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IN SITU EVALUATION OF RUBBLIZED PCCP MODULUS BY SURFACE WAVES

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Abstract

Deteriorated concrete pavements represent a major challenge in their rehabilitation. Rubblization using multi-head breaker (MHB) equipment, and compaction of rubblized concrete layer by vibratory Z-grid and rubber wheel static rollers is becoming an attractive alternative to traditional methods due to the speed of rehabilitation. The elastic modulus of the rubblized PCC was evaluated nondestructively using surface waves and compared to the modulus of typical base materials. The evaluation was done using a portable seismic property analyzer (PSPA). The elastic modulus is evaluated from the average velocity of surface waves in a certain wavelength range. The range varies from the shortest possible to measure to the one matching, approximately, the thickness of the rubblized concrete. The modulus obtained from surface wave testing is a low strain modulus and appropriate corrections (reductions) should be provided to describe it as a resilient modulus. A variation of the surface wave (phase) velocity with wavelength is an indication of a variation of modulus with depth. The modulus variation, excluding a few outliers, is constrained between 550 and 2800 MPa, with an average modulus between 1100 and 1400 MPa. This puts the modulus of rubblized PCC either higher than, or on the high side, of the modulus of a typical granular base. Significant variation of the modulus is attributed to the rubblization process, which provides the highest crushing of concrete near the surface, while near the bottom rubblized concrete has more appearance of a fractured rock and can form uneven interface between those two zones.

Keywords: rubblized concrete, modulus, NDE, surface waves, pavement

1 Introduction

Rehabilitation of deteriorated concrete pavements represents a major challenge. In many states, including New Jersey, placement of hot mix asphalt (HMA) overlays on top of the deteriorated concrete pavement has been a prevailing strategy. However, this type of rehabilitation would typically lead to reflective cracking at relatively rapid rates and, thus, significantly reduced serviceability of the rehabilitated pavement. Rubblization with HMA overlays as means of rehabilitation of some of the Portland cement concrete pavements (PCCP) is becoming an attractive alternative [1], [2]. It is rapid, with ability to rubblize almost two km per day, and cost effective, with cost savings of about 50% compared to reconstruction with PCC and about 33% compared to reconstruction with HMA. Rubblization also provides a lower risk to the owner and contractor through a reduced subgrade exposure to moisture damage. Finally, significant environmental benefits should be taken into consideration through reduced water and energy consumptions, and significant reduction in air pollutant emissions.
One of the main questions in the projects conducted in New Jersey was the value of the modulus of rubblized PCCP and how that modulus compares to traditional base materials, especially

to the modulus of a dense graded aggregate (DGA) base. The only previous information about the rubblized PCCP modulus was available from the FWD testing on rubblized PCCP with HMA overlays [3], [4], and [5]. Since the modulus from FWD testing is backcalculated, the ability of the surface wave testing to be conducted directly on the surface of the rubblized PCCP represented a significant advantage. Surface wave measurements using Portable Seismic Property Analyzer (PSPA) was used for that purpose on two Interstate section projects.
The first part of the paper discusses the rubblization process. The second part discusses fundamental aspects of surface wave based elastic modulus evaluation and its implementation in the field. The last part of the paper describes evaluation of modulus of rubblized PCCP, and discusses probable causes of a relatively high dispersion of the obtained results. The obtained moduli from surface wave testing are compared to those reported from FWD testing and to moduli for typical pavement base materials.

2 Concrete pavement rubblization

In general, rubblization can be described as breaking of existing PCC slabs into smaller pieces. Depending on the type of the process used and specifications for a given state, the size of the pieces may vary from 5-10cm up to 40cm. Rubblization of PCCP in the United States is typically conducted using two types of equipment: a multi-head breaker (MHB) and a resonant frequency breaker (RFB). The MHB is a self-propelled unit with multiple drop-hammers mounted on the rear of a machine or truck. The hammers weighing about 5.5 to 7 kN are set in two rows and strike the pavement approximately every 12cm. The MHB can break pavement up to 3.9m wide in a single pass, with the production of almost 2km per day. The MHB utilized in I-78 and I-295 rubblization projects in New Jersey are shown in Fig. 1a. On the other hand, the RFB delivers low amplitude, high frequency (resonant) energy to the slab through a shoe usually 17 to 28cm wide. High-frequency vibrations induce high tension in the top of the slab causing the slab to fracture along a number of shear planes. The effectiveness of rubblization depends on several variables: the shoe width, beam (supporting the shoe), frequency, loading pressure and velocity of RFB [6]. The RFB can rubblize almost 2.5 lane km per day.

Figure 1 MHB rubblizing PCCP (a) and compaction of rubblized PCCP by z-pattern and pneumatic tire rollers (b).

