Advances in Pavement Design through Full-scale Accelerated Pavement Testing – Jones, Harvey, Mateos & Al-Qadi (Eds.)
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PaveLab and heavy vehicle simulator implementation at the National Laboratory of Materials and Testing Models of the University of Costa Rica

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ABSTRACT: The LanammeUCR is an academic entity attached to the Civil Engineering Faculty of the University of Costa Rica. The Transportation Infrastructure Program (PITRA) of LanammeUCR, works directly with the Costa Rican government performing applied research, auditing and technology transfer. It is funded from a law that assigns 1% of the fuel tax collected in Costa Rica to LanammeUCR with the main objective of ensuring the efficiency of road investments in the country. To meet this objective, PITRA has allocated a considerable component of its funds towards the acquisition of high technology/state-of-the-art equipment such as an falling weight deflectometer, road surface profiler, Geo3D, and dynamic testing equipment for material characterization, among others. With the goal of improving the design and construction of pavements structures, as well as better understanding the different materials used, LanammeUCR decided to acquire a Heavy Vehicle Simulator (HVS) with instrumentation. With this Accelerated Pavement Testing (APT) equipment, LanammeUCR will be fully equipped to monitor the performance of different pavement structures and materials, and new and improved pavement technologies, and to develop and calibrate a mechanistic-empirical design guide for local weather, materials, and traffic conditions. This paper summarizes the draft plan for the design of the APT facility that will be constructed at LanammeUCR. The facility includes a saturation system to simulate pavement conditions during Costa Rica's intense rainy season.

1 INTRODUCTION

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 supervising and planning from the Administration (Ministry of Transportation and Public Works). To make matters even worse during this decade, the component of the national budget that was destined towards 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 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, mostly due to 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. 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.

Consequently, LanammeUCR has been working on characterization of local materials, improvement of asphalt mixtures to be used locally, and evaluation of the national road network since 2002. However, development of a pavement design procedure is difficult since new construction projects are limited.

Additionally, partly due to lack of knowledge in proper mixture and structural design, and partly due to deficient construction practices and poor quality control/quality assurance (QC/QA), most pavement projects still fail a few days after construction. Therefore, long term monitoring of properly designed and constructed road projects, from construction to failure, has been rather limited. This is an important setback in the objective of developing a structural design guide for Costa Rica since calibration or development of field pavement deterioration models is not possible.

To address this issue, and with the goal of properly characterizing the deterioration of new pavement structures, or rehabilitated pavement structures, the possibility of constructing and using full scale pavement test sites has been evaluated since 2005. After a detailed analysis of the different options/methods that are currently used worldwide to evaluate full scale pavement test section, it was determined that the best option for Costa Rica and LanammeUCR was to invest in an accelerated pavement testing (APT) facility. The facility will be equipped with a Heavy Vehicle Simulator (HVS) Mark VI model. This mobile machine will allow for accelerated trafficking of controlled or field test sections and will be capable of simulating 20 years of road deterioration in just a few months.

In conjunction with the acquisition of the HVS, the construction of a building that will house test tracks that can accurately simulate soil saturation conditions is being built with the intention of running the HVS under controlled conditions prior to taking the HVS to evaluate pavement test sections in the field.

All of the previous discussion is encompassed in the mid- and long-term research plan that has been established by Pitra and its Materials and Pavements Division. The plan establishes a line of research whose objectives will culminate in the development of new specifications to address all the material, climatic, traffic conditions associated with the country, and eventually, in the development of a mechanistic-empirical pavement design guide for Costa Rica. In this sense, the development of the APT program is a tool that will not only aid in the evaluation of natural scale test sections, but will also allow for the development of pavement deterioration and performance prediction models for the country. All of the previous will be complemented with materials and pavement research that has been performed at LanammeUCR for the past several years, and which is envisioned to continue in the future.

2 LANAMMEUCR

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 (Figure 1). The LanammeUCR was founded in the 1950s and since its establishment, has focused its efforts towards applied research, development 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 that the latest technological processes are applied.

Figure 1. LanammeUCR facilities.

