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PERFORMANCE EVALUATIONS OF PAVEMENT WORKING PLATFORMS CONSTRUCTED WITH LARGE-SIZED UNCONVENTIONAL AGGREGATES

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ABSTRACT

With recent focus on sustainable construction practices and the ever-increasing transportation cost and scarcity of natural resources, use of unconventional aggregate materials, such as primary crusher run and concrete demolition waste, have become viable for the construction of pavement working platforms over very weak and often wet subgrade soils. To this end, a research study was undertaken at the Illinois Center for Transportation to evaluate the adequacy and field performances of such large-sized aggregate materials and validate new material specifications. A state-of-the-art image analysis technique was utilized to characterize the size and morphological properties, e.g. shape, texture and angularity of two large-sized aggregates, referred to herein as primary crusher run and crushed concrete. For the field evaluation, full-scale test sections were constructed with these large-sized aggregate materials over a very weak engineered subgrade and subjected to accelerated pavement testing. Construction quality control was achieved through in-place density and modulus measurements on conventional aggregate capping surface layers using nuclear gauge, lightweight deflectometer and soil stiffness gauge type devices. Periodic rut measurements were carried out on the pavement surface throughout the accelerated loading process using an Accelerated Transportation Loading Assembly (ATLAS). Contributions of the underlying pavement layers to the total rut accumulation was evaluated through innovative applications of ground penetrating radar (GPR), a light weight penetrometer device, known as the French Panda, as well as a geo-endoscopy probe. Layer intermixing and material migration at the aggregate subgrade and subgrade interface was found to improve the layer stiffness and pavement performance results significantly.

INTRODUCTION

Adequate subgrade strength, often referred to as subgrade stability is essential for stable foundation to withstand construction traffic. Subgrade stability is also required for the long service life or adequate performance of a pavement subjected to traffic loading. According to the Illinois Subgrade Stability Manual or SSM (2005), subgrade can be classified as stable if (i) it has an immediate bearing value (IBV), or unsoaked California bearing ratio (CBR), of 6%; (ii) the limiting maximum rut depth under construction traffic is 12.5 mm (0.5 in.) or less, and (iii) it can provide enough support for placement and compaction of pavement layers (Bureau of Bridges and Structures 2005). However, typical Illinois soils are fine-grained and commonly found in wet conditions in the field. With high silt contents, these soils are often hard to compact. Moreover, due to limited clay contents, their cation exchange capacities can be quite low and therefore not effective for chemical stabilization, e.g., with lime and cement, to properly improve the weak subgrade. As a result, inclusion of aggregate layers as subgrade/subbase replacement is a common technique for the construction of working platforms over weak subgrade.

Previous research efforts have largely been concentrated on performance evaluations of different qualities of aggregate base courses. Mishra and Tutumluer (2013) studied the effects of shape, texture and angularity, fines content and moisture on unbound aggregate layer performance through constructing/testing full-scale pavement working platforms in Illinois. In their study, the typical base course aggregate gradation requirements limited the top size of aggregate materials to 25 mm (1-in.). On the other hand, Heckel (2009) investigated aggregate subgrade performance involving three different dense graded aggregate materials for construction platform applications with one of the materials being a primary crusher run aggregate with a large top size greater than 75 mm (3-in.). This field performance study by Heckel (2009) did not cover a wide range and properties of large sized aggregates, such as crushed concrete, reclaimed asphalt product (RAP) or other blended recycled materials, which have recently been included for use in the newly revised aggregate specifications of Illinois Department of Transportation (IDOT).

For constructing aggregate working platforms, IDOT follows a design procedure to determine the aggregate remedial thickness above subgrade as a function of IBV. For example, a very weak subgrade with an IBV value of 1 requires a rather thick 61-cm (24-in.) dense-graded base/subbase course aggregate material to be placed. Considering stricter environmental regulations and increasing material and transportation costs, transportation agencies have been looking for alternative and sustainable construction practices. In the light of such sustainable construction alternatives, current research at the University of Illinois has focused on the performance evaluation of primary crusher run type large-sized unconventional aggregates and recycled materials, popularly being cited as “aggregate subgrade” materials, to be used as for building working platforms over weak subgrade soils. This paper presents results from accelerated testing of pavement working platforms constructed with the large-sized primary crusher run type virgin and recycled aggregate materials.

