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NON-DESTRUCTIVE DAMAGE ASSESSMENT OF RCC BRIDGE DECK SLAB 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. According to research studies, nowadays modern NDT methods have become more quantitative and less obtrusive, which in many scenarios, translates into savings over time. As a result, these advanced NDT methods have the potential that could lead to significantly lower repair rates while maintaining existing safety standards as long as adequate criteria and procedures are adopted. This paper emphasize on experimental analysis of deck slab model by Impulse Response Method for detecting damage by collecting SIR data at multiple, densely spaced locations to improve the conclusions. Test model is constructed with pre-The damages are localized by analyzing in WIN SIR Software by Olson Engineering. ASTM Standard C1740-10 prescribed parameters are also found out.

Keywords: Non Destructive Testing, Impulse Response, Mobility, Honeycombing and Voids Index.

I. INTRODUCTION

Identification of Structural damage has evolved a prior need before doing Structural Audit of civil structures like buildings, roads and bridges. Damage is change to the material and/or geometric properties of a structural or mechanical system, including changes to the boundary conditions and system connectivity, which adversely affect current or future performance of that system. 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 in the same way an Engineer tests the fitness of the material. So, NDT is necessary because it does not destruct the structure while testing in any form and can be tested many times using several types of tests through the complete life cycle to ensure its continued integrity.

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. The introduction of portable computers and small data acquisition cards has improved the data quality and allowed the possibility to gather large amounts of test data within a short period of time.

In this paper, Test slab has been provided with damages at pre-known locations and precisely constructed. IR Testing is done and certain set of parameters suggested by ASTM Standard C1740-10 [1] such as Average mobility, Mobility slope & Peak-Mean mobility ratio are found out. Honeycombing and Debonding at pre localized positions in test slab are identified using IR Technique successively.

1.1. 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 [3]. 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 [5].

The Slab Impulse Response (SIR) system is designed to identify subgrade voids below slabs-on-grade less than two feet thick. 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. Slab IR can be performed on reinforced and non-reinforced concrete slabs as well as asphalt or asphalt-overlay slabs. Figure 1.1 shows the picture of impulse response testing apparatus used.

Fig 1.1: Slab Impulse Response Testing Apparatus

1.2. Working Principle

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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 computer to analyze the results[11. 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). Figure 1.2 below shows Test Set-Up and Apparatus for Impulse-Response Test.

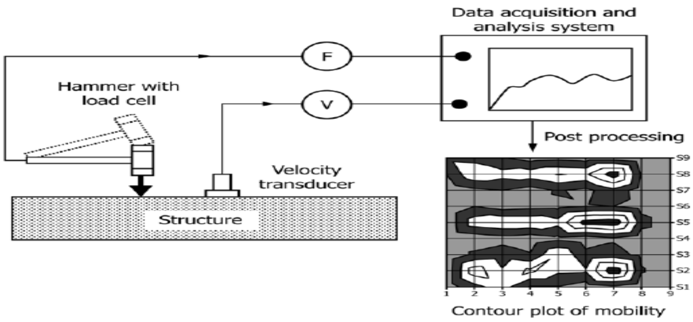

Fig 1.2.: Schematic of the Test Set-Up and Apparatus for Impulse-Response Test (Courtesy: ASTM C1740-10)

The range of velocity response divided by the range of force and the "mobility" is a function of frequency. The resulting impulse response spectrum has units of velocity/force, which is referred to as mobility given in units of speed per power (m / s) / N. The mobility plot provides information on the dynamic stiffness of the structure. Figure 1.3 below shows typical mobility plot [10].

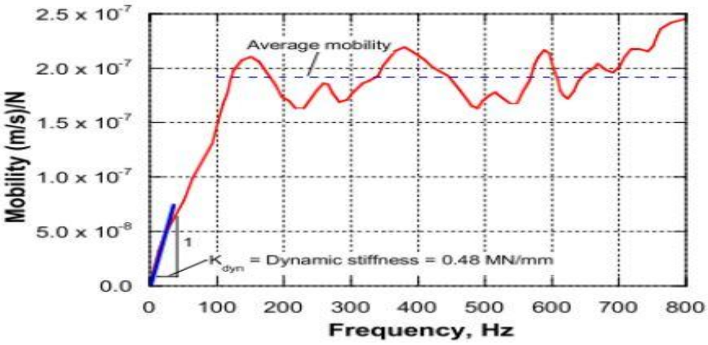

Fig 1.3: Example of a Mobility Spectrum obtained from an Impulse Response Test

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 test slabs using the IR method. The parameters used in the Slab IR data interpretation of the mobility spectrum used for assessing integrity are:

Sr. No.	Parameter	Description
1.	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.

