Advances in Asphalt Research and Specifications in Central America

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ABSTRACT. *Central America (CA) is geographically area located to the south of Mexico and north of the South American continent, with a population of 30 million people and less than 600,000 square kilometers of area. The region is surrounded by the Caribbean Sea and the Pacific Ocean and includes these countries: Belize, Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica and Panama. Tthe last two countries are the e most developed.. Panama is widening the canal and constructing thousands of new buildings and financial areas. Costa Rica has the largest microchip plant in the world (Intel) and competes internationally for high-technology industries (HP, DELL, Pharmaceutical, etc) and service companies.*

Research and specifications for asphalt materials were very limited until the year 2000. The reason was that each country reduced their efforts in adopting AASHTO specifications for penetration and viscosity graded asphalt. The Marshall design procedure was the only methodology used for designing hot-mix asphalt (HMA).

The turning point for the asphalt industry was in 2000 when the Central American Manual for Highway and Bridge Construction (CA 2000) adopted the PG grading system and the Superpave method as an option for asphalt binder selection and HMA design. Additionally, in 2002, Costa Rica devoted one-percent of the fuel tax to perform applied research, project auditing, and technology transfer through the Transportation Infrastructure Program (PITRA) of the National Laboratory of Materials of the University of Costa Rica (LanammeUCR). This decision allowed the development of a state-of-the-art laboratory and inviting back to the country Master and PhD graduates to perform the mentioned activities. Today, LanammeUCR has all the Superpave equipment for binders and mixtures, dynamic devices for mechanical characterization of HMA (dynamic modulus, flow number, Hamburg *wheel track, Asphalt pavement analyzed, beam fatigue), and equipment for materials characterization ranging from nano-scale (AFM, TGA, DSC, FTIR, Raman spectroscopy) to full-scale (a heavy-vehicle simulator, HVS, to arrive in Costa Rica by September 2012). This investment in equipment and training of personnel made LanammeUCR the regional laboratory for this area.*

The most important current research lines are focused on developing specifications and material analysis representative of the tropical weather conditions and the weak soil foundation characteristic of the region. Examples of these research projects are: 1) calibration of the Witczak´s model for Central America´s HMA mixtures; 2) development of a new moisture damage test for tropical weather; 3) adaptation of chip and slurry seals for local conditions: 4) nano-characterization of neat and modified asphalt binders; 4) development of fatigue and rutting models for HMA mixtures; and, 5) the most ambitious project, to develop an empirical-mechanistic pavement design guide for the CA region.

KEYWORDS: *Local Calibration, Performance Testing, HMA Testing, HVS, MEPDG*

1. Introduction

Central America is the central region of the American Continent. It is considered a subcontinent that connects the southern part of North America (Mexico) with South America (Colombian border). As of now, the Central America population reaches 42 million people distributed on almost 524,000 square kilometers. Seven countries are part of Central America: Belize, Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica and Panama. Each one has a wide biodiversity, due, among other things, to their location in the tropics and between the Caribbean Sea and Pacific Ocean.

Figure 1. *Costa Rica's geographic location*

Costa Rica and Panama are the most economically developed countries in the region. Panama has been growing exponentially in the last few years, with an economic growth of 10% in 2011 (greater than the 9.2% of China). This growth promoted in big part by the widening of the Canal, has increased investment in the country. The unemployment rate in Panama is just 4.4%, which is expected to drop even more if the economic growth reaches another 10% in 2012.

Costa Rica, on the other hand, with a territory of 51,100 km^2 and a population of around four million, has ecoutourism as a big part of its economy, receiving approximately $2.2 billion, from around two million yearly foreign visitors. Additionally, due to a tax exemption that the government offers to international investors, and the high education level of its residents, an increasing number of high tech companies are operating in Costa Rica. Among these companies, Intel microprocessor´s facility is currently generating close to 20% of Costa Rican exports and around 5% of the GDP. Other companies with large operations in Costa Rica, include GlaxoSmithKline (pharmaceutical), Procter & Gamble (Consumer products), Hewlett Packard (Computers and technology), among others.

Costa Rica also produces cash crops for export, with the current main three crops: pineapples, bananas and coffee. Since 2007, Costa Rica has been the world's largest exporter of pineapples, accounting for more than 80% of all EU, US and Russian imports only in 2010. Banana and coffee, were for decades the two main cash crops for Costa Rica, however even though they continue to represent a significant income for the country, they have decreased on the world ranking of exports, keeping Costa Rica in the top ten exporters for each product due to its great quality. In fact, Costa Rica´s coffee is sold in some countries to mix with inferior quality grains due to its high content of caffeine.

Regarding Education, Costa Rica has one of the highest literacy rates in Latin America (94.9% as of 2010), due to the great yearly investment. The lack of a standing army, abolished permanently in 1949, permitted the investment and development of a high quality education system, free and mandatory for everyone. Also, the healthcare system in Costa Rica was ranked in 2000 as number 36th by the World Health Organization (WHO), among its 191 members around the world, above the USA, which ranked 37th. It is the highest ranked country in Central America, with a life expectancy at birth of 79 years, and above the age of 100 for Nicoya's Peninsula, considered as a “Blue Zone” for this particular reason. These characteristics and the way of life of the locals made Costa Rica the happiest country of the world in 2011.

Despite having good health and education indexes, Costa Rica had for several years a very deficient road system due to a lack of government control and empiricism in the decision-making process, which led to project failures within the first few months following construction. This problem continued until 2000 due to a very limited program in research and creation of specifications for asphalt materials.

The main reason for this delay was that most countries decided to reduce efforts by adopting the AASHTO and ASTM specifications to test materials, including the penetration and viscosity grading systems for asphalt. The Marshall design procedure was for years, the only methodology used for designing new hot-mix asphalt (HMA).