OBJECTIVE AND SCOPE

The objective of this research study was to evaluate the adequacy and field performances of large size aggregate subgrade materials as unconventional aggregates for constructing pavement working platforms and validating material specifications. To this end, 12 pavement test sections of construction platforms and 12 pavement test sections of low volume flexible pavements (with asphalt concrete surfaces) were constructed in full-scale and evaluated for rutting performances under simulated traffic loading. Seven different types of materials with varying top size, composition and fines content were used to construct the above mentioned sections. However, this study summarizes results from only 4 construction platform test sections considering the space limitation of this paper. Quality control tests, such as nuclear density measurements using nuclear density gauge and stiffness measurements with GeoGauge and lightweight deflectometer, were conducted during the placement and compaction of each layer. The effectiveness of using primary crusher run (referred to in this paper as Type A material) type virgin aggregates and blended recycled materials (referred to in this paper as Type B material) as "aggregate subgrade" was investigated through accelerated testing of the constructed test sections. Test section performances were evaluated using an Accelerated Transportation Loading Assembly (ATLAS) at the Illinois Center for Transportation (ICT). Surface profile measurements were carried out at different number of load repetitions to compare these materials for their rutting performances, which were linked to in-situ material strengths obtained from cone penetration testing. Subsurface rutting trends were also evaluated using ground penetrating radar.

DESIGNS AND CONSTRUCTION OF FULL-SCALE TEST SECTIONS

Four full scale test sections, Sections I to IV, were constructed using two different dense-graded capping aggregates placed over the two large-sized aggregate subgrade materials, i.e., Type A primary crusher run virgin aggregate and Type B blended recycled materials (see Figure 1). Sections I and II had primary crusher run aggregate subgrade materials; whereas, the remaining two sections were built with 60%-40% blend of large-sized recycled concrete and coarse fractionated RAP materials. All of the sections had 53-cm (21-in.) thick aggregate subgrade capped with 8-cm (3-in.) thick dense graded base course aggregates. Odd numbered sections had dolomitic virgin aggregate capping (referred to as Type C material); meanwhile, even numbered sections were capped with RAP aggregates (referred to as Type D material). The motivation for selecting such thickness profiles can be attributed to the thickness design procedure outlined by the IDOT SSM for IBV/CBR = 1% soils.

Figure 1 shows the dimensions of the constructed test road. The sections were designed in a way that the ATLAS loading assembly could maintain a constant speed throughout the testing phase. Approximately 39.6 m (130 ft.) long test strip was constructed with the similar thickness profile to accommodate on each end enough space for ATLAS placement and speed stabilization. Also, a 3 m (10 ft.) long test strip was introduced in between the two Type A and Type B aggregate subgrade sections so that there was negligible migration of materials during the placement and construction of the layers.

Aggregate Materials Used

Four different aggregate materials, Types A to D, were selected for constructing the test sections. Dry sieve analyses were carried out on three of the four aggregate materials according to ASTM C136 specification. Figure 2(a) shows the particle size distributions of material Types B, C and D. Since conventional sieve analysis was not possible in case of Type A primary crusher run aggregates, an advanced image analysis equipment, known as Enhanced UI Aggregate Image Analyzer (E-UIAIA), was used to extract the dimensions of the aggregate particles. Details of the extraction procedure can be found in the literature (Moaveni et al. 2012). Particle dimensions varied between 79 mm (3.1 in.) and 193 mm (7.6 in.). This particular material was selected to replicate the IDOT gradation band CS02. More than 80% of the particles had a flat and elongated (maximum to minimum dimension) ratio in the range of 1 to 1.5 indicating cubical shaped large stones. In addition, angularity index (AI) varied over a wide region spanning from rounded (AI = 250 ~ 350) to angular (AI = 475 ~ 550) particles, although majority of particles were found to be smooth textured with surface texture indices varying from 1 to 1.375 (Kwon 2007). The E-UIAIA imaging indices suggest that the primary crusher run aggregates were smooth textured cubical shaped particles which could produce various degrees of aggregate interlocking due to wide ranges observed in the angularity index or AI values.