2.	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[3][8].
3.	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.[9]
4.	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]

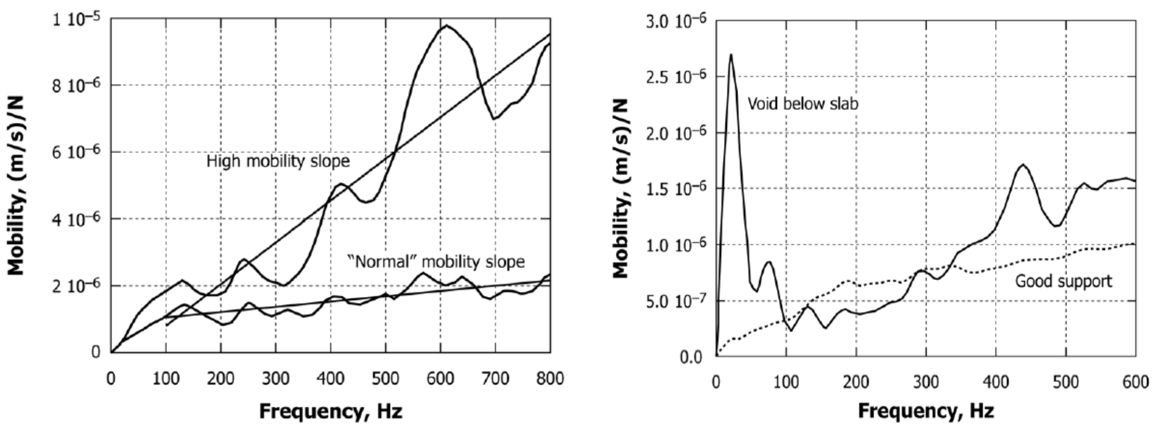

Fig 1.4.: Typical response due to flaws compared with sound responses.

If honeycomb in concrete is present, an increasing slope in the mobility plot is seen (left figure). If a void is present under a structure, a high mobility is measured at low frequencies (right figure).

II. METHODOLOGY

Test slab under consideration is 2 x 1.5 x 0.25 m. of M - 25 grade (nominal mix is adopted) including steel centering, plywood/ steel formwork , steel props, compaction, finishing uneven and honeycombed surface with CM 1:3 of sufficient minimum thickness to give a smooth and even surface or roughening surface if special finish is to be provided and fixing reinforcement in position of various diameters including cutting, bending, hooking the bars binding with wires or tack welding and supporting as required. The R.C.C. Slab is provided with plastic sheets covering steel bars, corroded reinforcement cage and pre- embedded honeycombed portion in position as per detail drawing given in figure 2.