Rubblized concrete is compacted prior to the placement of HMA overlay. The first compaction is with a vibratory Z-pattern roller to further reduce the size of the broken concrete. In addition, the rubblized PCCP is compacted using either a vibratory or pneumatic tire roller, or both. Compaction using vibratory Z-pattern and pneumatic tire rollers is shown in Fig. 1b. Different states specify different numbers of passes of the rollers to achieve desired levels of breakage of concrete. New Jersey Department of Transportation (NJDOT) specifications require two passes of vibratory Z-pattern roller and 2 passes of smooth drum vibratory roller. Rubblized PCCP before and after compaction is shown in Figs. 2a and 2b, respectively.

Neither MHB nor RFB produce uniform breaking of PCCP, either horizontally or vertically. As shown in the images of a vertical cross section of rubblized concrete in Figs. 2c and 2d, crushing of concrete using the MHB is the highest near the surface, while near the bottom rubblized concrete may have more the appearance of fractured rock. The variability is also significant in the horizontal direction. This significantly affects the variability of the measured modulus.

3 Modulus evaluation using surface waves

Evaluation of elastic modulus of the surface layer of layered systems like pavements can be effectively done using surface waves. Of particular interest for granular type materials and soils is the spectral analysis of surface waves (SASW) method [7]. The method is based on the phenomenon of dispersion of surface waves in layered systems. The conduct of the SASW test is illustrated in Fig. 3. Elastic waves are generated by an impact, detected by a receiver pair and recorded by a transient recorder. For layered systems, the SASW test requires two main steps. In the first step, the velocity-frequency relationship of surface waves, commonly called the dispersion curve, is determined. In the second step, layer velocities are obtained from an inversion or backcalculation process. The elastic modulus profile of the evaluated systems can then be easily obtained using simple relationships between the velocity of propagation and measured or approximated values for mass density and Poisson's ratio of different layers. In the case of modulus evaluation of a fairly uniform surface layer, the backcalculation is typically not conducted. Instead, the modulus is obtained from the average phase velocity for a given surface wave wavelength range.

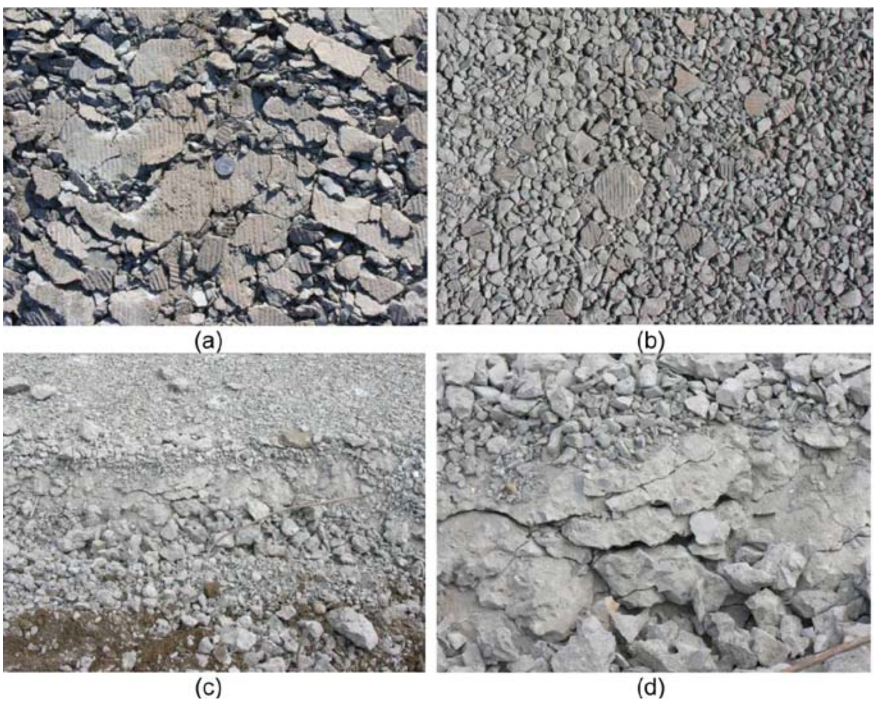


Figure 2 Surface of rubblized PCCP before (a) and after compaction (b). Views of the cross section of a rubblized PCCP (c) and (d).