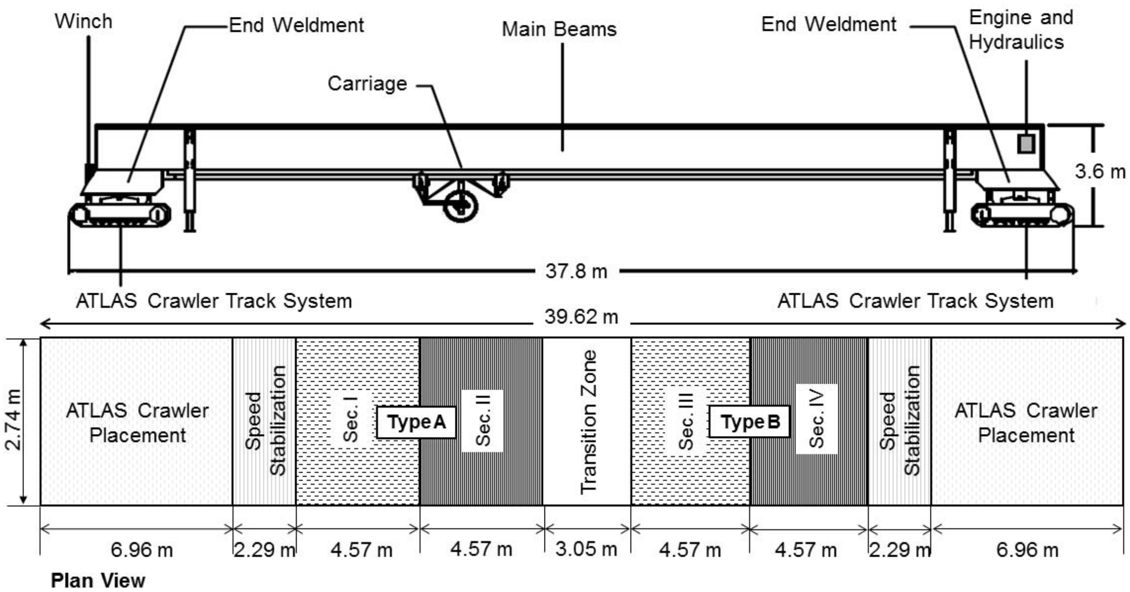

Figure 1: Plan view of the constructed test sections

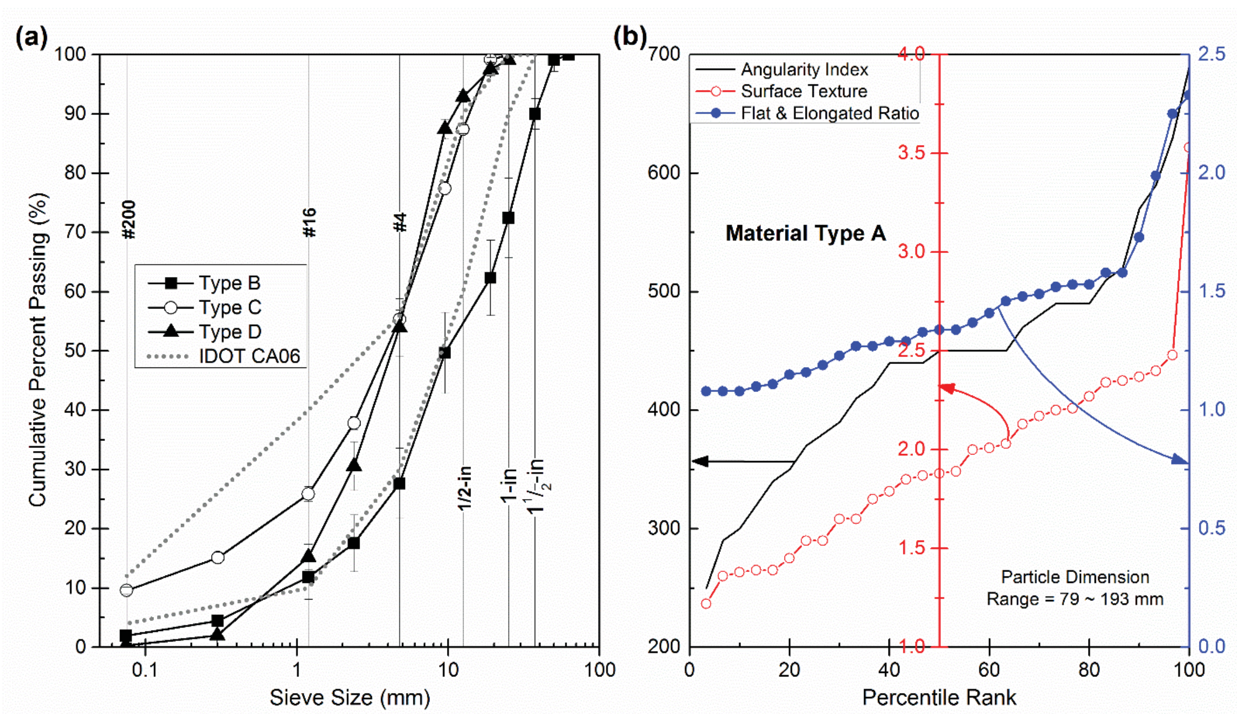

Figure 2: (a) Particle size distributions of Type B, C and D aggregates; (b) Aggregate imaging based shape indices of Type A aggregates

Among the remaining three materials, Type B was selected as the aggregate subgrade to satisfy IDOT's gradation envelope for CS01 designation. This material exhibited the highest amount of inconsistency in terms of percent passing each sieve size. Type C and Type D aggregates were selected as the capping layers to replicate typical Illinois base course aggregate gradations. Type C virgin aggregates were the finest among all the materials with more than 10% passing the No. 200 sieve (smaller than 0.075 mm) or referred to herein as the fines content. Compared to Type C, material Type D was coarser with less than 1% fines content.

