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Pavement Performance Evaluation of Geogrid Stabilized Roadways

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ABSTRACT

Pavement surface roughness, one of the indicators of pavement performance, is affected by the structural stability of the pavement layers. Some commonly used indices of surface roughness are Present Serviceability Rating (PSR) and International Roughness Index (IRI). In the last decade, several advanced techniques were introduced to measure IRI cost-effectively and rapidly. This paper describes the use of smartphone-based technology for measuring IRI of pavements. A section of Highway Route-39 between El Carbón and Bonito Oriental in Olancho and Colón, Honduras was constructed with a mechanically stabilized aggregate base course layer. Such mechanical stabilization was achieved by using a multi-axial triangular aperture geogrid. Mechanical stabilization contributes to preserving material stiffness for an extended service period and offers an opportunity to pavement designers to optimize pavement layers to attain the same or higher targeted pavement life. The conventional design of pavement with a layer of aggregate base over a cement-treated granular subbase was replaced with a geogrid-based design without the need for cement treatment. The improved design included a layer of geogrid at the interface of aggregate base and untreated granular subbase layers. After heavy trafficking for two years, the pavement IRI was collected and evaluated to understand the effects of traffic and environmental loads. On average, the IRI of geogrid stabilized pavement was found to be 14% less than that of the unstabilized pavement.

RESUMEN

La rugosidad de la superficie del pavimento, uno de los indicadores de su desempeño, se ve afectada por la estabilidad estructural de las capas del pavimento. Algunos de los índices de rugosidad de la superficie más usados comúnmente son el Indice de Seriviciabilidad Presente (PSR) y el Indice Internacional de Rugosidad (IRI). En la última década, se han introducido varias técnicas avanzadas para medir el IRI de una forma costo eficiente y rápida. Este documento describe el uso de la tecnología basada en teléfonos inteligentes para medir el IRI de los pavimentos. Una sección de la Carretera 39 entre El Carbón y Bonito Oriental en Olancho y Colón, Honduras, se construyó con una capa de base granular estabilizada mecánicamente. Dicha estabilización mecánica se logró mediante el uso de una geomalla multiaxial de apertura triangular. La estabilización mecánica contribuye a mantener la rigidez del material durante un período de servicio extendido y ofrece una oportunidad para que los diseñadores de pavimentos optimicen las capas del pavimento para lograr la misma vida útil o mayor. El diseño convencional de pavimento con una capa de base granular sobre una subbase granular tratada con cemento fue reemplazado por un diseño con geomalla sin la necesidad de un tratamiento con cemento. El diseño mejorado incluía una capa de geomalla en la interfaz de la base granular y la capa de subbase granular no tratada. Después de un intenso tráfico durante dos años, se recolectó y evaluó el IRI del pavimento para comprender los efectos del tráfico y las cargas ambientales. En promedio, se encontró que el IRI del pavimento estabilizado era 14% menor que el del pavimento no estabilizado.

1. INTRODUCTION

Regular maintenance and upgrade of pavement are better and more cost-effective than replacing severely deteriorated pavements (Peshkin et al. 2004; Cuelho et al. 2006). Pavement condition assessment procedures offer an opportunity to access existing functional and structural characteristics of pavement (Bianchini and Bandini 2010). A well-functioning pavement has smooth ride quality and is free of visual distress. Road users, like drivers, are typically concerned with functional characteristics. On the other hand, the structural characteristics refer to the internal stability of the pavement system. A pavement with undeteriorated pavement layers is considered to be a structurally sound pavement.

Transportation-related agencies, such as State Departments of Transportation (DOTs), local transit authorities, public works or street maintenance offices of cities, are concerned with structural and functional pavement distresses. These agencies rely on pavement condition information for identifying and prioritizing transportation projects for maintenance and rehabilitation, allocating budgets and planning for new construction (Haas 2001). Similarly, the National Highway Performance Program (NHPP) utilizes pavement condition data such as International Roughness Index (IRI), percent cracking, rutting, and faulting for developing transportation plans.