Figure 2. *Condition of the highway system in 1999*

This situation led to an increase of several problems in the national road system, from fatigue cracking to permanent deformation. However, the most common type of distress, which could be found in most roads was, and continues to be, moisture damage. This problem, added to weak volcanic soils, silts and clays, saturated in most cases, triggered the poor road condition. Furthermore, road deterioration was accelerated since traffic weigh control was never a priority in the government decisions, and the overweight trucks accelerated the deterioration of the road system throughout the country.

After 2001, the PG grading system was introduced in Central America as an option to the conventional grading systems. Shortly, in 2002, Costa Rica started to look for ways to improve the condition of the roads and better ways to assess moisture damage adequately. It was decided that the specifications currently used in Costa Rica needed to be calibrated or adapted to the weather and load conditions of the country that are very different than the ones found in the United States.

From 2002, Costa Rica has been facing a new great challenge on pavement engineering. It was made clear that a change in road infrastructure involving quality control, quality assurance systems (QC/QA), specifications and mainly material analysis was needed, with the objective of improving the condition of the country's road system.

2. The LanammeUCR´s Research Model

The National Laboratory of Materials and Testing Models (LanammeUCR) is an academic entity that is attached to the Civil Engineering Faculty at the University of Costa Rica. The LanammeUCR was founded in the 1950s and since its establishment, has focused its efforts towards applied research, formation of professional engineers and technology transfer in the fields of civil and transportation infrastructure.

LanammeUCR's main objective is the generation of specialized information and its transfer. Additionally, LanammeUCR lends its services and expertise to both the public (local and municipal governments, regional governments) and private sectors to ensure the latest technological processes are applied.

Figure 3. *LanammeUCR Facilities*

In an effort to ensure the competitiveness of the laboratory, LanammeUCR has strived to ensure that the quality of the results it generates are accurate, repeatable, and trustworthy. In order to do so, testing procedures that are used need to be validated and follow proper QC/QA tests. Consequently, since 2001, LanammeUCR implemented a quality assurance system following the ISO/IEC 17025 specification entitled: "General requirements for the competence of testing and calibration laboratories".

Additionally, in 2002, LanammeUCR accredited the first set of laboratory procedures with the Costa Rican Accreditation Entity (ECA). Since then the scope of the accreditation has been widened to include 77 testing procedures and several calibration procedures. Furthermore, to ensure the accuracy of the testing results, LanammeUCR participates in the proficiency sample programs carried out by the AASHTO Material Reference Laboratory (AMRL) and the Cement and Concrete Reference Laboratory (CCRL).

2.1 The Law 8114

Since the early 1990's it was evident that the state of the Costa Rican transportation infrastructure was rapidly deteriorating. This condition worsened due to the lack of supervision and planning from the Administration (Ministry of Transportation and Public Works). To make matters worse during this decade, the component of the national budget that was destined for road investment was drastically reduced (MOPT, 2011). This was a consequence of policies at the macroeconomic level regarding public spending, resulting from investment adjustment programs established under the guidance from the International Monetary Fund (IMF).

The reduction in road spending resulted in an accelerated deterioration of the Country's transportation infrastructure. Additionally, establishing contacts with the private sector to perform new construction or maintenance activities was a difficult process due to the complexities of the adjudication procedure and the lack of a budget. In order to address these issues, the National Transportation Council (CONAVI) was created in 1998 as established by Law 7798 with the objective of planning, programming, administrating, financing, performing, and supervising the maintenance and expansion of the national road network.

However, due to the lack of funding, the emphasis of road investment quickly shifted from new construction to maintenance of the existing infrastructure. This changed the role of the DOT to that of comptroller and supervisor. This change in priorities still remains, but is currently complemented by construction of new projects by means of concessions awarded to the private sector.

In 2002, Law 8114 destined economic resources for the maintenance and rehabilitation on the national road network. Additionally, the law assigned responsible supervising entities to ensure the quality of the national and municipal road networks. The law consists on a special fuel tax of 30.0% of the market price of the fuel: from the total collected, 1.0% goes to LanammeUCR. Part of the responsibilities assigned by law to LanammeUCR are those of performing applied research in topics related to road infrastructure that should result in the improvement of materials and pavement structures in use, and updating the national specifications at least every ten years. Specifically, Law 8114 gave LanammeUCR the following duties: a) To perform the evaluation every two years of the national road network (about 4,000 km, evaluated with falling deflectometer, laser profilometer for IRI, rutting and macrotexture, microtexture, video-camera evaluation of distresses, ground penetration radar, vulnerability of road corridors, road safety and the evaluation of about 1,500 bridges), b) to perform technical auditing of projects; c) to evaluate the road system under concession contracts; d) to provide technology transfer and certification to engineers, field inspectors and laboratory technicians; e) applied research on materials, pavements, bridges, transportation and road safety; f) to advise the Minister of Transportation when needed; g) to develop all the specifications for the Costarican DOT, and; h) to advise local governments in any of the previous activities.

2.2 The Transportation Infrastructure Program (PITRA)

As a part of the Faculty of Civil Engineering, LanammeUCR encompasses programs in several areas such as transportation infrastructure, seismic engineering and risk management, structural, and geotechnical engineering. The Transportation Infrastructure Program (PITRA) is in itself subdivided in several units that specialize in evaluation of the road network, technical auditing, and management of the municipal network, bridges, and production of technical specifications. All in all, Pitra is composed by a team of 40 technicians, 52 engineers, 2 lawyers, 5 chemists, 17 administrative personnel, and 24 undergraduate research assistants. PITRA has the management and generates all the products of the Law 8114.