Modification of Subgrade Strength

The initial step in pavement test section construction was to modify the subgrade strength to replicate very weak subgrade condition; i.e. IBV/CBR = 1%. At first, the low-plasticity clayey silt subgrade was graded on site and then tilled to a depth of 30.5 cm (12 in.). Laboratory standard compaction characteristics were established in a related previous study (Mishra 2012). Based on the compaction characteristics and the tilled earthwork, the required amount of water to reach a subgrade CBR of 1% was sprayed uniformly all over the soil. After that, the subgrade was proof-rolled and in place CBR was assessed using an empirical relationship proposed by Kleyn et al. (1982). In addition, soil samples were collected in a grid-like pattern and in situ moisture contents were evaluated according to ASTM D4643. Based on the moisture distribution, zones lacking required moisture to reach CBR = 1% were identified and water was added to compensate the moisture deficiency. This procedure was repeated on a trial and error basis till the subgrade for the designated test sections reached the desired strength.

In-Place Density Assessment

During the placement and compaction of aggregate layers, achieved field densities were measured using a Troxler® 3450 nuclear density gauge using the back-scatter method. Laboratory standard Proctor compaction test results shown in Figure 3 reveal that Type C materials exhibited approximately 17% higher maximum dry densities compared to the values of Type D RAP aggregates. Similarly, higher optimum moisture contents were recorded for the dolomitic virgin aggregates. In place densities exhibited the same trend with respect to the laboratory compaction characteristics. It was assumed that higher amounts of filler materials found in the virgin aggregate gradation matrix might have contributed to the higher nuclear density gauge readings. On the contrary, RAP aggregates showed greater relative compaction in comparison to virgin aggregates. This can be attributed to two possible explanations: (a) in place moisture contents of the aggregates were in the range of 5.2% to 5.5%, quite close to the optimum moisture content of the coarse fractionated RAP to result in a higher relative compaction for RAP aggregates; (b) the compressibility of asphalt mastic might have also induced higher level of compaction. Only wet densities were recorded for Type D materials since RAP aggregates tended to exhibit erroneous moisture contents due to the presence of hydrogen bound asphalt mastic.

In Situ Modulus Evaluation

Field modulus properties of the constructed aggregate layers were measured using a Dynatest® lightweight deflectometer (LWD) model 3031 and a Humboldt® soil stiffness gauge

(GeoGauge™). Results for Sections I through IV are presented in Figure 4. The measured moduli typically increased with the addition of capping layers in Sections III and IV. Stiffnesses measured with the GeoGauge were found to be consistently higher than the LWD moduli. Since, the LWD device has a larger depth of influence, the moduli measured with LWD could be influenced by the underlying layers leading to lower stiffness characteristics. This is in accordance with similar observations reported in a recent NCHRP study (Von Quintus 2009). Hence, the reported GeoGauge moduli could be more representative of the capping layers when compared to the LWD moduli more commonly affected by the stiffness characteristics of the underlying layers.

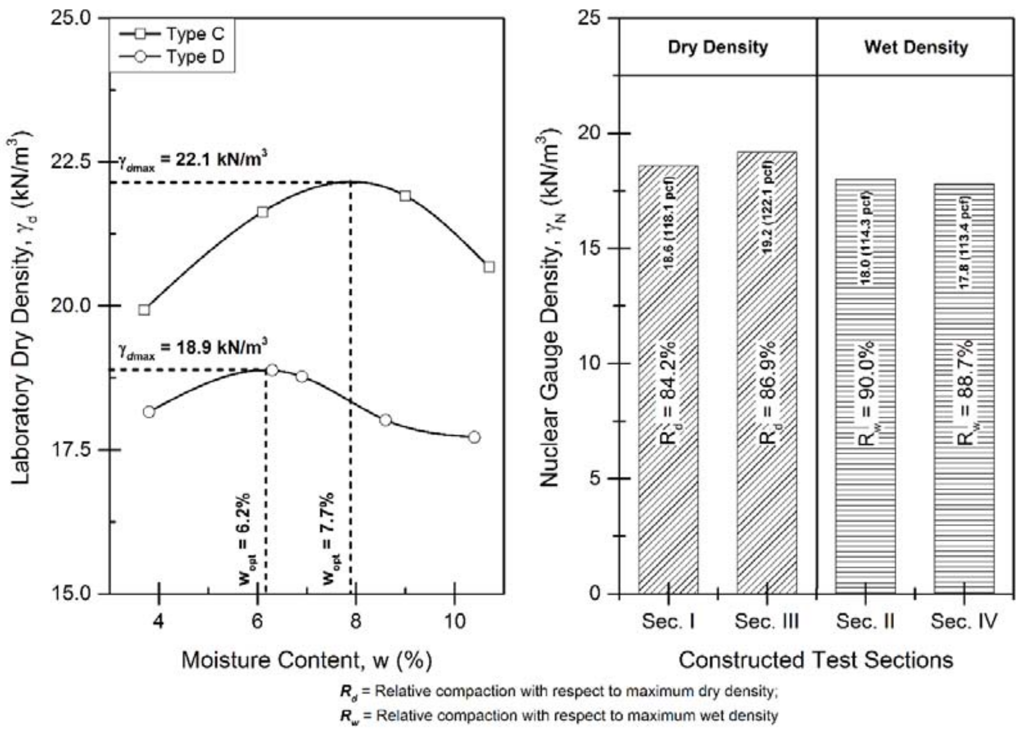

Figure 3: Laboratory standard Proctor and field compaction characteristics of capping materials