In an effort to ensure the competitiveness of the laboratory, LanammeUCR has ensured that the quality of the results it generates are accurate, repeatable, and trustworthy. In order to do so, the 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), and since then the scope of the accreditation has been widened to include 77 testing procedures and several calibration procedures.

2.1 *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 into several units that specialize in evaluation of the road network, technical auditing, management of the municipal network and bridges, and production of technical specifications. All in all, Pitra is composed of a team of 40 technicians, 52 engineers, 2 lawyers, 5 chemists, 17 administrative personnel, and 24 undergraduate research assistants.

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 focuses mainly 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 to ensuring good 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 understood.

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 comprehensive 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 established a pavements laboratory. In 1997, the pavements laboratory consisted of a Marshall hammer, 2 viscometers, and 1 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.

2.2 *Law 8114*

As mentioned previously, Law 8114 was implemented to ensure the quality of the national road network. As part of the law (Article 6), several responsibilities are assigned to LanammeUCR to ensure that the previous conditions are met. These responsibilities can be summarized as:

1 Programs to educate and certify laboratory technicians
2 Technical audits of active projects
3 Biannual evaluation of the entire paved road network
4 Annual evaluation of roads and bridges awarded to concessioners
5 Updating the national road and bridges specification manual once every ten years
6 Technical audits of laboratories involved in the road industry
7 Technical advice to the heads of the DOT, Vice Minister, and Minister
8 Professional development courses and technology transfer activities aimed at inspectors and engineers, and
9 Research on topics related to the problems that the national paved road infrastructure is facing.

To ensure that LanammeUCR can perform these activities, Law 8114 assigns approximately 1% of the total fuel tax that is collected in Costa Rica. Pitra was created because of the responsibility that LanammeUCR holds towards Costa Rica. Internally, Pitra manages the funds to ensure that its assignments defined by law are met. Consequently, it is through appropriate planning that a percentage of the funds

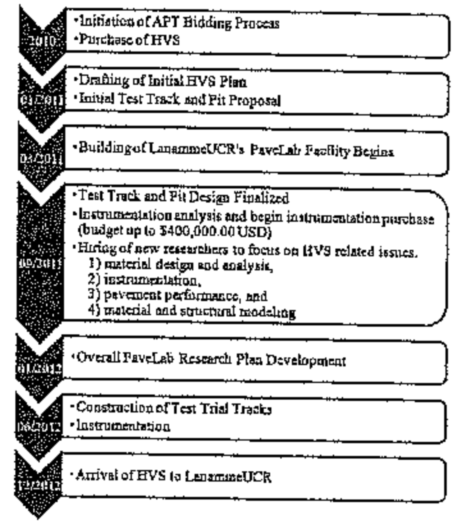

Figure 2. PaveLab project schedule.

from Law 8114 have been budgeted towards the purchase of high technology/state-of-the-art equipment for the pavement laboratories within LanammeUCR and for the field evaluation laboratory.

It is through this budget geared towards equipping the laboratory to perform applied research that the purchase of an HVS and construction of the APT facility (PaveLab) is being undertaken. Additionally, part of the budget is also going towards instrumentation for the HVS and for hiring specialized personnel to be involved in the material design and analysis, instrumentation, pavement performance, and material and structural modeling.

3 LANAMMEUCR

As previously stated, in 2005 the possibility of using APT facilities began to be analyzed, mainly because of the need for 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 discussion is within the scope of the responsibilities defined by Law 8114, and the research plan established internally by Pitra.

In 2009, the HVS was entered into the budgetary reserve for the upcoming years. From that point in time, the PaveLab Project has been scheduled and planned as shown in Figure 2.

PaveLab's research and testing plan is still under development and 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) to ensure that the testing that is performed as part of the 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 the saturation testing pits. This will allow comparison of different types of HMA mixtures and soil stabilization methods that are currently used or that are intended for future use in the country.
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.

It is planned that initial research will involve 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 in 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, through the PaveLab APT Committee, it is expected that the results will be spread to the 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.

Please note that PaveLab's Research and Testing plan is still under development and is subject to change based on research performed prior to the start of operation in 2013, and based on the input of the different sectors that are involved.