Additionally, to complement all of these units, there is a Materials and Pavements Program that complements the work of the other units by means of applied research in different pavement related issues. The Materials and Pavements Program mainly focuses on: granular materials and soils, asphalt mixtures, material chemistry, preservation techniques, and pavement evaluation and monitoring.

Current research activities are aimed towards analysis and evaluation of physical, mechanical, and chemical properties of the different materials that are used in the road infrastructure, development of specifications for materials adapted to Costa Rican conditions, development and calibration of pavement infrastructure performance models, and in the mid- to long- term, development of a Structural Design Guide for the Country, and eventually, for the Region. All of the previous is fundamental in ensuring the proper performance of the national road infrastructure since material, climatic, and traffic conditions are very particular to the region and as such need to be properly accounted for.

More recently, research is being performed in coordination with other units of Pitra to expand the focus of research from specific pavement and pavement infrastructure related topics, to a more integrated transportation perspective that includes bridge and structural analysis, geotechnical analysis, traffic and safety research.

To aid Pitra, and Pitra´s Materials and Pavements Program in performing applied research and its other functions, LanammeUCR is equipped with a pavements laboratory. In 1997, the pavements laboratory consisted of a Marshall hammer, two viscometers, and one penetrometer. However, since then the pavements laboratory has grown and currently includes a conventional HMA laboratory, a dynamic analysis laboratory, a rheology and materials laboratory, and a field laboratory. All of the previous is complemented with a civil infrastructure laboratory capable of evaluating concrete and aggregates, soils, full-scale structures and resistance of materials.

2.3 Summary of the goals of the Law 8114

A summary of the achieved goals from the Law 8114 can be described as follows: a) more than 3,000 engineers and technicians trained at very low cost; b) five consecutive graduations of laboratory and field technicians; c) About 175 training courses, seminars, workshops and conferences; d) fifty research projects finished, e) development of a state-of-the-art laboratory; e) 150 audited projects; f) more than 40,000 km of pavement evaluated; g) more than 250 bridges evaluated; h) evaluation of the seismic and landslide vulnerability of more than 15 road corridors, and; h) one scientific journal edited for more than 10 years, a bi-weekly technical bulletin and special technical publications, h) more than ten counseling projects for the Minister of Transportation of the country.

In 2009, a technology transfer center was established, composed by a state-of-the.art auditorium for 150 people, a classroom and a specialized library for civil engineering and materials. Also, new research horizons have made LanammeUCR authorities to construct a new facility shown in Figure 4. The new building is expected to be inaugurated in June 2012.

Figure 4. *LanammeUCR New Facilities*

3. Research Activities

Because LanammeUCR is part of the Universidad de Costa Rica, and because of the responsibilities assigned by Law 8114, PITRA performs applied research activities in the areas of materials and pavements. More specifically, research is currently being performed in granular materials and soils, asphalt mixtures (HMA), material chemistry and material science, pavement preservation, pavement evaluation and monitoring, and full scale accelerated pavement testing.

Although the research currently under way is for distinct topics in the various areas of pavement engineering, all of the projects are geared towards meeting very specific objectives that PITRA has defined as its short- and mid-term research goals: 1) characterization of existing materials used in pavement construction, 2) implementation of new materials and technologies, and 3) development of pavement management tools.

All of the previous objectives are encompassed within a more ambitious project denominated PROMEVIAL. PROMEVIAL stands for Project for the Improvement of the Highway Infrastructure, and as the name suggests, it is intended for improving the National road infrastructure, with the purpose of significantly changing the quality of life of costarricans. As part of this project, and to ensure that the different tasks it encompasses are met, support is being given by several international consultants or agencies.

The project involves the development of an updated set of national specifications based on performance measures, in order to reduce the use and dependency on outdated empirical specifications and the development of material databases that can be used in the analysis, design, and QC/QA of pavement construction, maintenance and preservation. Additionally, an important goal of the project is to account for weather parameters such as moisture, precipitation, and temperature. This is fundamental since, as has been previously highlighted, the most common type of distress in Costa Rica is associated with moisture damage, and to date, based on current testing procedures, it has been very difficult to assess the moisture susceptibility of the different types of mixtures in current use.

Based on the information generated as part of the project, and based on previous and other ongoing research projects, pavement response models (stress and strain) that account for climatic and loading conditions are being developed. Likewise, transfer functions to estimate pavement performance are being calibrated for Costa Rica's conditions. Based on the previous models, one of the final products of PROMEVIAL is the development or calibration of a structural design guide for Costa Rica. Under discussion is whether an international guide is to be calibrated (eg. AASHTO's DarwinME) or a new guide is to be developed. However, in the short term the initial version of the design methodology will be available.

Consequently, in order to achieve the previous objectives, several research projects are currently being performed. A brief description of some of these projects follows.

4. Costa Rican Material Characterization

The different projects that are being carried out to achieve this major objective involve the physical, mechanical and chemical assessment of the different materials that are currently in use throughout the Country. This process is being performed to calibrate material response models that properly characterize the materials in current use, which will allow in the future for the prediction of pavement behavior.

Additionally, the data generated by this effort will serve as input for current pavement design and constructions methods that are currently being used in the Country, based on material properties and conditions that have been adapted from other regions with no proper calibration to the local conditions. Finally, proper knowledge of the available materials will not only help improve initial construction requirements, but will also help design pavement preservation and maintenance strategies that are not currently used.