According to Figure 4, RAP capping layers used in Sections II and IV exhibited higher GeoGauge moduli values than the capping layers built with virgin aggregates. Previous studies similarly reported higher moduli for RAP aggregates, which conforms to this finding (Guthrie et al. 2007; Dong and Huang 2013). As mentioned earlier, the LWD moduli can be considered as the composite moduli of the capping layer and aggregate subgrade due to a higher depth of influence. To this end, Figure 4 also reveals that the LWD moduli reported for Sections III and IV were higher than those of the remaining two sections. This can be attributed to the larger voids associated with the uniformly graded primary crusher run Type A aggregates.

RUTTING PERFORMANCES

Longitudinal surface depression or rutting is deemed to be the appropriate failure criterion for granular materials. Henceforth, rutting performances of the full-scale test sections

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were evaluated under trafficking using ATLAS. A 44-kN (10-kip) unidirectional moving wheel load was applied repeatedly at a constant speed of 8 km/h (5 mph) inducing approximately 690 kPa (100 psi) tire pressure on the finished granular surface. Surface profile measurements were taken after different number of load applications to evaluate the rutting performances of the constructed test sections. The failure criterion for rutting was selected to be the stroke limit of wheel assembly at approximately 7.5 cm (3 in.). Details of the rutting measurement procedure can be found in a recent field study by Mishra and Tutumluer (2013).

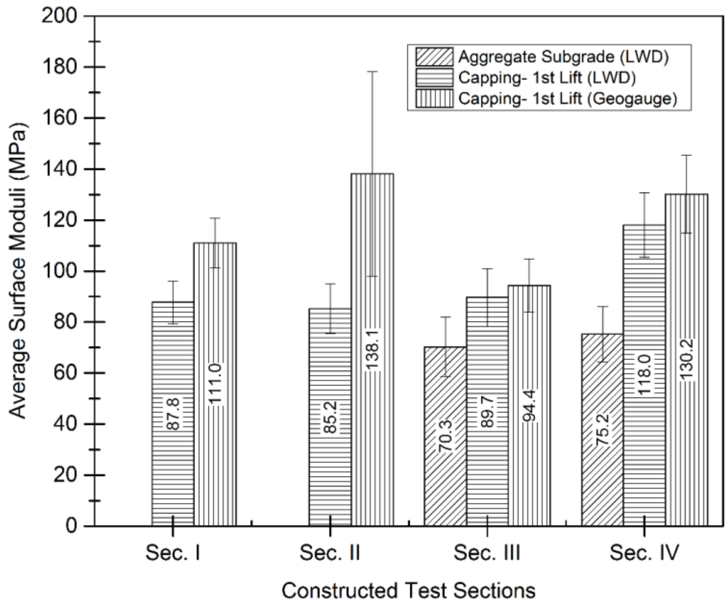

Figure 4: Surface measured moduli on aggregate subgrade and capping layers

Figure 5 shows the rut accumulations in Sections I through IV with increasing number of load applications. Use of the large-sized unconventional aggregates as “aggregate subgrade” materials instead of the typical base course aggregates with 2.5-cm (1-in.) top size was found to be beneficial for the rock-stabilization technique applied to IBV/CBR=1 engineered subgrade soils. All of the sections survived 4,000 passes of the repeated loading. Section II exhibited the deepest rut profiles among all the sections. Accordingly, the Type B aggregate subgrade sections showed lower permanent deformation trends than Type A sections. Note that the Type B aggregates have comparatively finer gradation than that of Type A. Due to the lack of smaller aggregate particles to fill in the voids, Type A primary crusher run aggregates more readily penetrated into the weak subgrade when compared to Type B materials creating more of a layer profile over the subgrade. This might have resulted in higher wheel path permanent deformations in Sections I and II. Further, there was often a higher accumulation of moisture from rainwater in Sections I and II when compared to Sections III and IV. Moreover, Figure 3 indicates that Section I achieved the lowest relative compaction. These might have contributed to significant differences in the rutting trends and magnitudes observed between Sections I and II built with Type A aggregates. Note that common experience with RAP materials suggests that although RAP may exhibit a high resilient modulus, it may often be very susceptible to excessive rutting.