4 PAVELAB'S HVS

The HVS model acquired by LanammeUCR is the Dynatest/CSIR HVS Mark VI, which was the latest model released by Dynatest prior to the purchase date. This equipment does not have self propulsion or self powering features. However, its redesign and new features offer a great range of testing options. Some of the characteristics of this model are as follows:

- The HVS Mk VI can apply at least 26,000 bidirectional passes or 13,000 unidirectional passes of the load carriage in a 24 hour period, along an 8 m test section.
- The HVS load levels are between 30 and 100 kN (7–22.5 kips). Loading up to 200 kN (45 kips) is possible with an aircraft wheel and ballast options.

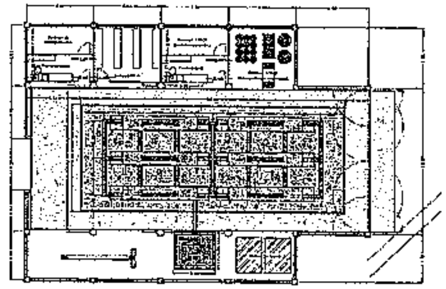

Figure 3. Plan view of the HVS building with the test pit in the middle.

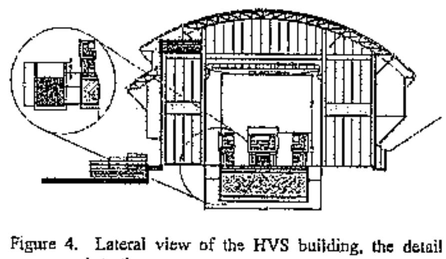

Figure 4. Lateral view of the HVS building, the detail corresponds to the water system.

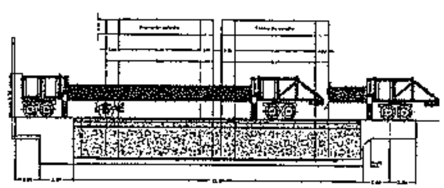

Figure 5. Lateral view of the HVS location over the pit.

- The maximum wheel speed is 12.8 km/hr ± 3 km/hr (8 mph ± 2 mph). The speed can be increased to 20 km/hr when using the beam extension.
- The equipment is capable of shutting itself down automatically at a programmed number of passes. Also, in case of a malfunction, the HVS can be stopped within one pass by two different mechanisms.
- The HVS is capable of duplicating traffic wander or wheel distribution by means of integrated mechanisms.
- The equipment can be operated in a range of temperatures varying from −15°C to 40°C (5°F to 105°F).
- Some of the new features that this model has in comparison to the previous models are:
  - A redesigned frame and a simplified hydraulic system based on the HVS Mk V carriage design.
  - The possibility of a beam extension, which allows higher testing speeds and a longer test track.