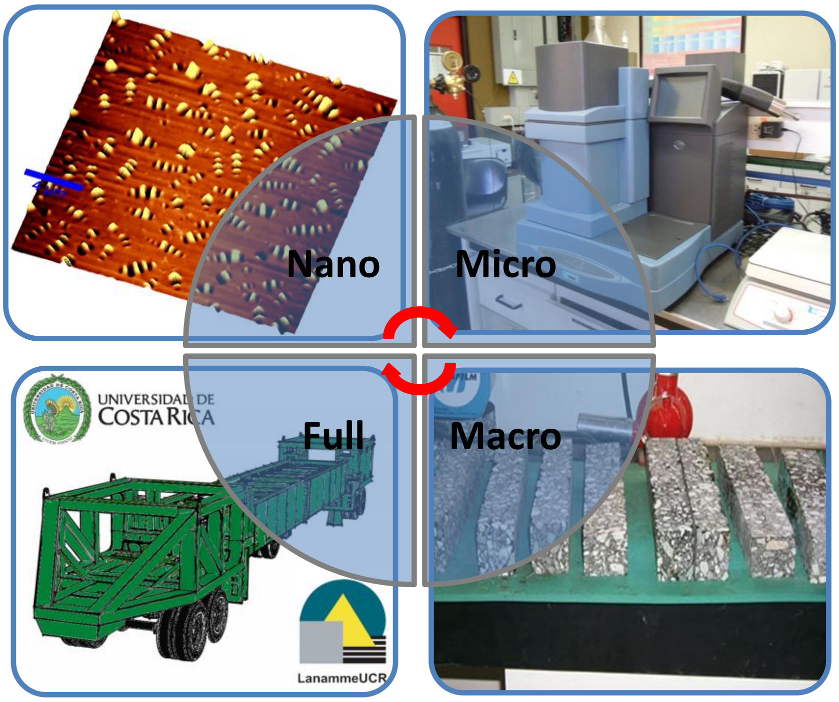


Figure 5. *LanammeUCR installed testing capacity (scales of analysis)*

In order to characterize the different materials of interest, LanammeUCR has an installed capacity that allows it to analyze a material from nano scales to full scale. Consequently, the different laboratories that compose LanammeUCR can measure materials at the nano scale by means of techniques such as Atomic Force Microscopy (AFM), Raman spectroscopy, Fourier Transform Infrared spectroscopy (FTIR), Atomic Absorption spectroscopy, Thermogravimetric Analysis (TGA), Differential Scanning Calorimetry (DSC), Iatroscan analysis, among others. Similarly, at the micro scale, materials can be analyzed by means of rheology (DSR) and dynamic mechanical analysis (DMA), and the macro scale, materials can be evaluated for fatigue resistance (four point bending beam), modulus (MR and E*), creep, resistance to rutting (Asphalt Pavement Analyzer – APA – and Hamburg Wheel Tracking Test – HWTD –), and moisture damage by means of traditional test protocols. Furthermore, LanammeUCR has several nondestructive field vehicles equipped with instruments that allow for the measurement of deflections, skid resistance, profile, surface deterioration, and texture.

To complement all the previous types of analysis, LanammeUCR is currently starting its accelerated pavement program, which will be based on a Heavy Vehicle Simulator machine.

5. ME Design Guide Development

The development of a ME Structural Design Guide for Pavements in Costa Rica responds to the applied research and update and development of technical specifications that are the responsibility of LanammeUCR. To achieve the goal several activities are currently being performed to generate the data and information required to calibrate or develop a design methodology. Among this activities are the following: i) Development of material and pavement performance databases, ii) Load surveys, iii) Calibration of resilient modulus for granular materials and soils, iv) Seasonal variation of moduli, v) Calibration of E* for HMA in Costa Rica, vi) Development of fatigue laws for HMA, and vii) Development of permanent deformation laws for HMA, and viii) Additional materials analysis.

The work for most of these activities is currently starting or already under way as will be described in the following sections.

6. Development of Databases

As part of the road network evaluation that is performed every two years by LanammeUCR, the status of the national paved network has been measured by means of profiler (IRI) and FWD equipment (deflections). This data has been collected every two years since 2004, for a total of over 22,000 miles of evaluated pavement. The data, in conjunction with other information, can currently be used to determine the status of the national road network, and allows for pavement management since it is possible to identify which sections of the overall network need some type of preservation, maintenance or rehabilitations strategies. Examples of the data for the entire network are shown in Figures 6 and 7.