Similarly, Figure 5 shows that Type D RAP capping materials exhibited higher rutting trends than the virgin aggregate counterparts.

FORENSIC EVALUATIONS OF CONSTRUCTION PLATFORMS

Rutting in granular materials is closely linked to the applied stress levels experienced in the field in relation to the shear strength characteristics of these aggregate layers. In addition, these pavement layers may behave differently based on the material composition, gradation, morphological properties, and the presence of water. Henceforth, ground penetrating radar (GPR) scans were used to assess the relative contributions and modes of rutting in the aggregate layers and the subgrade while accelerated pavement testing was undertaken, i.e., this is well before any trenches to be cut at the end of the testing effort. Moreover, during pavement testing, variable energy penetration tests, i.e. French Panda tests, were also carried out in the wheel path at the transverse rutting profile measurement locations followed by geo-endoscopy testing for the evaluation of material strength and visualization of the intermixing of aggregate subgrade and engineered subgrade soil, respectively.

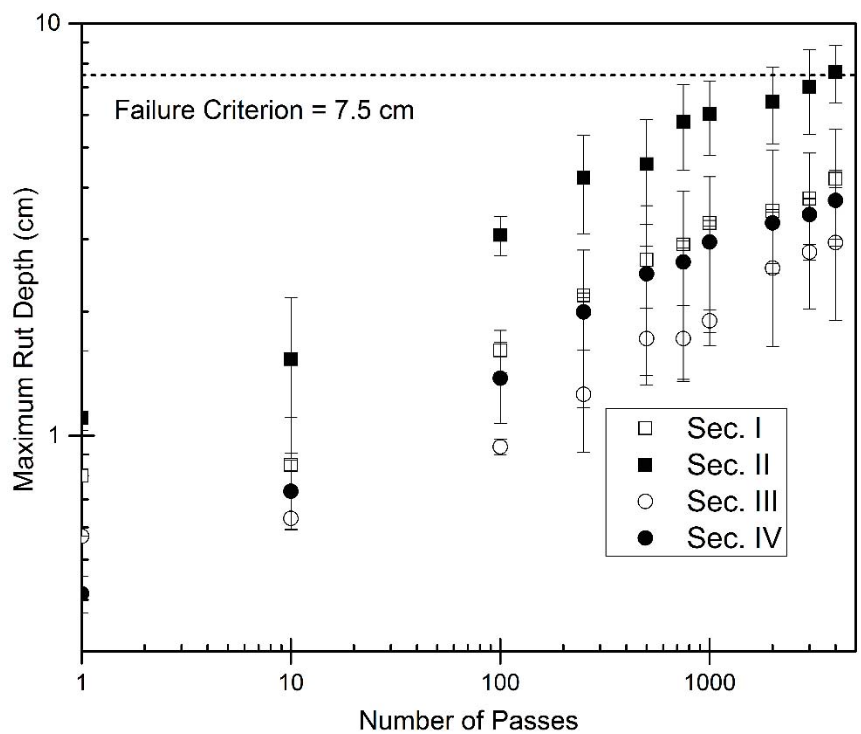

Figure 5: Rutting accumulations with number of load applications for Sections I through IV

Ground Penetrating Radar Scans

Subsurface rutting modes were evaluated using a customized GPR assembly (Mishra 2012). A 2-GHz GPR antenna was moved in the transverse direction at a slow constant speed over the construction platform to identify the mode of longitudinal depression and the contributions of aggregate layers and subgrade to rutting accumulation in the loading direction.

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Figure 6 shows the GPR scans of the constructed test sections before and after the accelerated pavement testing. As observed, none of the sections exhibited any type of heaving at the edge of wheel path on the surface. This observation rules out the possibility of shear failure within the aggregate layer structure of capping aggregates. However, Type A aggregates behaved differently compared to Type B aggregates. According to Figure 6, localized shear depression in the subgrade was the dominant mode of rutting in case of primary crusher run Type A aggregates as opposed to a wide spread of deflection spectrum shown in blended recycled aggregates. The localized shear deformation can be attributed to the presence of large air voids in Type A aggregates. Further, GPR scans on Section II reveal that thicknesses of the constructed Type A aggregate subgrade layers varied over the transverse profile of the construction platform. The highest magnitude of rutting in this section can also be traced back to the varying layer thickness as observed in the GPR scans.

