Impulse Response (IR)

Target of Investigation

Impulse response methods can be used to evaluate pavements by detecting the following:

- Debonding, delamination, and honeycombing within concrete pavement.
- Voids below concrete slabs and at joints.

Distress at the interface of a portland cement concrete overlay and concrete pavement can induce debonding. Debonding will destroy the integrity of the pavement and cause a loss of structural capacity. Delamination in concrete pavements is caused by inappropriate construction and distress from rebar corrosion.[1] Without proper treatment, delamination may cause further deterioration problems, such as spalling. Honeycombing in the pavement can be caused by a poorly graded concrete mix or insufficient vibration at the time of placement. Honeycombing can provide paths for moisture and cause further deterioration owing to freeze–thaw cycles or rebar corrosion. Voids below the concrete surface course usually occur near cracks and joints or along the pavement edge. Voids can be caused by many factors, such as the expulsion of water and soil through an open joint or shoulder under traffic loads, the compaction of base materials, subgrade failure, and bridge-approach failure. Voids may cause distress and serviceability loss in concrete pavements.

Description

The impulse response method is a nondestructive testing method used in quality control and condition assessment of pavements and deep foundations. The method was first developed in the 1970s and used in performing quality control for drilled shafts. More recent uses of the impulse response method include determining subgrade moduli and detecting the presence of voids or loss of support below rigid pavements and slabs and in reinforced concrete bridges and concrete tunnel linings. The method uses a mobility spectrum to measure the dynamic response of concrete pavement. Damaged areas are detected when the mobility spectrum takes significantly different shapes and amplitudes from those at sound locations.[2] An impulse response testing system is shown in figure 1.

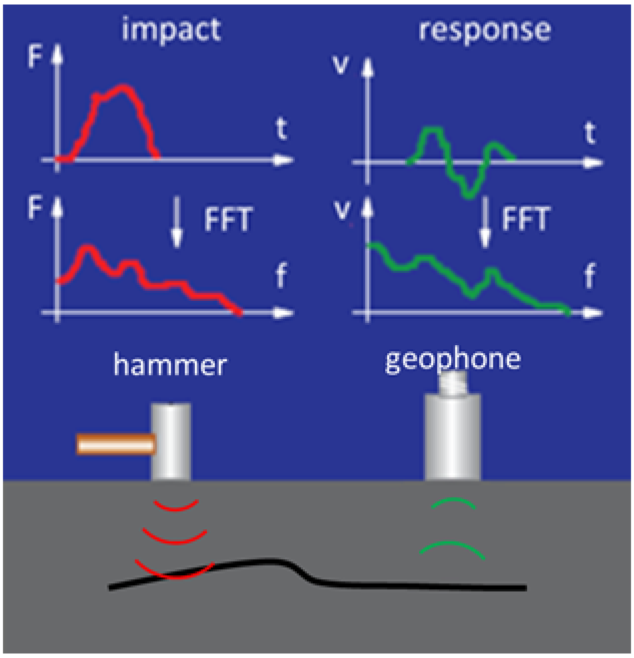
Source: FHWA.

Figure 1. Photo. Impulse response testing system.

This photo is of an impulse response testing system. There is a black hammer, a velocity transducer, and a laptop sitting on top of a data acquisition box. The hammer and transducer are connected to the data acquisition system by cables.