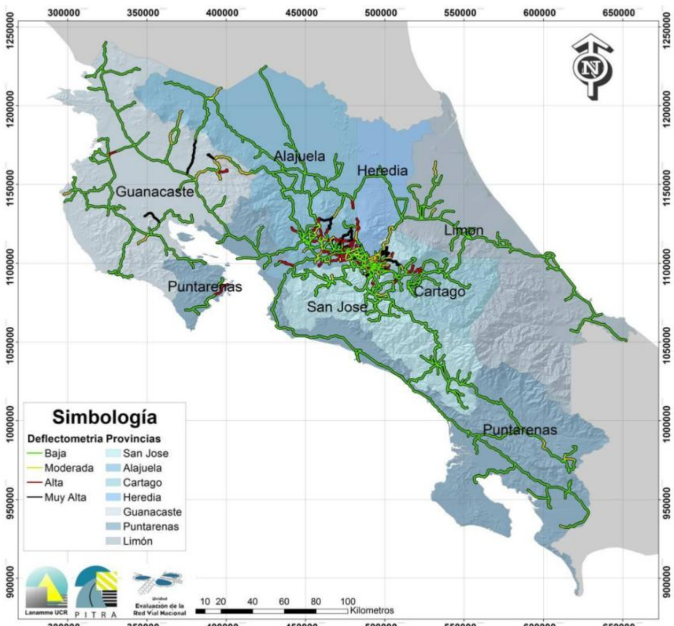


Figure 6. *Measured deflections for National Road Network (2010)*

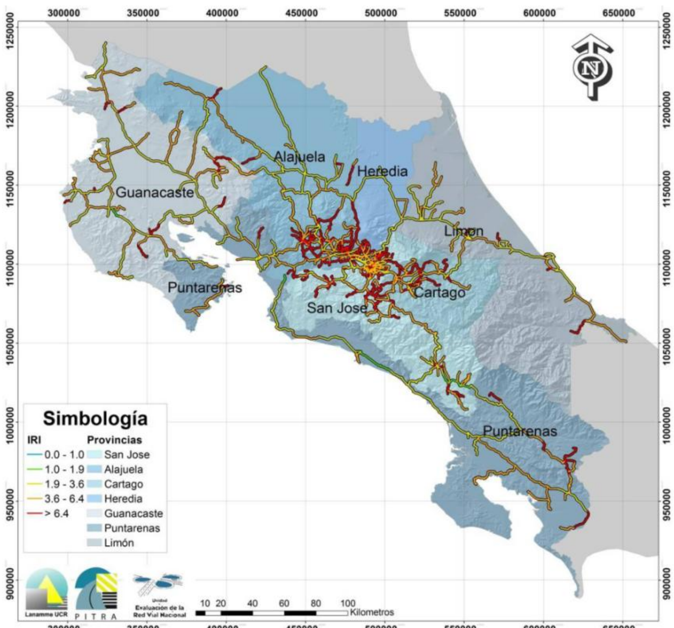


Figure 7. *Measured IRI for National Road Network (2010)*

In addition to the profile and FWD information that has and will continue to be collected, several additional performance data is currently being collected. Since 2010, over 1.000 miles of automated rutting data has been collected. Furthermore, more than 3.100 miles have been evaluated with the Griptester to determine skid resistance. This measure is highly important in Costa Rica due to the high levels of annual precipitation and because of the alignment of local roads. Both rutting and skid resistance can be used to determine dangerous areas where skidding and aero planning is likely to occur.

To complement the previous results, the retro reflectivity of the paint along the national roads is currently being monitored. The measurement of this parameter is relatively new to the Country. However, it is very important since historically the paints that have been used to delimit national roads have not demonstrated proper retroreflectivity. This is critical since for a considerable percentage of the time the roads are also wet, making the visibility of the material very difficult.

Additionally, for critical areas where problems are recurrent (not only the pavement structure, but the climate and terrain conditions) a more detailed vulnerability analysis of the entire corridor is performed. This analysis has been carried out for some of the most important highways (NR 1, NR 2, NR 27, NR 32, and NR 34).

Finally, to complement the performance information that has been collected, material information is also gathered and stored in many of the cases. More specifically, HMA performance testing is performed in the laboratory: dynamic modulus (E*), resilient modulus (MR), fatigue (4PBB), and permanent deformation (RLT, APA, HWTD).

7. Load Surveys

In the structural design of pavements, traffic and climate are the main factors that determine the thickness of the pavement to be used. However, in recent decades, the accelerated increase in traffic loads has resulted in a more rapid deterioration of the national road network. Consequently, there is a considerable need to quantify the loads that traffic the main roads in the country. This becomes more important when the only available data some years back was AADT measurements from the 80's and 90's that were used to extrapolate to today. Consequently, in an effort that was started at LanammeUCR in 2004 axle load data has been collected for the major corridors. This effort was strengthened from 2008 onwards, when the government through the DOT, specifically the Department of Weights and Dimensions, has continued to quantify and regulate the loads traveling over some of the major highways in Costa Rica. Based on this data that is continuously gathered, load spectra for the most common trucks that travel our roads have been developed. Examples of the spectra that have been generated to date are shown on Figures 8 and 9.

An additional benefit of measurement of the loads being transported along the major highways has been the reduction of overloaded trucks. During the initial years of monitoring the loads, it was identified that along some of the routes, up to 25% of all trucks were carrying loads above the allowed limit. This was a critical factor on a road network that up to recent years has received no improvement to capacity. However, to date, the percentage of trucks exceeding the weight limit is typically below 3%.