A portable seismic property analyzer (PSPA), was used in the evaluation of the modulus of rubblized PCCP. The device, shown in Fig. 4a, consists of an electromagnetic type impact source, on the right far end, and two receivers (accelerometers). The near and far receivers are in this case 15 and 35cm away from the source, respectively. Once the device is placed on the ground, a series of impacts from the source is detected by the receiver pair and recorded on a notebook size computer. Modulus of the material can be obtained directly in the field, as it is illustrated in Fig. 4b for a PCCP modulus measurement. However, the data are commonly reanalyzed in the office for possible improvements. The reanalysis process is illustrated in Figs. 5a and 5b. In the first step the equipment setup and approximate material properties are defined, as shown in Fig. 5a. A cross power spectrum is invoked to establish the phase-frequency relationship between the two receivers (bottom left corner of Fig. 5b). From the known receiver spacing, frequency and the measured phase angle, the phase velocity of surface waves is calculated using a simple relationship between those four parameters. A dispersion curve obtained from this process is illustrated in the bottom right corner of Fig. 5b.

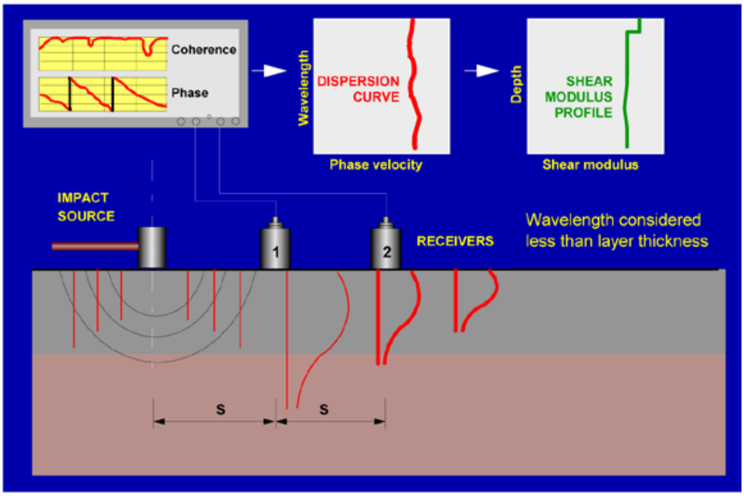
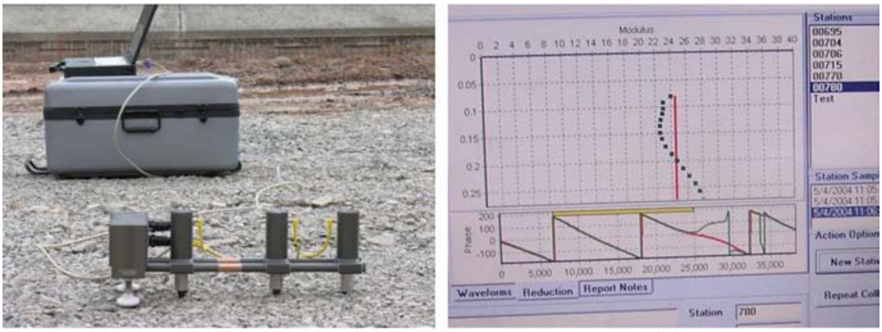


Figure 3 Schematic of the SASW test for surface layer testing.

Qualitatively, the variation of the phase velocity with wavelength is related to the variation of modulus with depth. The modulus is evaluated from the average velocity of surface waves in a wavelength range from the shortest possible to measure (about 5cm) to the one equal to the approximate thickness of the rubblized concrete. It should be emphasized that the modulus obtained from seismic testing is a low strain modulus. While strain dependence of modulus is expected, no work examining the strain effect on rubblized PCCP has been reported yet.

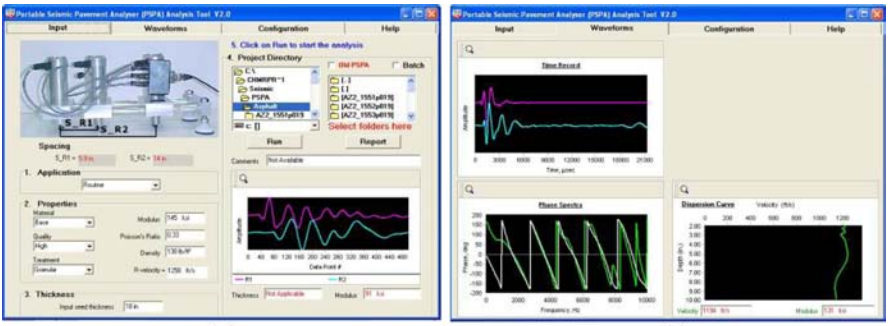
4 Results and discussion

The PSPA testing was conducted in 30m increments on both I-78 and I-295 rubblized PCCP sections. However, results for only the I-78 testing are shown herein. The tested rubblized PCCP was 24m long and 22.5cm thick jointed reinforced concrete pavement on a 30cm thick granular base. The I-78 section was tested at 18 stations of a single rubblized PCCP lane, while the I-295 section was tested at 13 stations of two rubblized PCCP lanes. The data were collected at three points across a rubblized lane. However, a later reanalysis showed that a number of tests did not provide data that would be reliable for the modulus evaluation and those were not included in the summary analysis for the sections. A successful test can be easily recognized by the shape of the cross power spectrum, which should be similar to the one in Fig. 5b.