Physical Principle

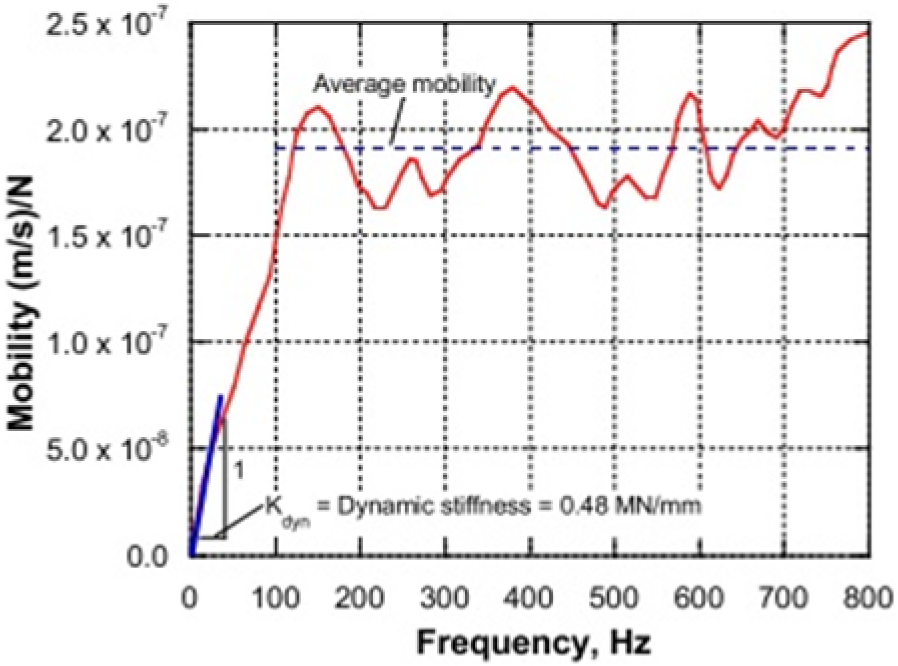
The impulse response method evaluates the dynamic characteristics of a structural element's response to a given impulse. As shown in figure 2, an impact load is applied on the surface of the pavement with an instrumented hammer; the resulting stress wave propagates in the pavement and is reflected by the interfaces. The dynamic response is measured using a geophone at a nearby location on the surface. The signal of the applied impact force and the response from the geophone are transformed into the frequency domain to obtain the corresponding spectrum. The ratio of the measured velocity response to the impact force in the frequency domain is called the mobility spectrum. An example of a mobility spectrum is shown in figure 3. Compared to the impact echo method, the impulse response method relies more on the structural response under the impact, and the frequency range of interest is also much lower.



Source: FHWA.*F* = force; *f* = frequency; *t* = time; *V* = velocity; FFT = fast Fourier transform.

Figure 2. Illustration. Signal processing of impulse response test.

This illustration is a schematic of signal processing. Impulse response testing is shown in the lower part of the figure. A block represents the concrete pavement, and a curve through the block represents a defect. The hammer impacts the surface of the concrete, and the response of the concrete is picked up by the geophone. In the upper part of the figure are four charts. Two charts show the impact. The upper left chart, with an x-axis representing time and a y-axis representing force, shows the force signal in the time domain. The lower left chart, with an x-axis representing frequency and a y-axis representing force, shows the force in the frequency domain after fast Fourier transforming. Two charts show the response. The upper right chart, with an x-axis representing time and a y-axis representing velocity, shows the velocity signal in the time domain. The lower right chart, with an x-axis representing frequency and a y-axis representing velocity, shows the velocity in the frequency domain after fast Fourier transforming.



© 2018 Germann Instruments.1 (m/s)/N = 0.737(ft/s)/lbf.

Figure 3. Graph. Example of a mobility spectrum.[(3)]

This graph has an x-axis representing frequency in hertz that ranges from 0 to 800. The y-axis represents mobility, ranging from 0 to 2.5 times 10 to the power of negative 7 meters per second per newton. A curve on the chart represents the mobility spectrum. A dashed line represents the average mobility at between 100 and 800 hertz on the x-axis and at about 1.9 times 10 to the power of negative 7 on the y-axis. The reciprocal of the slope of the solid line represents the dynamic stiffness, which equals 0.48 meganewtons per millimeter.

Data Acquisition

ASTM C1740-10, *Standard Practice for Evaluating the Condition of Concrete Plates Using the Impulse-Response Method*, provides the procedure for using the impulse response method to rapidly evaluate the condition of existing concrete pavements.[(4)] The equipment manufacturer's instructions should also be followed to operate the equipment correctly. The general procedures for data collection on pavements are summarized as follows:

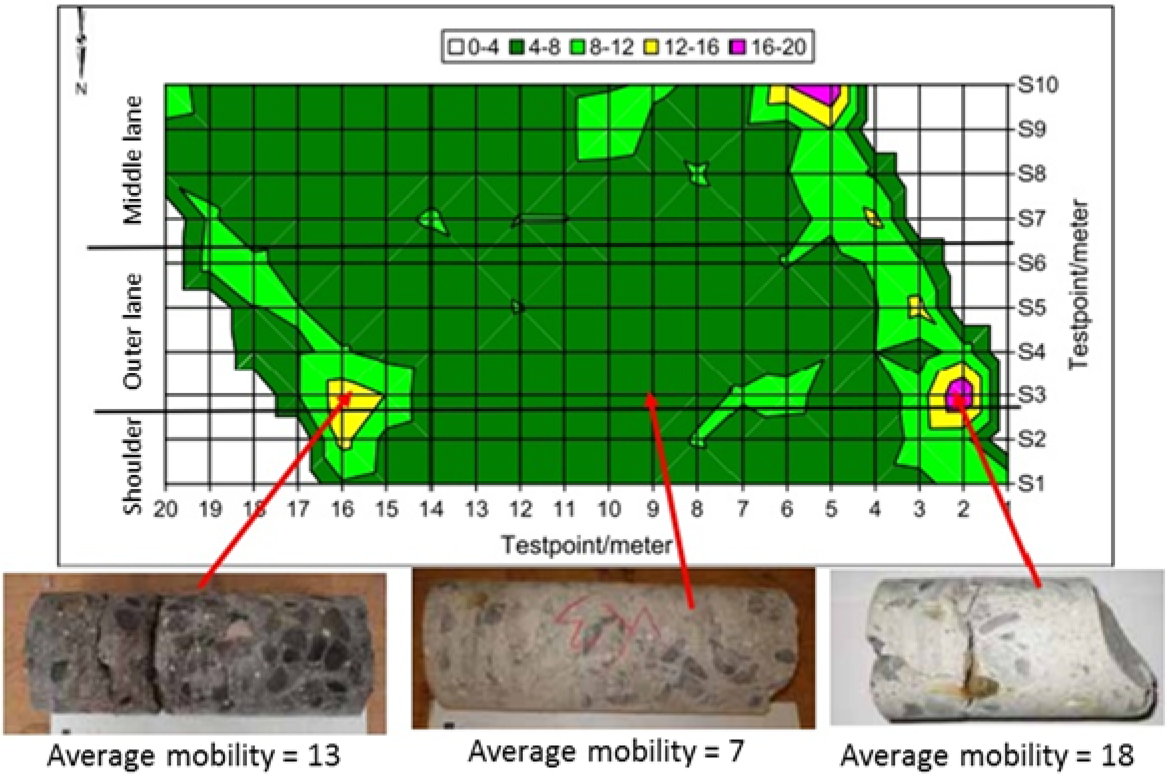
1. Remove any debris from the survey area to prepare the surface. Grind the surface if it is too rough. Remove loose material before placing the transducer on the surface. Make sure of good contact and proper impact between the hammer and pavement.
2. Lay out a grid on the surface of the concrete slab to be tested. Grid spacing normally ranges between 500 and 2,000 mm (20 and 80 inches). Closer spacing can be used for smaller slabs or to locate smaller anomalous regions.
3. Impact the concrete surface with a hammer to generate transient stress waves in the concrete.
4. Measure the response with a geophone placed adjacent to the impact load.
5. Record the force and velocity waveforms with a data acquisition system. The system can synchronize data acquisition of the impact load and velocity response.

Data Processing

The impact force is measured by the load cell, and the velocity is measured by the geophone. These signals are then transformed from the time domain to the frequency domain by using the fast Fourier transform. The mobility spectrum is obtained by dividing the velocity spectrum by the impact force spectrum at each test point. The mobility spectrum summarizes the response of the concrete pavement as a function of frequency. Key parameters, such as the average mobility and dynamic stiffness, are computed from the mobility spectrum for each test point. Average mobility is calculated from the mobility values over the 100–800 Hz frequency range. Dynamic stiffness is calculated as the inverse of the slope of the mobility spectrum up to 40 Hz. A series of regularly spaced, high peaks in the mobility spectrum usually indicate resonant frequencies.

Data Interpretation

Average mobility and dynamic stiffness are related to density, elastic modulus, thickness, and presence of internal defects. Average mobility and dynamic stiffness can be displayed in the form of contour plots in order to identify likely locations of anomalous regions. An example contour map of the average mobility of a bridge slab is shown in figure 4. The locations of three drilled core samples are labeled.[3]



© 2018 Germann Instruments.Note: S1–S10 are grid line names.1 m = 3.3 ft.