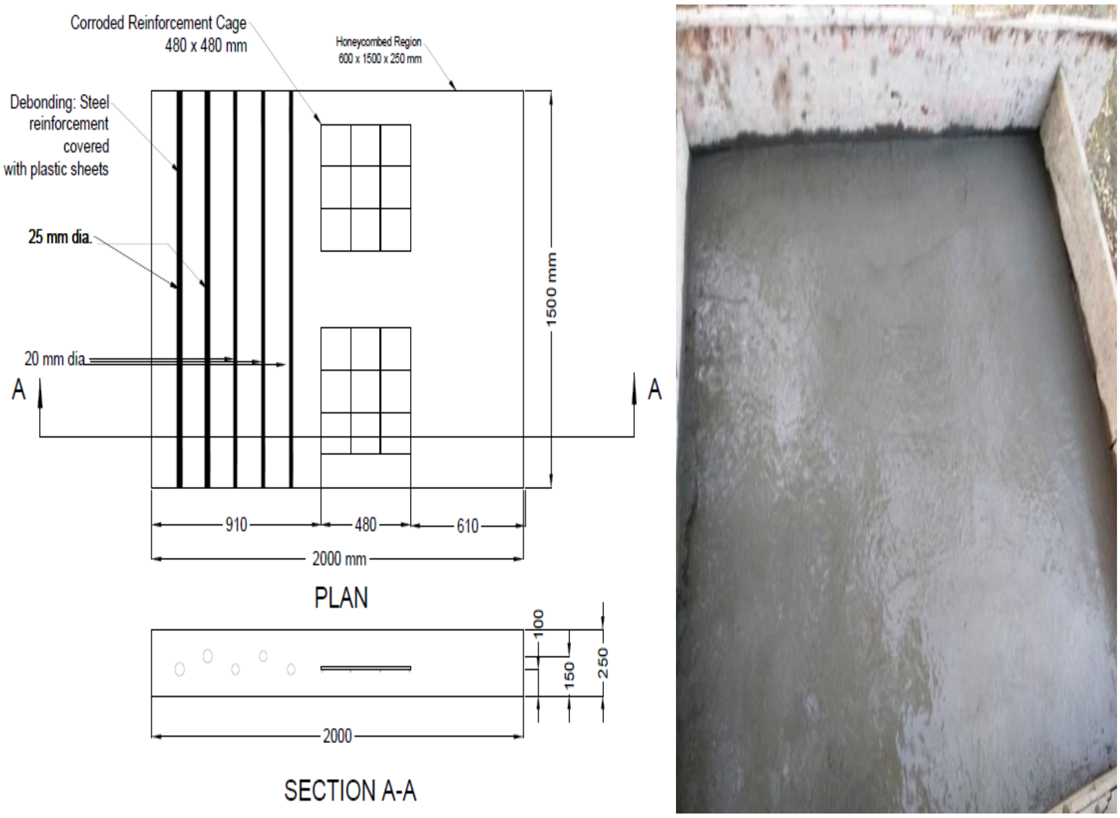

Figure 2.1: Test slab drawing(left) Finished slab(right).

Figure 2.2. IR Testing in action on Honeycombed surface

Figure 2.3: Corroded cage

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Figure 2.4: Reinforcement bars covered with plastic sheets fixed in position.

The test locations are selected as per localized locations from drawing for IR testing. Impulse response is successfully applied over the test slab and results are collected from NDE 360 Platform and analysis is done in WinSIR Software.

III. RESULTS

Damage		Filename	Average Flexibility (mm/kN)	Average Mobility (mm/sec)/kN	Peak-Mean Mobility Ratio	Remarks
Debonding	Bar1	sir1.nde	0.1554223	9.7763388	4.0502845	Debonding is steel reinforcement having no contact with concrete. It is provided by covering the reinforcement bars with plastic sheets. Peak mean mobility values > 2.5.
		sir2.nde	0.1347841	8.1425847	3.8708802	
		Sir3.nde	0.1005235	12.1598538	2.1448261	
		Sir4.nde	0.1672924	15.1229262	2.6076683	
	Bar2	sir13.nde	0.1528993	6.9166772	5.920857	
		sir14.nde	0.1281111	9.3419071	3.53703	
		sir15.nde	0.1238307	7.8289261	4.1312573	
		sir16.nde	0.1597492	10.4685446	4.2847392	
	Bar3	sir17.nde	0.1361266	6.5039407	4.7656395	
		sir18.nde	0.1127378	7.7560469	3.3578355	
		sir19.nde	0.1628649	7.8450255	4.9653699	
		sir20.nde	0.1849497	8.1108065	5.713929	
	Bar4	sir21.nde	0.1352309	7.1978679	5.2748056	
		sir22.nde	0.1522349	6.3532567	6.0508735	
		sir23.nde	0.1894598	9.3796013	5.0725597	
		sir24.nde	0.2029937	9.2331657	6.0407967	
	Bar5	sir25.nde	0.1531794	8.8478566	5.0647885	
		sir26.nde	0.1668374	11.1122771	4.0175557	
		sir27.nde	0.2383115	14.7406072	4.2186926	
		sir28.nde	0.3758796	16.7322788	5.0669202	