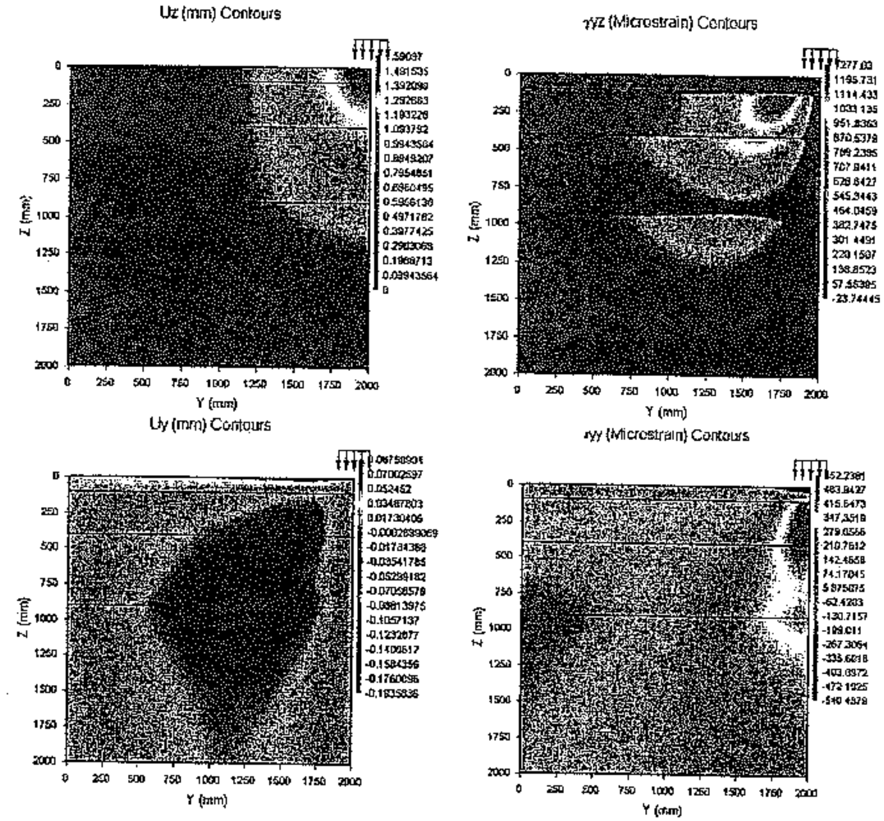

Figure 6. Example of *EverStressFE* analysis for a simple structure under a standard 40 kN load.

- Easier towing due to the reduced weight.
- The HVS Mk VI wheels are turntable mounted, which makes it more maneuverable on site. This feature will be of special help to LanammeUCR, because of space limitations within the PaveLab facility that is being prepared for the equipment.

Also, as mentioned previously, LanammeUCR will also destine $400,000 to the acquisition of part of the instrumentation that the equipment requires in order to gather more data for further analysis. The selection of instrumentation is based on past experience at other APT facilities (Choubane et al., 2011; Jones et al., 2002). Some of the equipment and parts that are planned to be purchased are the following:

- Dynamic loading equipment
- Automated onboard 3D laser profiler
- Pavement Data Acquisition System
- Dynatest PAST II and SOPT sensors
- Stress in Motion Sensor (SIM Pad)
- Multi Depth Deflectometer with 3 Levels
- Crack Activity Meter (CAM)

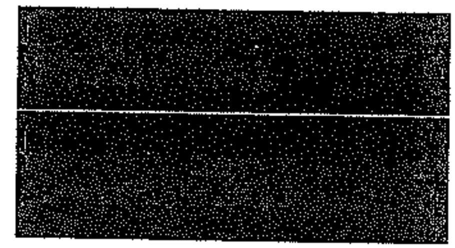

Figure 7. Analyzed test pit sections using FEM.

Each of these additional components is considered to be of great importance for the development of the HVS program in Costa Rica. Furthermore, a yearly evaluation of the different new equipment alternatives will be performed to ensure that new components are developed or acquired so that the equipment capabilities can keep up with the state of the practice

4.1 *APT facility*

The APT facility that will house the test tracks for the PaveLab program will be located at the new Laboratory of Road Safety and Enforcement. This building is part of LanammeUCR and is expected to be ready by the first quarter of 2012. Even though the facility is be part of this new project, its construction is completely independent from the rest of the structure to make sure that it meets the necessary power requirements, the emergency power supply requirements, and the weather-proofing and sound isolation necessary for optimal operation.

Figures 3 through 5 show the current layout of the APT facility. As shown, there will be six test areas (green rectangles) distributed on a 22 m by 9 m pit. To control the water table, a gravity operated water distribution system will be constructed adjacent to the test pit as shown on Figures 3 and 4 (blue colored). The overall design of the test pits is based on experience at other APT facilities (Hugo et al., 2004).

Several analyses were made to determine the optimal dimensions of the test pit. An initial analysis was made using the *EverStressFE* software package, defining simple pavement structures. These first results were used to evaluate the necessary depth to dissipate the stresses on the structure. An example of this analysis is shown in Figure 6. As shown, the stresses generated by the HVS (40 kN load) are negligible below a depth of 2 m. Similar analysis with loads up to 200 kN were also performed. This was used to estimate the optimal dimensions for the test pit.