Figure 4. Contour map. Average mobility and related cores.[3]

This figure consists of a contour map and three photos. The contour map shows the results of impulse response testing for a concrete slab. The x-axis is the test point in meters ranging from 20 to 1, and the y-axis is the test point in meters ranging from S1 to S10. The map is divided according to the lanes of the slab, and is labeled "Middle lane," "Outer lane," and "Shoulder." A color-coded scale of the average mobility ranges from 0 to 20. On the map, most of the area has values between 4 and 8. The lower left corner (with x values between 20 and 17 meters and y values between S1 and S6) and the upper right corner (with x values between 4 and 1 meters and y values between S4 and S10) show low values between 0 to 4. High values between 16 and 20 are found near coordinates (2, S3) and (5, S10), and another high value between 12 and 16 is found near the coordinate (16, S3). In the lower part of the figure, photos of three cylinders of concrete are linked to the map by arrows. The cylinder on the left has a wide crack. It is linked to the location (16, S3) and has an average mobility of 13. The cylinder in the middle has no crack. It is linked to the coordinate (9, S3) and has an average mobility of 7. The cylinder on the right has a crack, and its bottom part is missing. It is linked to the coordinate (2, S3) and has an average mobility of 18.

When debonding or delamination is present within the concrete surface course or voids exist beneath it, average mobility will increase and dynamic stiffness will decrease greatly. The peak mobility below 100 Hz becomes appreciably higher than the average mobility between 100 and 800 Hz. Voids beneath slabs are more likely when the ratio of this peak to average mobility exceeds 2.5.[5] Figure 5 is an example of the mobility spectrum for locations where voids exist beneath the pavement.

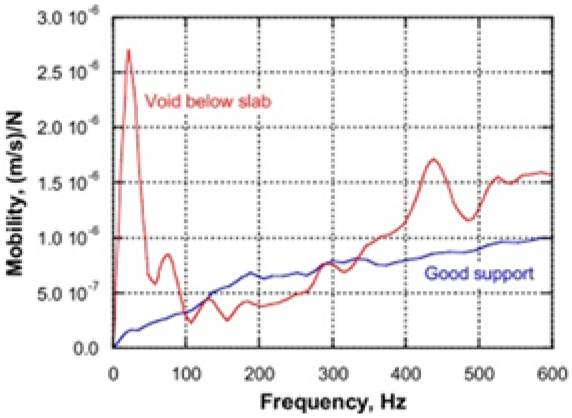


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Figure 5. Graph. Comparison of mobility spectrums for concrete with good support and concrete with a void.[3]

The x-axis of this graph is frequency in hertz, ranging from 0 to 600. The y-axis of this graph is mobility, ranging from 0 to 3 times 10 to the power of negative 6 meters per second per newton. Two curves in the chart represent mobility spectrums. One curve represents the mobility spectrum when a void is below the concrete slab; it shows a peak at 20 hertz. The other curve represents good support under the concrete slab; it is rising slowly.

When honeycombing exists in a concrete pavement, mobility increases with frequency over the frequency range of 100–800 Hz.[6,7] As shown in figure 6, the mobility slope is determined from the best linear fit to the mobility spectrum between 100 and 800 Hz. A contour plot of the mobility slope can be used to indicate regions where honeycombing is likely owing to poor consolidation.

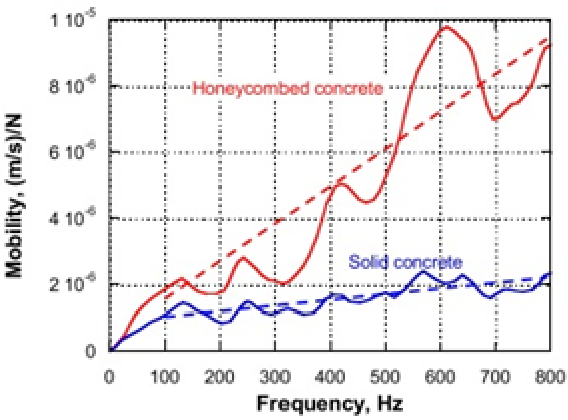

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Figure 6. Graph. Comparison of mobility spectrums of solid concrete and honeycombed concrete.[3]

The x-axis of this graph is frequency in hertz, ranging from 0 to 800. The y-axis of the graph is mobility, ranging from 0 to 10 to the power of negative 5 meters per second per newton. Solid lines represent two mobility spectrums. One line represents the mobility spectrum for a honeycombed concrete slab. Another line represents the mobility spectrum of solid concrete. Two dashed, straight lines are linear fittings of the mobility spectrum between 100 and 800 hertz. The dashed line corresponding to the honeycombed concrete has a greater slope than the dashed line corresponding to the solid concrete.

Advantages

Advantages of the impulse response method include the following:

- Simple procedures for data collection.
- Automatic data processing and fast output.

- Good repeatability of test results.

Limitations

Limitations of the impulse response method include the following:

- Small defects might be undetectable.
- Reliable data interpretation is highly dependent on the selection of test points.
- Testing large areas is time consuming.

References

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