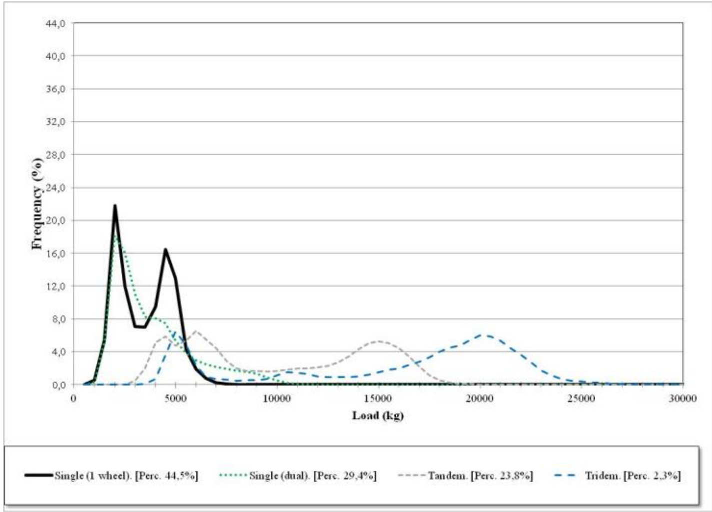


Figure 8. *Axle load spectra for National Route 2*

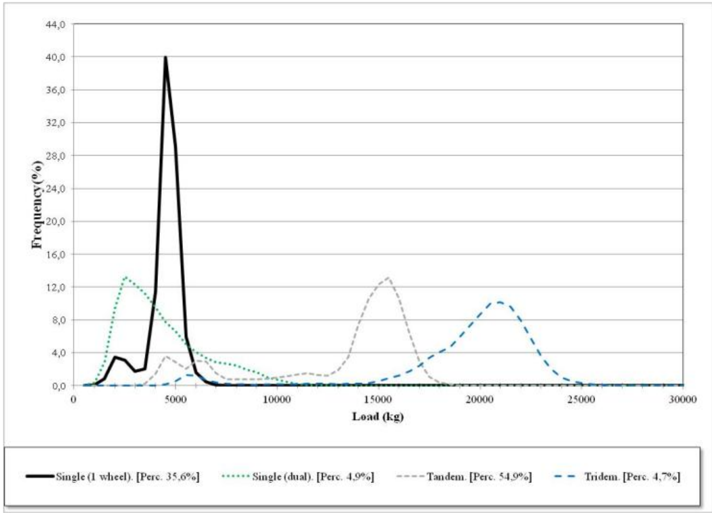


Figure 9. *Axle load spectra for National Route 32*

8. Resilient modulus of granular materials

These components of the project began with the implementation of the resilient modulus (M_R) test for granular materials. The test was selected because it is clear that the M_R is a better indicator of the behavior of the granular materials, as compared to the CBR, and should be the parameter that is evaluated for proper design of pavement structures. In order to properly set up the test, five of the more common granular materials that are used in the Country as base and subbase materials were evaluated at two moisture contents and at two different compaction efforts.

(a) (b)

Figure 10. *(a) M_R sample preparation and (b) testing equipment*

Based on the generated results, two M_R models were calibrated based on the following structural forms: $M_R = k_1 P_a (\theta/P_a)^{k_2}$ and $M_R = k_1 P_a (\theta/P_a)^{k_2}$ $(\tau_{oct}/P_a + 1)^{k_3}$, where M_R is the resilient modulus of the granular material in kPa, k_i are material constants, θ is the sum of the principal stresses in kPa (σ_1+ σ_2+ σ_3), Pa corresponds to the air pressure in kPa (88.38 kPa for Costa Rica), and τ_{oct} is the octahedral shear stress in kPa. Based on statistical analysis, it was identified that the prior structural form ($M_R = k_1 P_a (\theta/P_a)^{k_2}$) provides the best fit for the granular materials that are typically used in Costa Rica.

The project is still ongoing and currently a larger set of granular materials for base and subbase are being evaluated. Additionally, several types of soils are also being characterized. The purpose of the project at this stage is to improve the fit for the prediction models, and to account for other factors such as pore pressures and the compaction method.

9. Seasonal Variation of Moduli

Due to the high degree of variation in precipitation throughout the Country, and throughout the year for any given location, it is important to account for the variations in the strength of the supporting layers of the pavement structure. Therefore, in order to quantify the variation in the structural response of the pavement the FWD was used. The study consisted of measuring the deflection under the loading plate (D0), with respect to the time of year. The analysis was carried out monthly for a period of time between 2003 and 2006 in 32 locations and tried to capture the diversity in elevations, climates, and soil conditions throughout the Country. Figure 11 shows the geographical distribution of measurements.

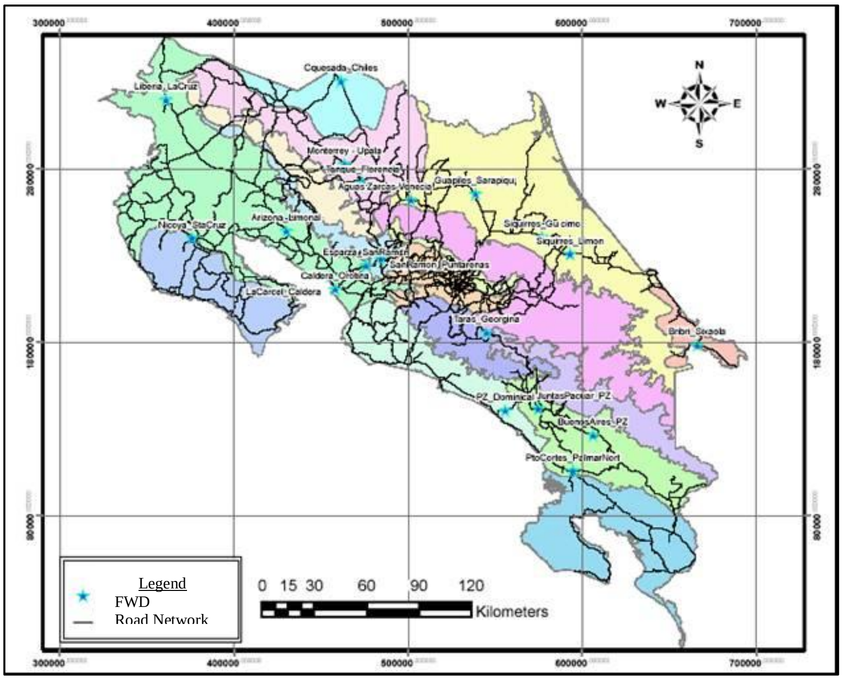


Figure 11. *Moduli variation study zones*

The study was complemented with a climatic study of each of the measurement locations. Consequently, for each location, detailed precipitation and temperature data is available. The data was statistically analyzed and trends in the change of modulus were characterized for each location. The information is considered to be very valuable since it will allow for corrections or adjustments to the capacity of the supporting layers through a given design or analysis period, and should consequently be an important factor in the development of the structural design guide.

10. Dynamic Modulus E* for HMA

As with the case of the resilient modulus for granular materials and soils, the dynamic modulus (E*) models for HMA have to be calibrated to the local conditions. Consequently, the ongoing research in E* characterization of local mixtures is currently being performed to improve the accuracy of E* models such as the one developed at ASU (Witczak Model). The initial stage of the project consisted on the E* characterization of 10 distinct mixtures, which included dense gradations going above, thru, and below the prevention zone, microsurfacing, SMA, and a typical plant gradation.