Pavement management system (PMS), developed from pavement condition information, are also popular among transportation agencies for cost-effective management of a pavement system (AASHTO 2012). At the network level, the use of PMS provides an overall status of the existing road network. At the project level, the pavement condition assessment is a useful tool for in-detail evaluation of pavement sections. Regular pavement condition assessment helps in tracking pavement performance, identifying deteriorated pavement sections and providing necessary preventive measures. Other uses of pavement condition assessment are understanding the benefits of newly implemented technologies such as the use of new types of asphalt concrete mixes, composite pavement sections or geosynthetic stabilized sections.

Pavement condition evaluation typically consists of determining pavement condition index (PCI) and measuring pavement roughness. The conventional way of determining pavement PCI is through manual surveys (e.g. walking, windshield, walking plus windshield). As those surveys require extensive time and effort, provide inconsistent results and can keep the surveyor in an unsafe working situation, several automated technologies were developed to replace the manual surveys in the recent years (McQueen and Timm 2005; Montoya 2013; Dennis et al. 2017). The use of digital image processing and automated pavement distress identification protocols were the basis of such automated technologies. Similar advancements were also made for measuring pavement roughness (e.g., IRI) cost-effectively and rapidly. This paper describes the use of smartphone-based technology for measuring pavement roughness in terms of IRI for a section of Highway known as Route-39 which serves as an agricultural and tourist corridor between El Carbón and Bonito Oriental in Olancho and Colón, Honduras.

2. BACKGROUND

Pavement conditions, reflected by the presence of distresses and the surface smoothness, show the serviceability of any road network. The most common types of pavement distress are cracks in different forms as described by Miller and Bellinger (2003). The presence of cracks disrupts direct transfer of vehicle loads to underlying pavement layers, and hence results in the localized concentration of stresses. Additionally, the cracks allow moisture to penetrate the base/subbase layers and subgrade. An increase in the moisture level has severe decremental effects on the mechanical characteristic (stiffness) of bases and subgrade (Tamrakar and Nazarian 2017). ASTM D6433 (2018) recommends using Pavement Condition Index (PCI) as a composite pavement index. PCI is represented in a numerical value ranging from 0 to 100 with 0 being the worst condition and 100 being the best possible condition.

On the other hand, pavement roughness (or smoothness) simply represents the ride quality. In other words, the roughness of the road surface is an indicator of vertical disturbances, as noticed by the vehicle users, along the longitudinal road profile. Common devices used for measuring pavement roughness are a Profilometer, Profilograph, Roughometer and Ridemeter (Kelly et al. 2002). Roughness is measured in terms of Present Serviceability Rating (PSR) or International Roughness Index (IRI). In 1962, American Association of State Highway Officials (AASHO) developed the PSR method during the AASHO Road Test Program. The pavement roughness measurement with the IRI method was introduced by the World Bank in the 1980s (Sayers et al. 1986). An IRI is a standardized measure of the reaction of a vehicle to the roadway profile and roadway roughness that is expressed in terms of vertical "inches per mile" or "meters per kilometer". Several studies were conducted for relating PSR with IRI (e.g., Gillespie et al. 1980; Arhin et al. 2015). The typical IRI threshold limits for newly constructed pavements are shown in Table 1.

Table 1. Typical IRI Threshold Limits for New Pavement (From Arhin et al. 2015)

	New Pavement IRI (m/km) Limits		
	Freeways	Arterials/ Collectors	Local Roads
Good	≤ 1.26	≤ 2.53	≤ 2.84
Acceptable	1.27 - 2.53	2.54 – 4.73	2.85 – 5.52

Pavement IRI measurement by a standard profiler or any other similar device is extremely time-consuming and uneconomical for a large pavement project. Further, the IRI data analysis and management are more tedious for processing a large amount of raw IRI data. The need for partial or full closure of a road to traffic adds an additional burden on road users. In order to overcome these challenges, several automated technologies were developed to measure pavement IRI rapidly without traffic closures. Accelerometers or geophones are commonly selected for measuring vehicle motions and estimating pavement roughness (Timm and McQueen 2004; Vavrik et al. 2013; Massahi et al. 2017). In addition to this, a GPS system is typically used for geo-referencing the collected data. Compared to the manual surveys, the automated surveys provide consistent and accurate results without compromising the safety of the data collector and without disrupting traffic flow.