Corrosion C1: Cage 1 C2: Cage 2 480x480 mm	C1	sir32.nde	0.2675844	7.1120551	4.0345862	Two Corroded reinforcement cages not show proper inference and need to be analysed further.
		sir33.nde	0.1005704	6.7460263	4.3027493	
		sir34.nde	0.1229476	7.7138238	4.1254178	
		sir35.nde	0.1057913	6.9780518	3.9919175	
	C2	sir36.nde	0.1138736	7.0314526	3.6455207	
		sir37.nde	0.2009689	8.4942865	6.1140532	
		sir38.nde	0.0984566	6.4594267	4.4448219	
		sir39.nde	0.10167	7.6238052	4.2302336	
Honeycombing		sir40.nde	0.2028536	117.4257239	0.5623612	A reduction of the thickness of the slab results in an increase in avg mobility referred to honeycombing.
		sir41.nde	0.0940118	150.9663379	0.5340089	
		sir42.nde	0.1740315	187.1648096	0.3074478	
		sir43.nde	0.1923518	160.4202781	0.4656907	
		sir44.nde	0.1528436	90.6432355	0.6209383	

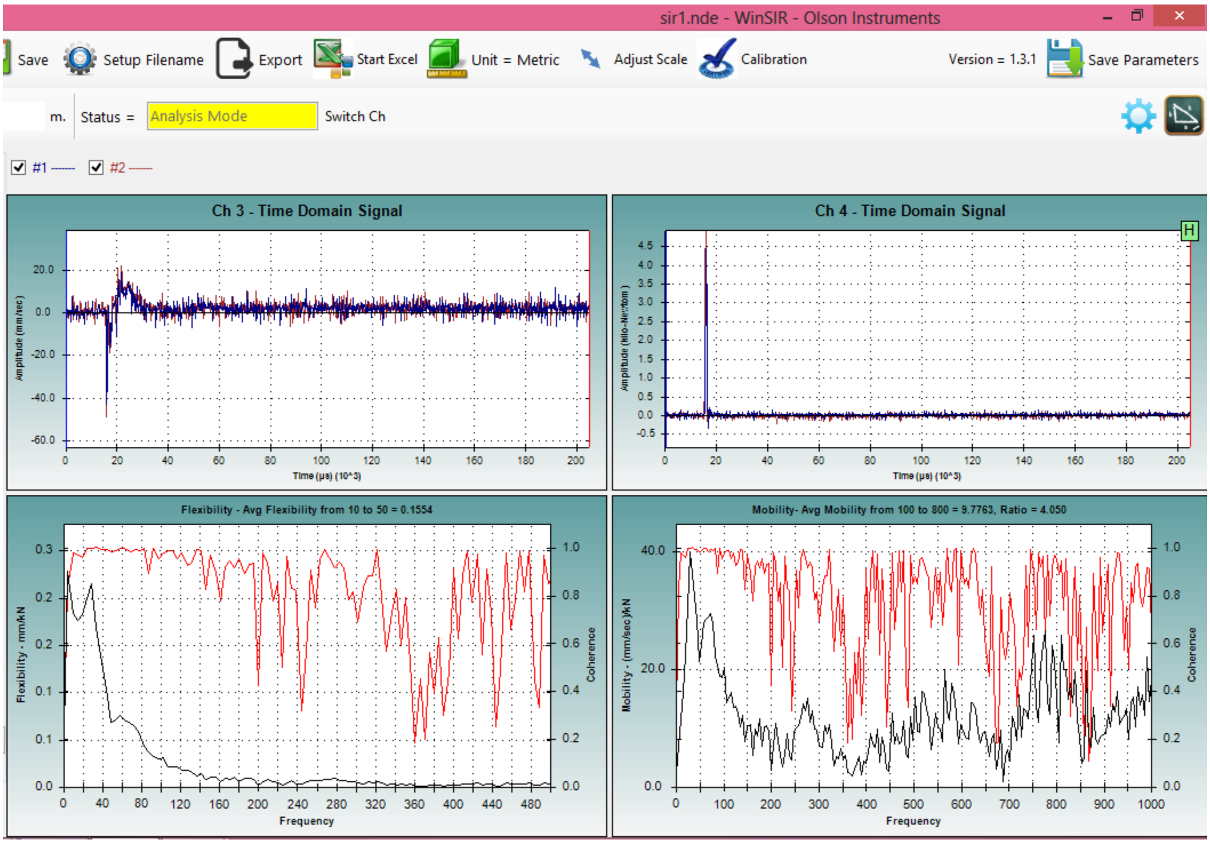

Figure 3.1: WinSIR window for Test point 1 over debonded bar1.