In general, it was observed that the higher stresses/strains occurred in the area between the surface and approximately 1.0 m below the surface. More importantly, it was found that in general, a test pit depth over 2.5 m was adequate to ensure that the monitored stresses and strains would be similar to those in the field under the same loading conditions.

Finite element method (FEM) analysis was also used to check the stresses and strains estimated previously for a pavement structure subjected to a maximum load of 40 kN. The 40 kN load is equivalent to an applied wheel pressure of 120 psi over a circular area with 124 mm radius. It is important to clarify that even though the HVS can apply a load up to 100 kN (on its basic configuration), the 40 kN load was considered as the typical load applied by a single truck tire. For the FEM analysis, *ABAQUS* was used to solve the model.

Based on the FEM analysis, the same loading condition was analyzed under two different scenarios as shown in Figure 7:

1 A pit with a ramp to facilitate the entrance of construction equipment, and
2 A pit without a ramp access.

In both cases, it was assumed that testing would be performed on two sections along the longitudinal direction. For the analysis, the depth of the pit was set to 2.5 m to expand on the results previously obtained using *EverStressFE*. The results from these analyses are shown in Figures 8 and 9.

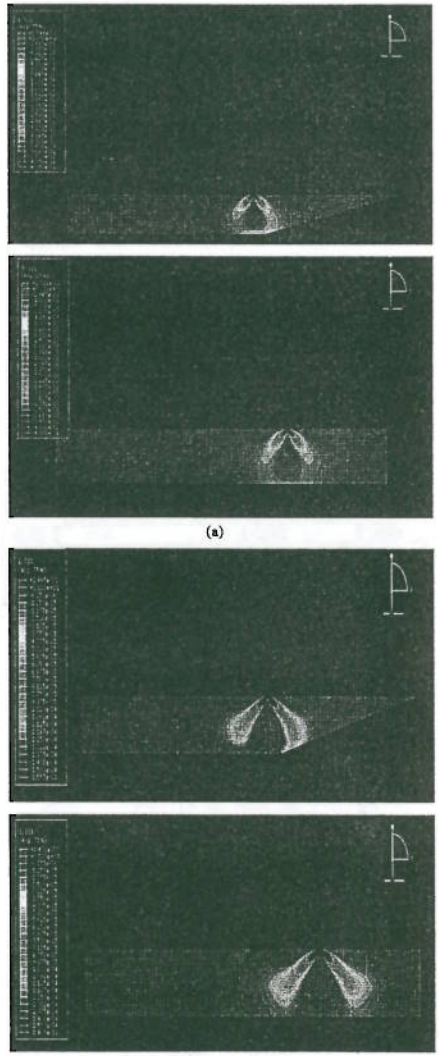

Figure 8. (a) Horizontal stresses and (b) horizontal strains for test section close to test pit ramp.

The results shown on the figures correspond to the application of the load at the extreme of the test section (closest to the test pit edge which is the critical condition due to the ramp configuration – load point. 2). All the data generated by the FEM was subsequently analyzed using spreadsheets. A selection of the results is shown in Figure 10.

Even though the figure does not show significant differences on the dissipation of the stresses and strains (when comparing the use of an access ramp to not using it), the figure does indicate a slight difference in stresses and strains between the condition with a ramp and no ramp. Furthermore, the construction of the access ramp to the test pit would incur in a loss of available testing area within the test pit.