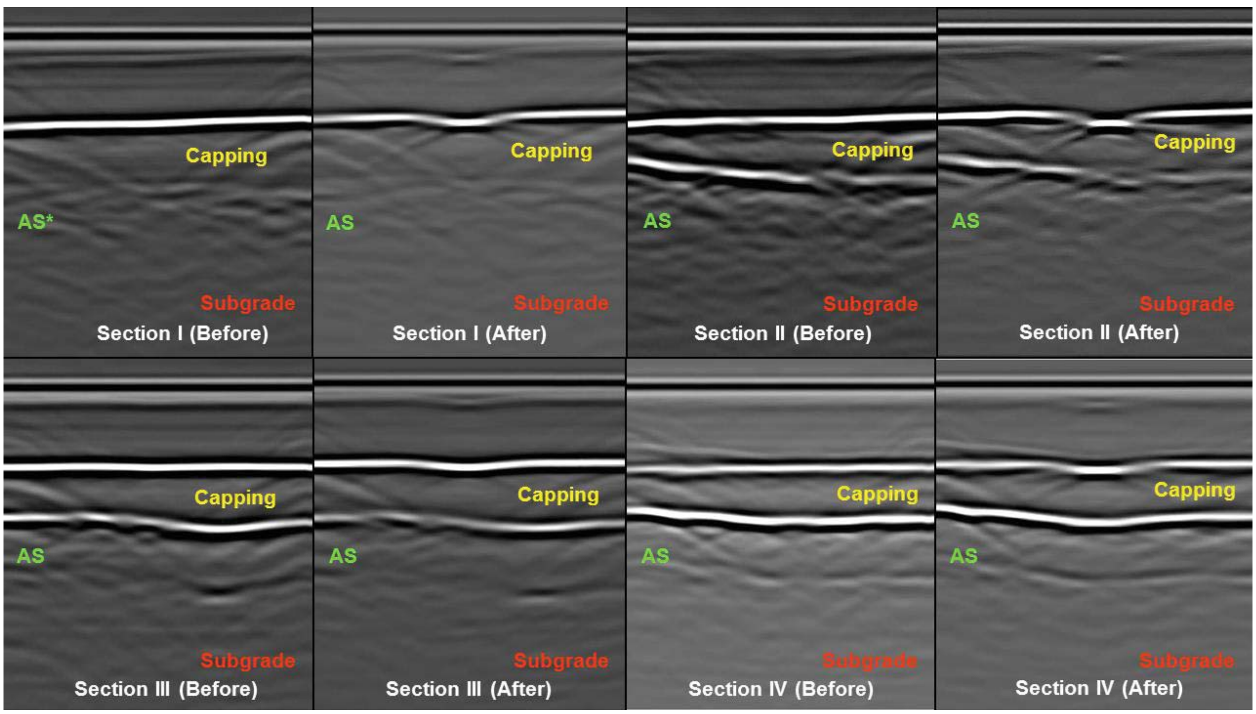

Figure 6: GPR scans of the constructed test sections (AS* = Aggregate Subgrade)

Variable Energy Penetration Testing and Geo-Endoscopy

A lightweight variable energy dynamic cone penetrometer was used to assess the strength profile of underlying layers in the constructed test sections. Known as the French Panda device, this is a light dynamic cone penetrometer with variable energy developed at the Blaise Pascal University of Clermont-Ferrand in France (Gourvés and Barjot, 1995). The device uses 2 and 4 cm^2 cones, which are fixed to the bottom of the penetrometer setup. The beating energy is manual and variable using a handheld hammer. It automatically supplies the energy required to penetrate the substructure materials tested with depth. For each blow of the hammer, the depth of penetration and impact energy are recorded to calculate the dynamic cone resistance with the

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corresponding depth (Gourvés and Barjot, 1995; Zhou, 1997) using pre-established engineering correlations (Zhou, 1997).

The Panda device with 4-cm^2 cone was driven to a depth of 100 cm (approximately 40 in.) using a calibrated hammer on an anvil equipped with strain gauge and connector rods. With each blow to the anvil, the data acquisition system records the cone resistance that indicates the material strength. After the completion of penetration testing, a small geo-endoscopic camera was guided through that small borehole to identify the depth of water table and the extent of intermixing between soft subgrade and the overlain large aggregate subgrade materials. Figure 7 shows the cone resistance recorded from penetration testing along with geo-endoscopic images at different depths. According to the geo-endoscopic images, the depth of water table in Sections I through IV were found to be at 56.5 cm, 56.6 cm, 60.5 cm, and 55.3 cm, respectively. Section II had considerably lower CBR profiles than the other three sections indicating its susceptibility to excessive rutting compared to the other sections. Since section III had the deepest water table, it is expected to have the least pore water pressure in the aggregate-soil matrix; thereby, leading to a higher effective stress. As a result, Section III exhibited the least amount of permanent deformation under repeated loading. Another important observation is that all of the sections exhibited considerable strength in terms of cone resistance below the water table. This can be attributed to the strength originated from particle interlock upon the intermixing between soft subgrade and large rocks. Geo-endoscopic images confirm that the rocks penetrated deep into the weak subgrade and thus contributed to the stabilization of the CBR = 1% soil.