(a) (b)

Figure 4 Rubblized PCCP modulus measurement using PSPA: equipment (a) and cross poser spectrum and dispersion curve (b).



(a) (b)

Figure 5 Reanalysis: instrument setup (a) and reanalyzed cross power spectrum and dispersion curve (b).

Modulus of the rubblized PCCP significantly varies between test locations. The distribution of modulus for all successful tests on I-78 rubblized section is shown in Fig. 6. The modulus is constrained between 500 and 2700 MPa, with an average modulus of 1498 MPa (full red line) and standard deviation of 565 MPa (marked by the light blue zone). Similar high dispersion of results was reported by Galal *et al.* [5]. A relatively high dispersion of values of elastic moduli can be explained by strong variations in the structure of rubblized PCCP, as illustrated in Figs. 2c and 2d. Such variations can affect wave propagation patterns and can be described as violating the basic assumption of the SASW testing that the tested system has horizontal layering. However, its practical influence is expected to be minor because the undulations within the receiver spacing are small. All the previously reported rubblized moduli were back-calculated from FWD or HWD testing on overlaid rubblized PCC pavements. The surface wave method obtained modulus compares favorably with those from several authors [4], [5], and [8]. Especially good agreement is with the results for the modulus from a very comprehensive study on the rubblized airfield pavements [9]. In that study the modulus of rubblized PCCP was found to be PCCP thickness dependent, with the modulus increasing with thickness. The average modulus from I-78, 1498 MPa, falls well within the suggested range of 930-1620 MPa for PCCP 20-35cm thick.

The modulus of rubblized PCCP, despite high dispersion of the results, compares well to the modulus of a typical dense graded aggregate (DGA) base [10]. This is illustrated in Fig. 6 by a light brown shaded zone of a typical DGA base modulus. On the other hand, it is also lower than the modulus of commonly used stabilized base materials.

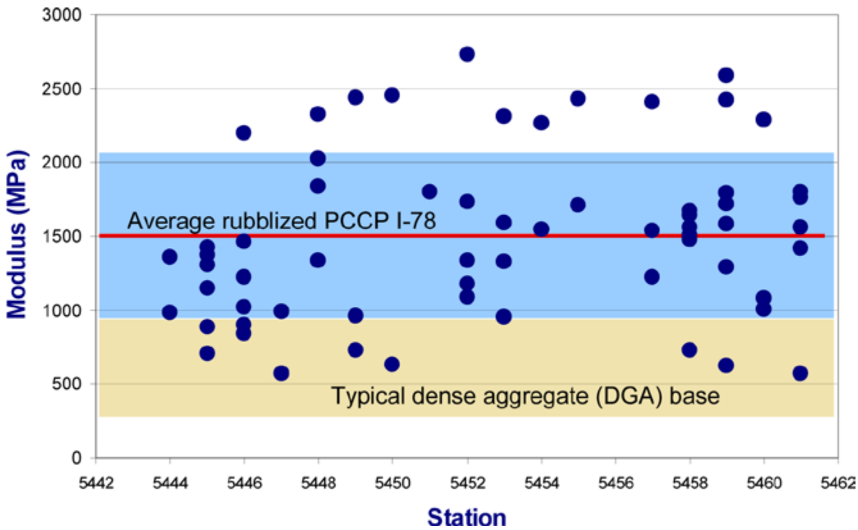


Figure 6 Modulus of rubblized PCCP on I-78 and typical dense graded.

5 Conclusions

Evaluation of the modulus of the rubblized PCCP, due to a very heterogeneous nature of the material, can be only done in situ. The SASW method provides an especially attractive option since the modulus can be evaluated directly on the rubblized PCCP layer. In addition to the average modulus, the variation of the surface wave velocity with wavelength can be related to the variation of modulus with depth, if such an estimate is needed. The shortcoming of the surface wave approach is that it provides only a low strain modulus. Evaluating a higher strain resilient modulus would require use of correlations with the modulus results obtained from other tests.

Excluding a few outliers, the modulus from all the testing conducted so far is constrained between 550 and 2800 MPa, with an average modulus between 1100 and 1400 MPa. In general, the modulus of rubblized PCCP is either higher than or on the high side of the modulus of a typical DGA base. Significant variation of the modulus is attributed to the rubblization process that provides the highest crushing of concrete near the surface, while near the bottom rubblized concrete has more the appearance of a fractured rock and form an uneven interface between those two zones.

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