3. PROJECT HISTORY

3.1 Location details

The project is located on Highway Route-39 between El Carbón and Bonito Oriental in Olancho and Colón Departments, Honduras and was constructed as part of the new agricultural and tourist corridor construction project between El Carbón and Bonito Oriental. The GPS coordinates of stabilized and unstabilized pavement are 15.740, -85.737 to 15.450, -85.589 and 15.450, -85.589 to 15.345, -85.628, respectively. The project site has a tropical climate with a temperature varying between 23°C and 35°C in a year. Similarly, the total yearly precipitation is about 1100 mm.

Figure 1 shows the project location including geogrid stabilized and unstabilized pavement sections. The total lengths of geogrid stabilized and unstabilized pavements are 46 km and 18 km, respectively. The pavement sections were constructed in 2016. The pavement was heavily trafficked since its construction. The annual average daily traffic (AADT) is about 1010, but expected to double by 2035. The majority of the vehicles travelling through this corridor is a T3-S2 type of truck.

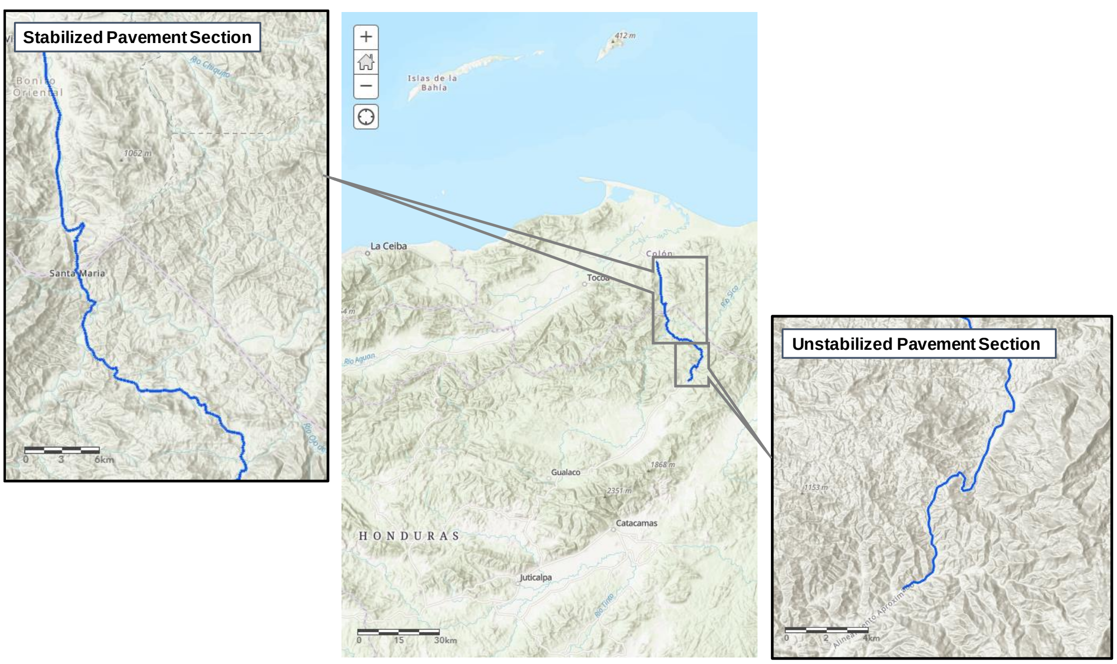

Figure 1. Project Location

3.2 Pavement Materials and Section Details

The geogrid stabilized pavement consisted of a chip seal surfacing over nominal 200-mm-thick geogrid-stabilized aggregate base, 200-mm-thick granular subbase and natural subgrade. On the other hand, the unstabilized pavement consisted of 250-mm-thick aggregate base, 300-mm-thick granular subbase and natural subgrade. The average subgrade modulus was estimated as 180 MPa based on the falling weight deflectometer testing (Vennapusa et al. 2018).