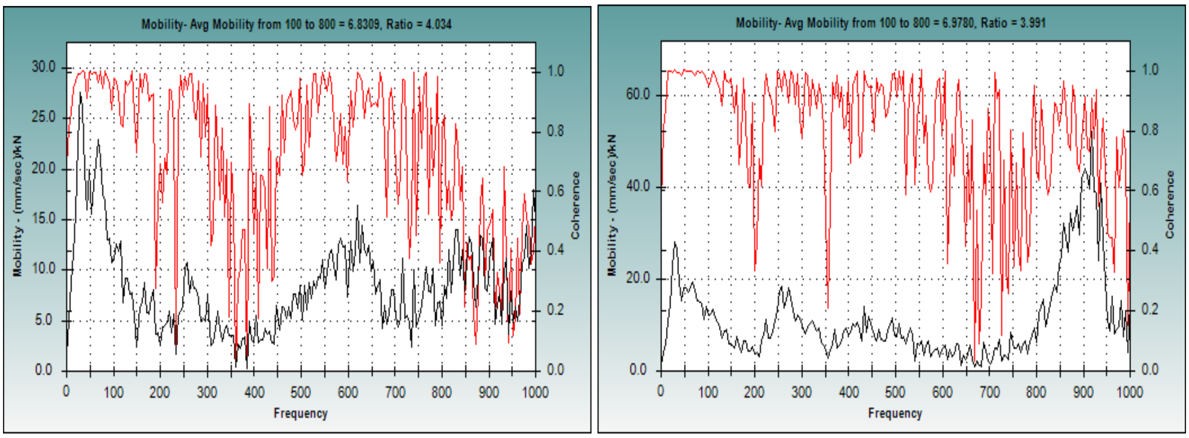

Figure 3.2: Mobility plots for sir 32 and sir 35 readings indicated corrosion.

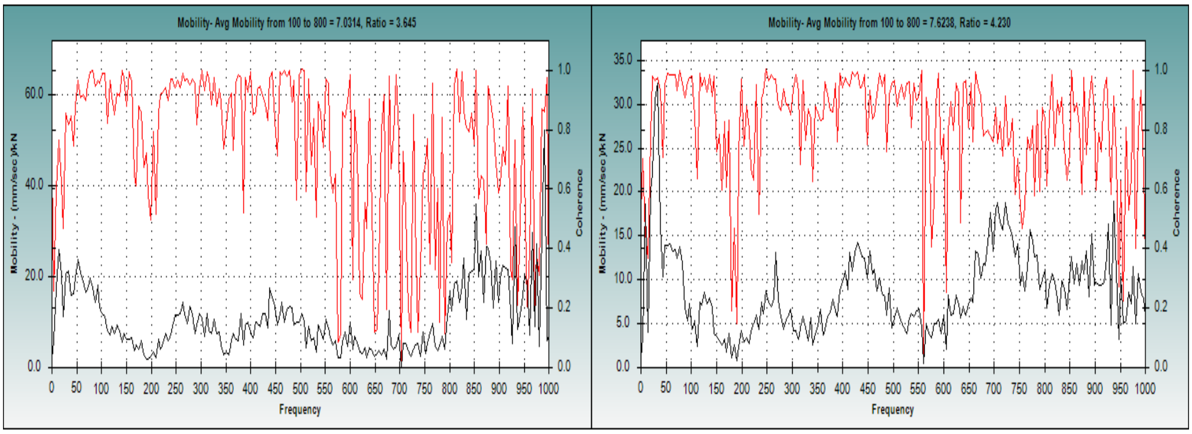

Figure 3.3: Mobility plots for sir 36 and sir 39 readings indicated corrosion.

