width of 6.5 m and 1.5m respectively. The span is 250 meters long. The bridge site is selected by considering the year of construction (age more than 50 years) and by studying type and occurrence of deteriorations (spalling, delaminations and cracks over piers) on particular deck slab the same are rectified on site from visible observations.

Test methodology is applied at respective test points with the help of Slab Impulse Response testing apparatus of Olson Instruments. Impulse Response testing is carried out in two phases, viz. firstly for pier to pier distance of 20 meters to identify the deteriorations at closely spaced intervals of 1 meter and secondly for whole bridge deck span of 250 meters with 98 test points with interval at 3 meters apart. Widening of bridge is done in 2001, at that time renovation of bridge is done but cracks and holes as outlets for rainwater are clearly visible above the piers as shown in figure 5.



Fig 5: Photograph showing deteriorations above pier and outlet holes for drainage from deck.

IV. RESULTS

The experimental data is collected from NDE 360 platform and analyzed in WinSIRSoftware;the defects observed above piers and at mid span are correlated.

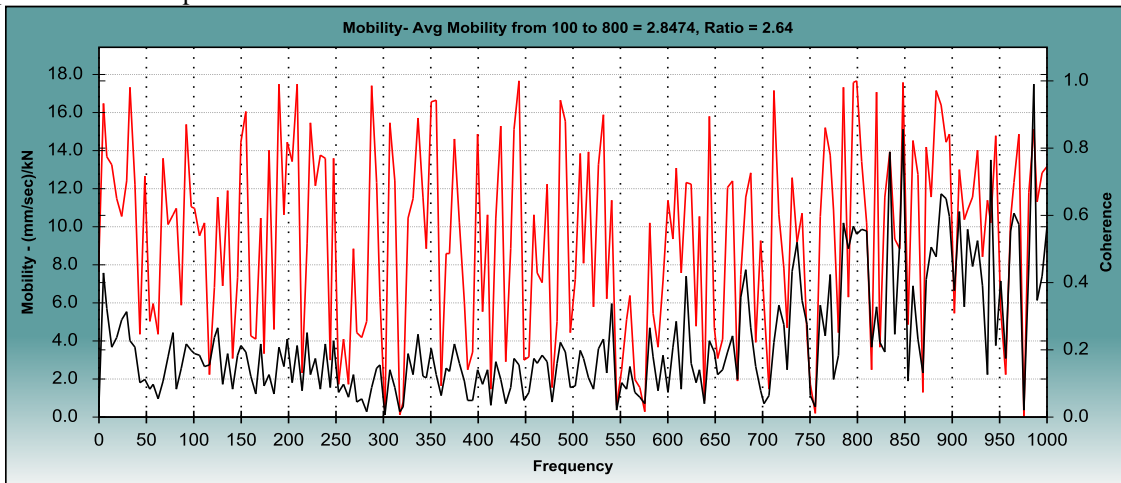


Fig 6: Mobility plot for test point 1.

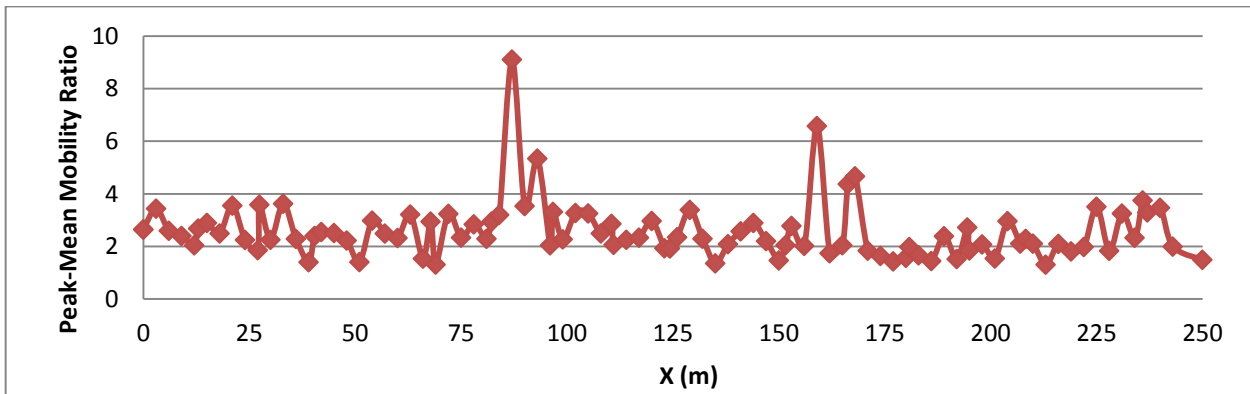


Fig 7: Graph of peak-mean mobility ratio versus distance for complete span (0 to 250meters) of bridge deck