For the geogrid stabilized pavement, a multi-axial geogrid was selected based on the site conditions and aggregate material types. The properties of geogrid are presented in Table 2. The triangular apertures of the multi-axial geogrid have much more uniform stress and strain distributions than the traditional biaxial geogrid with rectangular apertures (Dong et al. 2011). Under traffic loadings, this form of geogrid is more effective and efficient in distributing stresses in all directions (Abu-Farsakh et al. 2016; Robinson et al. 2017; Gu et al. 2017; White and Vennapusa 2017; Roodi et al. 2018; Vennapusa et al. 2018; Abu-Farsakh et al. 2019; Wayne et al. 2019). Placing a multi-axial geogrid at the interface between base and subgrade creates a mechanically stabilized layer which improves strength and stability of the pavement system. One of the benefits of such mechanical stabilization is the preservation of material stiffness for a longer period, thus extending service life. The mechanical stabilization also offers an opportunity for pavement designers (engineers responsible for the structural design of pavements) to optimize pavement layers to attain the same or higher targeted level of pavement performance.

Table 2. Properties of Geogrid

Parameter	Description
Geogrid	TX5 Multi-axial geogrid
Rib shape	Rectangular
Aperture shape	Triangular
Rib pitch	40 mm longitudinal and diagonal

3.3 Field Performance Evaluation

Automated plate load testing (APLT) was utilized to measure in-situ performance and confirm design requirements for this project during the construction phase. Using APLT, stress-dependent resilient modulus of unbound aggregate layers and composite modulus were measured at different locations. The results indicated that the in-situ material stiffness exceeds the predicted (design) stiffness. Permanent deformation tests were also conducted to estimate rutting resistance of the pavement. The details of testing, background information, project requirements and results are well documented in Vennapusa et al. (2018).

4. PAVEMENT CONDITION SURVEY

4.1 Description of TotalPave System

Currently available smartphones consist of several built-in sensitive sensors including an accelerometer. The accelerometer measures phone acceleration in x-, y- and z-directions, and determines motion and orientation of the phone. Such features are essential for map navigation, landscape or portrait display and so on. Several researchers (Hanson et al. 2014; Islam et al. 2014) had utilized smartphone-based acceleration data for capturing vehicle motion, estimating longitudinal road profile, and hence, measuring pavement IRI. As the manual steps involved in operating road profilers are replaced by the automated procedures through built-in functions of smartphones, the researchers had to overcome several challenges such as filtering unwanted signals due to vehicle damping, considering the effects of different models of phone and vehicles, adjusting the signal filtering window based on the sensitivity of the accelerometer and so on (Forslöf and Jones 2015).

The IRI data collection technology for this project was developed by TotalPave Inc. The principles behind the TotalPave system are explained in Cameron (2014). This system is calibrated against the standard profiler using different types of smartphones and vehicles (Hanson et al. 2014). The data collection process is fully automated. The user needs to mount a smartphone with a TotalPave IRI Calculator app to the vehicle's windshield. The mounting device should be sturdy so that the motion detected by the smartphone is totally from the vehicle. The TotalPave app allows users to level a smartphone vertically which helps to accurately detect motions in x-, y- and z-directions. The app collects data when the vehicle speed is more than 20 kph. The app also collects GPS data along with the acceleration data for proper positioning and displaying of IRI data within the map. The system analyzes the raw acceleration data and estimates pavement IRI. Using the web portal, users can view the IRI data plotted on the map. Recently, several studies were conducted by utilizing the TotalPave technology (Ali et al. 2019; Hossain and Tutumluer 2019; Tamrakar et al. 2019).

4.2 Survey on geogrid stabilized and unstabilized sections

The IRI surveys on geogrid stabilized and unstabilized sections were conducted on May 14th and 15th of 2019. On May 14th, the survey was conducted on the north-bound lane, starting from 15.345, -85.628. The survey on the south-bound lane was conducted on May 15th, starting from 15.740, -85.737.

5. PRESENTATION OF RESULTS

Figure 2 shows variation in the measured IRI for the entire project site through the color-coded map. The legend in the figure represents the IRI ranges. For each pavement section, the presented IRI value is an average of the north- and south-bound lanes. Using the map portal, the distribution of pavement IRI for every 100 m interval can be observed. Such a map can be beneficial for identifying locations of highly roughened pavement sections which could indicate the presence of pavement distresses.