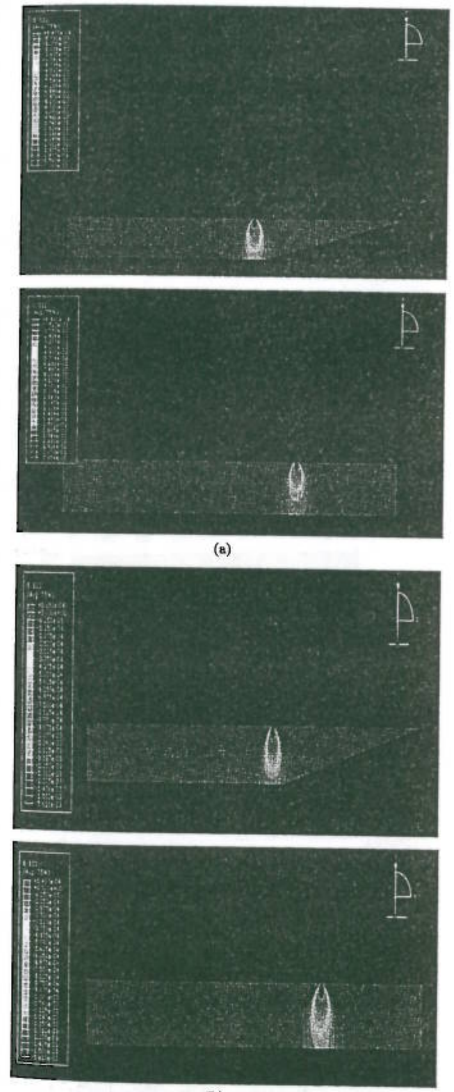

Figure 9. (a) Vertical stresses and (b) vertical strains for test section close to test pit ramp.

Finally, after analyzing all the data from this exercise and reviewing the literature with regards to typical test pit construction for other HVS sites, it was decided that the best working configuration for the HVS in Costa Rica would be: no access ramp and 3 m of depth. The decision of not using a test ramp is based on the fact that the use of the ramp significantly reduced the effective test area of the test pit: by eliminating the ramp, one additional test section can be allocated within the test pit.

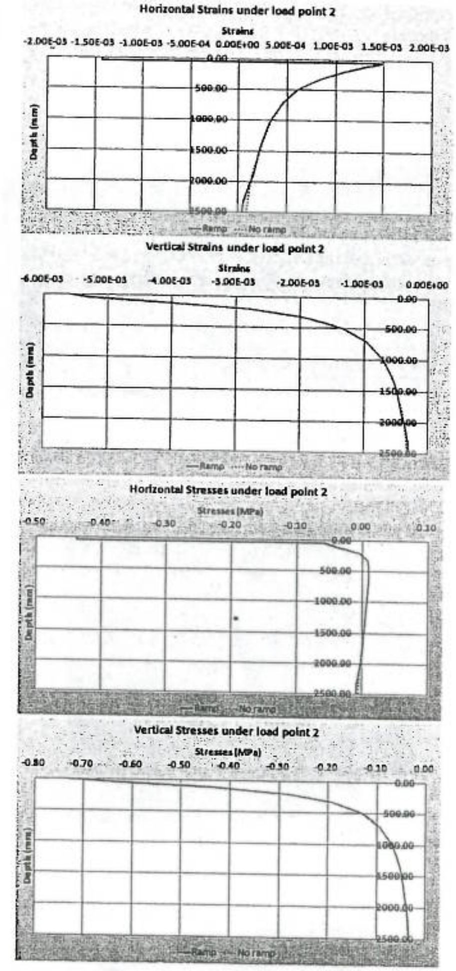

Figure 10. Horizontal and vertical stresses and strains for both geometric loading conditions.

Additionally, a 3 m deep test pit was selected after considering that higher testing loads might be applied in the future and this slight increase in test pit depth can accommodate an increase in applied load. This decision was later confirmed by the expertise of other HVS owners, and Dynatest, whose help and strong support have been fundamental in the design of this project.

5 CONCLUDING REMARKS

LanammeUCR was founded primarily to improve the quality of life of the Costa Rican' people and their competitiveness as a nation. 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 transfer and implementation of existing and new technologies.

With a focus on meeting the objectives set for LanammeUCR, PaveLab is initiating an APT program. The idea of acquiring an HVS is based on the mid- and long-term research plan of the institution that is geared towards meeting LanammeUCR's commitment with Costa Rica. PaveLabs's testing will be based on research that is aimed towards the development of new specifications for the country, and that will eventually lead to the development of a Costa Rican mechanistic-empirical pavement design guide. In this sense, the PaveLab's HVS is a tool that will allow evaluation of full-scale pavements in a natural, but controlled environment, and facilitate the generation of pavement deterioration models for the country that will indicate to 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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