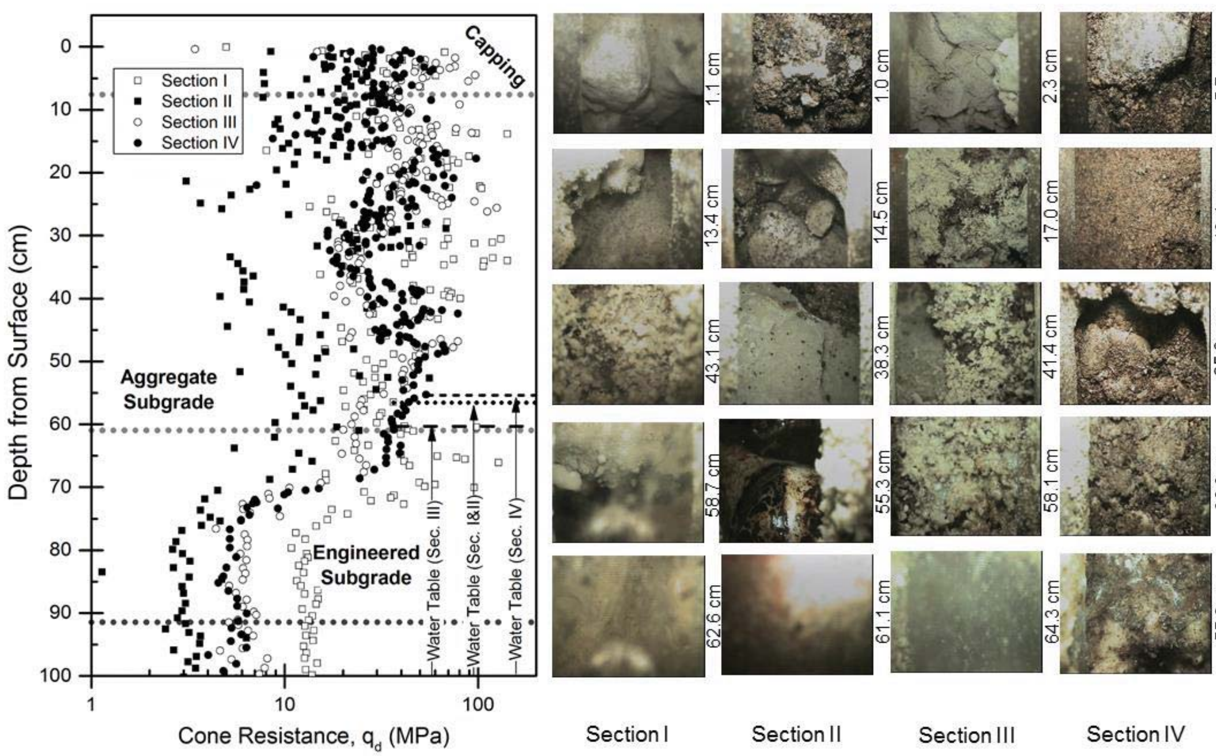

Figure 7: Cone resistance from variable energy penetration tests with geo-endoscopic images

SUMMARY AND CONCLUSIONS

This paper summarized preliminary findings from an ongoing Illinois Center for Transportation (ICT) research study at the University of Illinois aiming to demonstrate the adequacy and effectiveness of using large-sized unconventional aggregates as aggregate subgrade and validate related new material specifications for constructing pavement working platforms over weak subgrade soils. Twenty-four different full-scale test sections were constructed, among which results from only four sections are presented in this paper. All of the test sections discussed in this paper were constructed over a weak subgrade with an engineered strength of unsoaked California bearing ratio (CBR) = 1%. Performances of the large sized primary crusher run type virgin aggregates and recycled materials as aggregate subgrades were evaluated from full scale test sections using an Accelerated Transportation Loading Assembly (ATLAS). The transverse rut accumulation trends presented in this paper were further analyzed in light of ground penetrating radar, dynamic penetration testing and geo-endoscopic imaging. Based on the presented results and analyses, the following conclusions can be drawn:

(a) Large-sized primary crusher run type virgin aggregates and blended recycled materials can successfully be used as aggregate subgrade to stabilize the weak subgrade conditions.
(b) Substantial amount of intermixing of the large-sized aggregates and the weak subgrade was observed in all of the sections. Unlike the detrimental effects on typical 2.5-cm (1-in.) top size dense-graded base courses, this large-rock stabilization proved to be conducive for strengthening the weak subgrade soil.
(c) Aggregate packing characteristics can significantly affect the mode of rutting in granular materials. Comparatively well graded recycled materials exhibited better load distribution compared to uniformly-graded primary crusher run aggregates.
(d) Since reclaimed asphalt pavement (RAP) aggregates are prone to excessive rutting, thickness of the capping layer should be increased if RAP is to be used as the capping material.

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