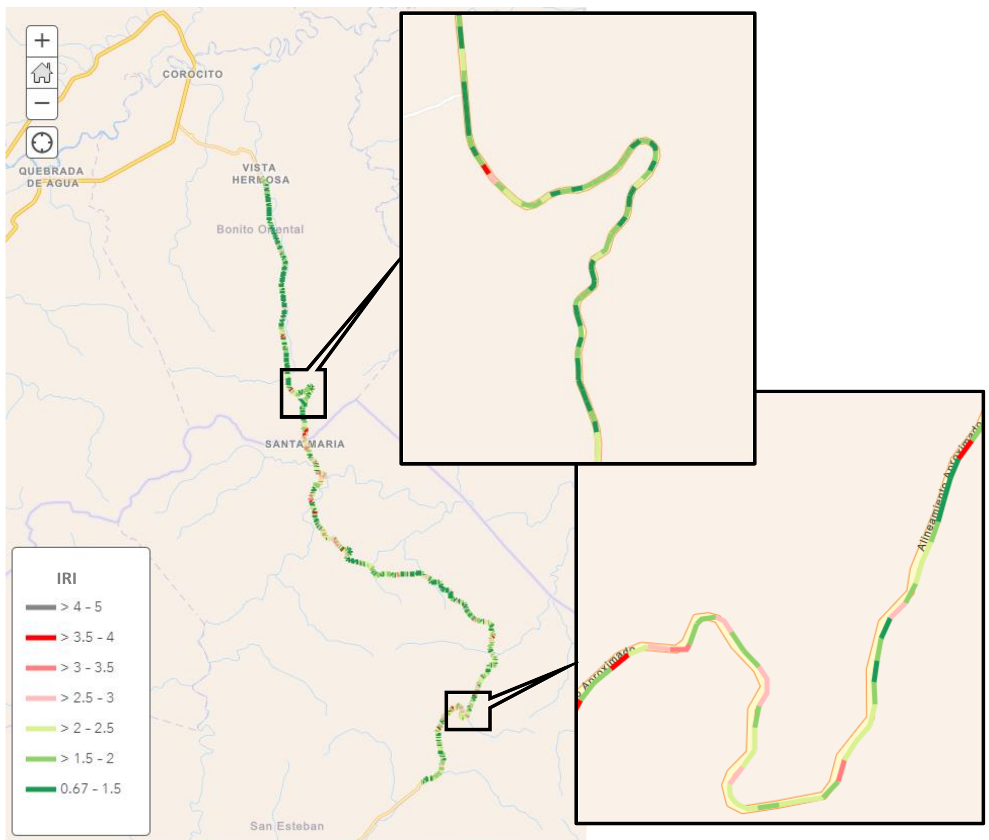

Figure 2. IRI Map

In order to present measured IRI for different pavement sections, the total pavement section is divided into 10 pavement segments (see Figure 3). Each pavement segment represents 10% of the total pavement length. For example, segment 1 for stabilized pavement represents the first 4.6 km length of the pavement. On the other hand, segment 1 for unstabilized pavement represents the first 1.8 km length of the pavement. Segment 1 and segment 10 represent the southernmost and northernmost segments. As seen from Figure 3a, the overall IRI for geogrid stabilized pavement is less than that for the unstabilized pavement. The average IRIs for geogrid stabilized and unstabilized pavement were 1.70 m/km and 1.96 m/km, respectively. In other words, the IRI of geogrid stabilized pavement was 14% less than that of unstabilized pavement.

Figure 3 also provides pavement IRI for the north- and south-bound lanes (see Figure 3b and Figure 3c). The average IRIs of the north-bound lane for geogrid stabilized and unstabilized pavements were 1.69 m/km and 1.85 m/km, respectively. Similarly, the IRIs of the south-bound lane for geogrid stabilized and unstabilized pavement were 1.72 m/km and 2.05 m/km, respectively. The geogrid stabilized pavement IRI for both directions were similar whereas the unstabilized pavement IRI for the south-bound lane was slightly higher than the north-bound lane. This fact indicates that the geogrid stabilized pavement has a uniform distribution of pavement roughness in both north- and south-bound pavements. On the contrary, the unstabilized pavement had a non-uniform distribution of pavement roughness. The basic statistics of measured IRIs for geogrid stabilized and unstabilized pavements are reported in Table 3.