Based on these initial set of mixtures, it was identified that the Witczak model produced biased results when used for predicting E* (Figure 12): positive bias when the modulus is low and negative bias when the modulus is high. Consequently, the model was calibrated to account for the behavior of local materials. Based on the calibration, the fit of the model improved considerable and the bias was minimized (Figure 13).

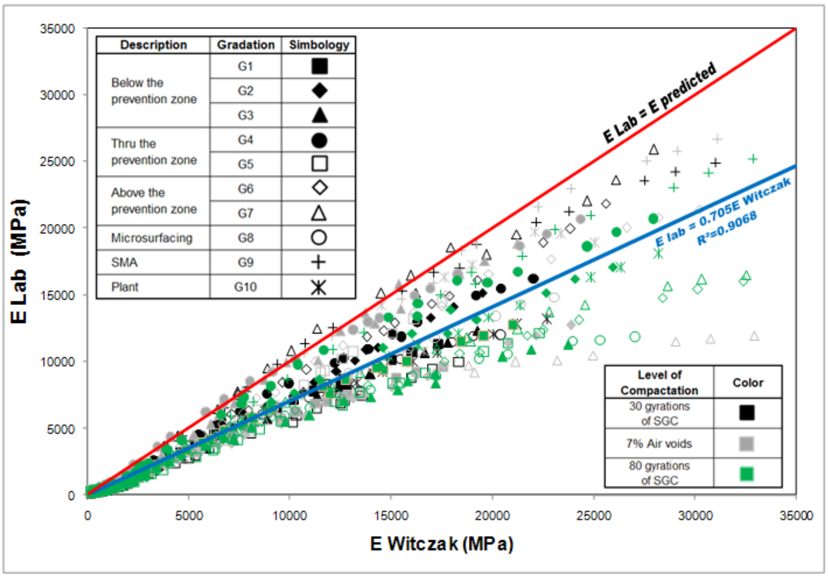


Figure 12. *Comparison of laboratory results and Witczak Model predictions*

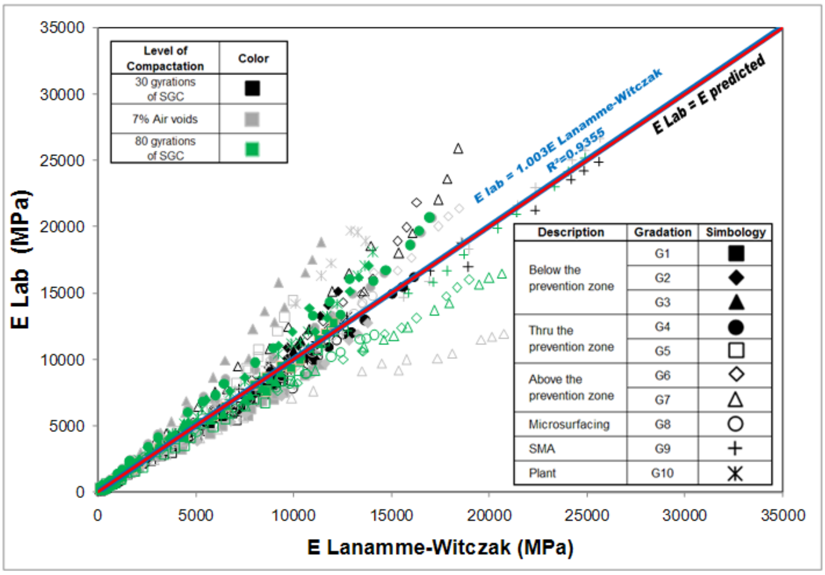


Figure 13. *Comparison of laboratory results and calibrated model predictions*

The calibrated model is the following:

$$\log E^* = 5,535833 + 0,002087\rho_{200} - 0,000566(\rho_{200})^2 - 0,002590\rho_4 - 0,078763V_a$$
$$-1,865947\left(\frac{V_{beff}}{V_{beff}+V_a}\right) + \frac{2,399557 + 0,000820\rho_4 - 0,013420\rho_{38} + 0,000261(\rho_{38})^2 + 0,005470\rho_{34}}{1+e^{(0,052941-0,498163\log(f)-0,691856\log(\eta))}} \quad [1]$$

where, E^* = dynamic modulus, psi.

η = bitumen viscosity, 10^6 Poise.
f = loading frequency, Hz.
V_a = air void content, %.
V_{beff} = effective bitumen content, % by volume.
ρ_{34} = cumulative % retained on the ¾ in sieve.
ρ_{38} = cumulative % retained on the 3/8 in sieve.
ρ_4 = cumulative % retained on the No. 4 sieve.
ρ_{200} = % passing the No. 200 sieve.

More recently, a wider range of mixtures is being evaluated based on E*, and all the additional information that is required by the model. This is being performed with the intention of further calibrating the model, or for developing models for specific conditions.

11. Development of Fatigue Equations

Because fatigue damage is the second most important failure mode in the Country (after moisture damage), proper characterization of the resistance of HMA to fatigue is required and will be an important component of the structural design guide. The HMA fatigue model was originally calibrated using the same 10 different mixtures that were used to calibrate the E* model. The resistance of the HMA mixtures to fatigue cracking was evaluated at 4.4°C, 21°C and 40°F using the flexural beam fatigue test (4PBB) under strain controlled testing mode.

The calibrated model is the following:

$$N_f = 10^{27.794} c(\epsilon_t)^{-5.477} (E^*)^{-2.311} \quad [2]$$

where, N_f = number of cycles to failure.

c = adjustment factor for local conditions (18,4 for Costa Rica).