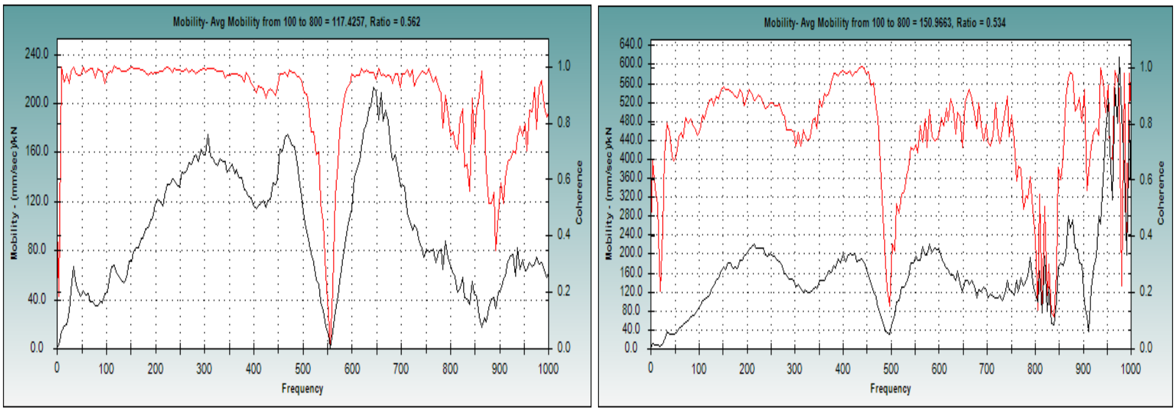

Figure 3.4: Mobility plots for sir 40 and sir 41 readings indicating Honeycombing.

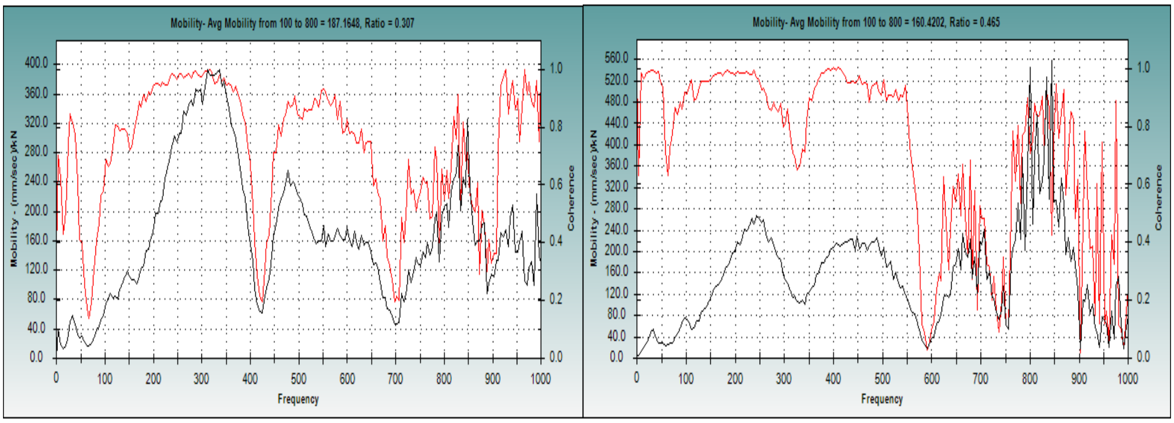

Figure 3.5: Mobility plots for sir 42 and sir 43 readings indicating Honeycombing

IV. CONCLUSIONS

i. Mobility plots are successfully obtained for all the test points taken using WinSIR Software.

ii. From the mobility plots for debonded bars show similar inference w.r.t. ASTM 1740-10 and the Peak to Mean mobility values are greater than 2.5 so debonding of reinforcement is localized.

iii. Mobility plots for corrosion showed that average mobility values and mobility plots are nearly same for all readings as compared to normal reinforcement bars provided in the test slab.

iv. Honeycombing of concrete is localized successfully with repeated same patterned mobility plots and decrease in mobility values for test points sir 40 to sir 44 w.r.t. codal provisions in ASTM 1740-10.

v. IR Technique is proven to be feasible for actual bridge site with deteriorations such as voids, honeycombing, debonding, corrosion, etc.

V. ACKNOWLEDGEMENTS

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