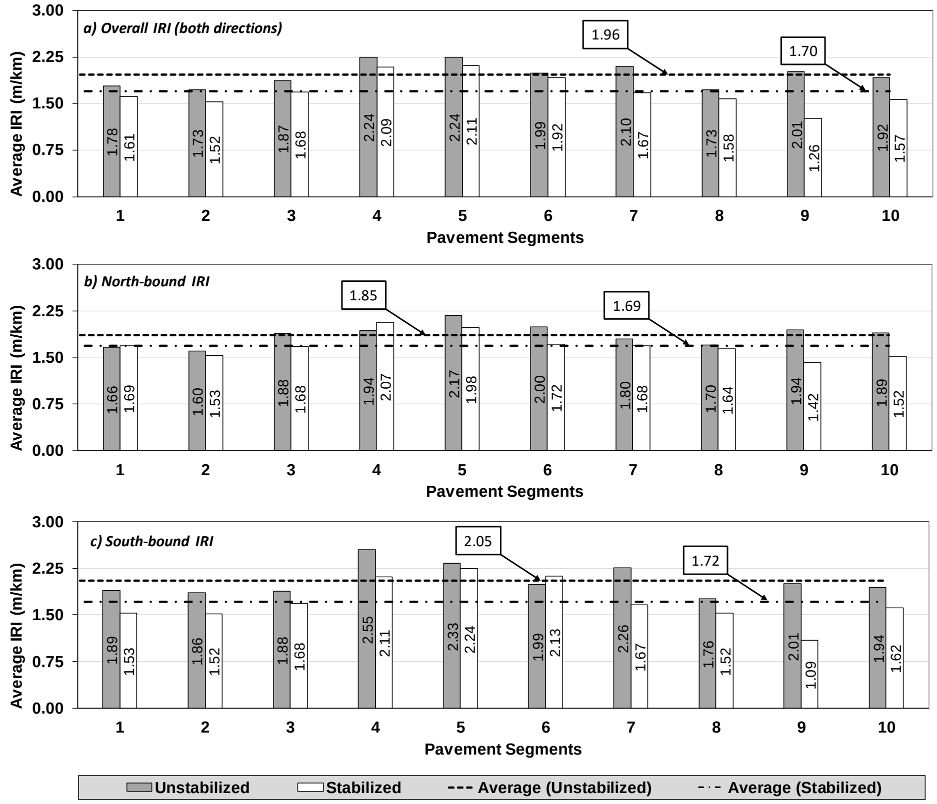

Figure 3. Measured IRI of Pavement Sections

Table 3. Basic Statistics of Measured average, minimum and maximum IRIs

Pavement Section		Measured IRI (m/km)	
		Unstabilized	Geogrid Stabilized
Overall	Avg.	1.96	1.70
	Min.	1.73	1.26
	Max.	2.24	2.11
	Std. Dev.	0.19	0.26
	COV	10%	16%
North-bound	Avg.	1.85	1.69
	Min.	1.60	1.42
	Max.	2.17	2.07
	Std. Dev.	0.17	0.19
	COV	9%	12%
South-bound	Avg.	2.05	1.72
	Min.	1.76	1.09
	Max.	2.55	2.24
	Std. Dev.	0.24	0.35
	COV	12%	21%

6. SUMMARY AND CONCLUSION

A section of Highway Route-39 between El Carbón and Bonito Oriental in Olancho and Colón, Honduras was constructed with a mechanically stabilized aggregate base course layer. Such mechanical stabilization was achieved by using a multi-axial triangular aperture geogrid. For this section of the project the original design of a pavement with a layer of aggregate base over cement-treated granular subbase was replaced with a geogrid-based design without the need for cement treatment. The improved design included a layer of geogrid at the interface of aggregate base and untreated granular subbase layers. The project consisted of 46 km of geogrid stabilized pavement and 18 km of unstabilized pavement. After heavy trafficking for over two years, the IRI information was collected and evaluated using the TotalPave technology to understand the effects of traffic and environmental loads on both pavement systems.

Based on this study, it was found that the average IRI of geogrid stabilized pavement is 14% less than that of the unstabilized pavement. The geogrid stabilized pavement also had a uniform distribution of pavement roughness throughout the pavement section. Overall, the results demonstrated that the mechanically stabilized section is performing better than the unstabilized section after two years of agricultural and tourist traffic, and climatic fluctuations.

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