ε_t = strain at the bottom of the HMA layer.

E^* = dynamic modulus for specific frecuency and temperature.

As was the case of E*, the fatigue models is currently being improved based on additional HMA mixtures that are being evaluated. In a similar fashion, work has also recently started on the calibration of permanent deformation models for the bounded and unbounded layers of the HMA structure.

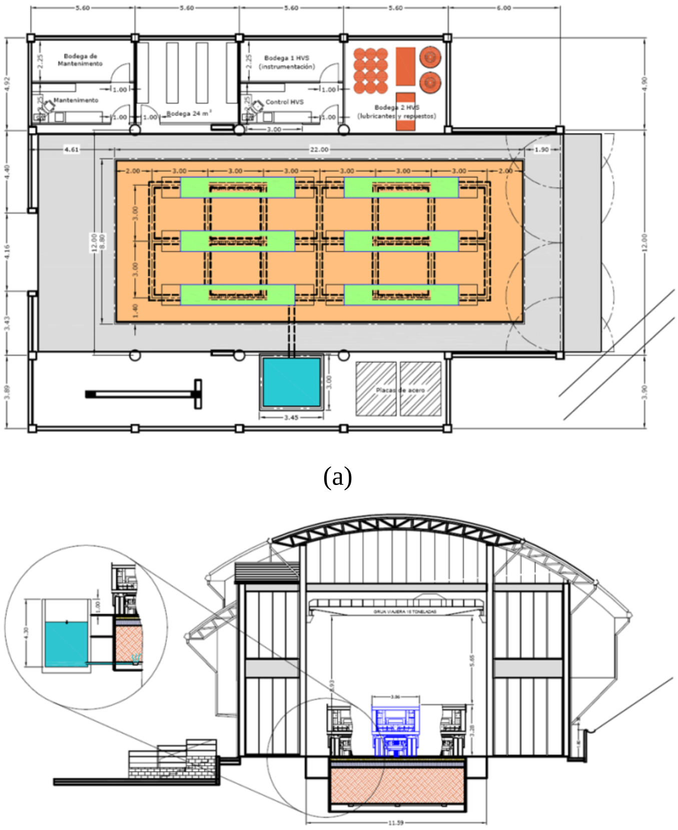
12. PaveLab

In 2005, the possibility of using an APT facility in Costa Rica began to be analyzed, mainly because of the need of evaluating the long term performance of existing pavement structures and new technologies that have proven effective in the laboratory, but have not yet been used in the field. All of the previous within the scope of the responsibilities defined by Law 8114, and the research plan developed by PITRA.

In 2009, the HVS Mark VI was entered into the budgetary reserve for the upcoming years. From that point in time, the PaveLab Project has been scheduled and planned to start operations by end of 2012.

PaveLab's research and testing plan is still under development. This is the case since it is the intention of LanammeUCR to form an APT Committee with the public sector (DOT, National Road Association, Construction Chamber, and the Association of Professional Engineers and Architects) in order to ensure that the testing that is performed as part HVS Plan will be for the benefit of the Country.

Based on the most recent planning, it is expected that initial HVS testing will be performed in two main phases: 1) from 2013 to 2015 it is expected that the HVS will be used in controlled experiments within LanammeUCR PaveLab's facilities, using saturation testing pits. This will allow for comparing different types of HMA mixtures and soil stabilization methods that are currently used or that are intended for future use in the Country, and 2) in a second phase starting in 2016, testing activities will not only be performed at LanammeUCR facilities, but the equipment will be taken to the field to evaluate different projects.



(a)

(b)

Figure 14. *(a) Plan view and (b) lateral view of PaveLab building with HVS equipment*

It is planned that initial experimenting will involved the comparison of HMA mixtures with modified and neat binders in order to quantify the improvement associated with including a modifier. This is very important since the use of modified binders in Costa Rica has been very limited and because only one type of binder is produced by the national refinery. However, due to the climatic and traffic diversity of the Country, the availability of several binder options is a necessity.

Most of the data analysis will be performed by PITRA's Materials and Pavement Program. However, thru the PaveLab APT Committee, it is expected that the results will be spread to engineering community so that they make an impact on pavement design and construction practices in the Region. Additionally, because of LanammeUCR's attachment to the Universidad de Costa Rica's Civil Engineering Faculty, an undergraduate and graduate thesis program will be developed to ensure that the information generated by the HVS can be used to its greatest potential.

13. Conclusions

Currently, LanammeUCR is one of the few laboratories in the region capable of providing reliable road analysis to the public and private sectors, assessment of the Country's entire paved road network, accurate evaluation of material quality, instruments for optimizing current decision processes, and tools for transference and implementation of existing and new technologies. All of the previous are responsibilities that LanammeUCR has acquired from the Country. Furthermore, as one of its core objectives, LanammeUCR was founded to improve the quality of life of the Costa Rican' people and their competitiveness as a nation.

It is based on the previous goal that all of the research effort currently being conducted is being performed. LanammeUCR's testing is based on research that is aimed towards the development of new specifications for the Country, and that should eventually lead to the development of a Costa Rican Mechanistic-Empirical Pavement Design Guide. In this sense, all of the infrastructure and equipment that LanammeUCR has acquired through the years are means that not allow evaluation of pavement structures, but will also facilitate the generation of pavement deterioration models for the Country that will indicate the pavement designers what type of pavements have proven effective or not, and under what type of conditions. It will also allow the Administration to check if the DOT, their subcontractors (private companies), and the newer modality – concessionaries – are designing and constructing pavements that can meet the expectations, both functional and structural, of the users.

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