Table below shows average mobility, peak to mean mobility ratios for test points with rectified deteriorations and the values for mid span are showing solid slab with no flaws and at test points above piers are beyond the ASTM standards showing voids.

Table 1: Results at different locations with detected voids(Ratio>2.5)

Test Point	Location	X (m)	Filename	Avg Mobility ({mm/sec} / kN)	Peak-Mean Mobility Ratio
6	Mid span	12	decki6.nde	4.4902945	2.0452496
7	Above Pier	12.94	decki7.nde	2.7281007	2.6822906
8	Mid span	15	decki8.nde	3.4078327	2.896878
12	Mid span	27	decki12.nde	6.1018364	1.8600095
13	Above Pier	27.39	decki13.nde	3.0656246	3.5888138
14	Mid span	30	decki14.nde	2.8869808	2.2556082
31	Mid span	75	decki31.nde	3.1746438	2.3382823
36	Above Pier	87	decki36.nde	3.4564225	9.1044459
39	Mid span	96	decki39.nde	3.462328	2.0452399

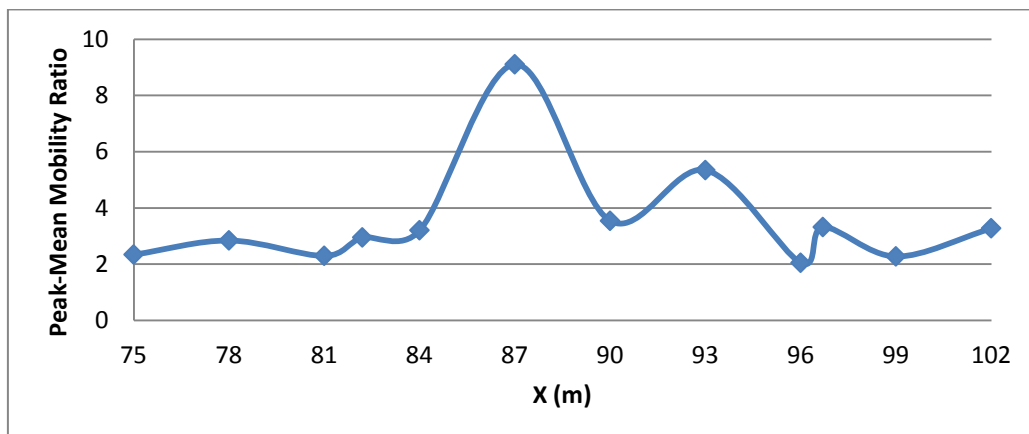


Fig 8. Graph showing maximum peak-mean mobility ratio versus distance (75 to 102 meters).

V. CONCLUSIONS

In this paper, the Slab Impulse Response (SIR) method for use on concrete bridge decks is investigated. Here we have discussed advantages and limitations of the standard method (ASTM C1740-10) that we have observed while applying the method to detect shallow deteriorations, with the aim of providing a better understanding of the underlying physical principles. The following can be concluded:

- i. Flexural resonance of deteriorations can occur outside of the frequency range of 0 to 800 Hz that is defined by the ASTM Standard.
- ii. Most Standard parameters do not monotonically change with the delamination size. As a result, even if the location of a delamination is known, its size cannot be uniquely determined.
- iii. Cracks above piers and at midspan (some points) have been detected successfully with SIR technique.

The results indicate interesting behaviors with respect to mobility plots and that should be investigated further. In particular we propose study of more physically meaningful IR parameters in the time domain, consideration of higher frequencies, repentance of similar patterns for mobility plots and study of effect of location of impact relative to delamination.

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