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ACCELERATED TESTING OF ROAD STRUCTURES MADE OF TRADITIONAL AND RECYCLABLE MATERIALS EXPERIMENTAL SET-UP

BY

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Abstract. This paper presents the set-up required for an experimental study focusing on the structural behaviour of classical road structures, hydraulically bounded mixture (HBM) pavements and reclaimed asphalt pavements (RAP). For that purpose, seven distinct road structure sectors were designed and executed on the frame of the Accelerated Loading Test (ALT) ”Laboratorul de încercări rutiere accelerate” (LIRA) Facility, abbrev. ALT-LIRA, located at the Faculty of Civil Engineering and Building Services in Iasi. The experimental sectors were instrumented with strain and pressure gauges to collect information regarding the stress-strain state at the level of the main structural layers. Each sector will be tested by applying a controlled, accelerated wheel loading under laboratory conditions. Important aspects regarding the behaviour of the road pavement structures, such as the normal strain variation at the formation level, the stress distributions at the level of the stabilized based courses, the shear strain distributions at the level of the bituminous courses and the total displacements of the pavements can be obtained and analysed by performing the envisaged experimental program based on the proposed set up.

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Keywords: accelerated pavement test; stabilized soil; recyclable materials; reclaimed asphalt pavement; reclaimed concrete material.

1. Introduction

The road infrastructure represents one of the most important means of transportation for people, goods and services. The maintenance and the extension of the road network are activities that deliver economic benefits and improve access to markets and labour.

According to European Asphalt Pavement Association (EAPA) and National Asphalt Pavement Association (NAPA) (2011) the total amount of asphalt produced in Europe to meet the material requirements for road construction is about 400 million tons. One the other hand, the growth and the rapid development of the road industry generates high amounts of waste materials. The total amount of waste generated in the European Union in 2010 was over 2.5 billion tons, of which almost 860 million came from construction and demolition activities. Furthermore, it is estimated that the waste generated from construction, demolition and renovation of residential and non-residential buildings in the United States in 2003 was close to 170 million tons (Eurostat, 2013). Some of these waste materials can still be used in construction since most of their components have proper physical, chemical and mechanical characteristics. Therefore, researchers currently focus on developing new recycling methods and technologies for reusing the waste materials in the construction of road pavement structures.

Nowadays, the public agencies and the asphalt manufacturers that are responsible for the maintenance and the extension of the road infrastructure have limited funds to cover the needs of the transportation industry. To contain or reverse this declining trend, it is crucial to identify and analyse the possibilities of recycling and/or rehabilitating the existing pavement structures so as to assure the road service conditions at a minimal cost. It can be easily observed that the profitability of the investments in road infrastructures is directly related to the success of the rehabilitation program.

The use of recycling technology in the road infrastructure sector is a proven method, globally implemented with remarkable results, involving the rehabilitation of the structural deficiencies along with the improvement of the load-bearing capacity. Also, compared to any other existing rehabilitation method or technology, recycling in the road sector leads to both increased construction speed and reduced maintenance costs. The road infrastructure recycling methods associated with the condition of sustainability requires an economic model that responds to the social demands for transportation without disturbing the natural cycles or impoverishing the natural capital. This economic model, called Circular Economy (CE), seeks to improve the traditional model of road construction project management based on strategies designed to reduce all types of waste in production, time, and effort, so as to generate the maximum amount of possible value.

2. Literature Review

Rohan (2016) states that until recently, the construction economy has functioned as a linear model „procurement – production – elimination". This economy model can be characterised as an isolated and autonomous system, meaning that it responds to the social demands for products and services by impoverishing the natural capital. Due to this major drawback, in 2015 the European Commission proposed the CE model as an alternative solution designed to protect non-renewable resources. CE is a comprehensive concept incorporating different meanings that promotes a responsible and cyclical use of resources possibly contributing to sustainable development.

Yuan *et al.* (2006) sustains that the CE concept is not regarded as a strategy to solve all existing environmental problems, but it has been widely recognized that could help improve resource productivity and eco-efficiency in various industries. Also, the authors consider that the current methodologies and strategies focused on the improvement of the industrial processes have emerged out of the frame of the traditional manufacturing industry.

Geissdoerfer *et al.* (2017) defined the CE model as a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowly closing or narrowing the materials and the energy loops. This is achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling.

Xiao *et al.* (2018) states that for the public agencies that are responsible for the maintenance and the extension of the road infrastructure, the CE model is associated with the idea of developing new recycling materials that can be used to construct an efficient, safe and cost effective pavement system. The most used recycling methods of road materials and infrastructures are: Reclaimed Asphalt Pavement (RAP) by hot or cold recycling, in place surface and base recycling, Central Plant Recycling (CPR) and Full Depth Reclamation with Cement (FDR). From these methods, the RAP cold recycling has been highlighted as one of the most advantageous techniques in case of low volume roadways. Nonetheless, recently, The Virginia Department of Transportation proved that RAP cold recycling is also appropriate for the rehabilitation of heavy traffic volume roadways only if a proper management system is applied (Gu *et al*., 2019). Usually, the management system focuses on reducing the ’’waste’’ associated with the recycling process, including unnecessary movements and inventories, transport time, defects, overproduction, waiting time and inadequate processing in the development of the recycling project.

Moreover, the RAP cold recycling approach is valuable in remedying the degradations of asphalt pavements due to rutting and fatigue (Alkins *et al*., 2008; Lane & Kazmierowski, 2005; Buss *et al*., 2017). At the same time, it is a road construction method that follows the basic parameters of sustainability (it preserves the non-renewable resources and energy) (Thenoux *et al*., 2007; Tabakovic *et al*., 2016; Turk *et al*., 2016).

3. Overall Description of the Experimental Program

The proposed experimental program consists of various Accelerating Pavement Tests (APT) performed on both classical and modern pavement systems, aiming to understand and describe the most suitable combination of material layers that make up the road structure to sustain heavy traffic. The typical combination of layers of a road pavement structure includes the ground layer, the subgrade layers, followed by the stabilized subbase layers, a combination of stabilized or bituminous base layers and, finally, the surfacing layers.

For this study, seven experimental sectors (Fig. 1) were designed and constructed. Two sectors consist of classical, flexible pavement systems (sector no. 1 and no. 7), otherwise known as “benchmark sectors”, while the remaining five sectors were built with semirigid pavements (sector no. 2,...,6). The first four experimental sectors were designed taking into account a traffic level up to 1.00 million standard axles (m.s.a.) and the experimental sectors from no. 5 to 7 were designed to sustain a traffic level higher than 1.00 m.s.a.

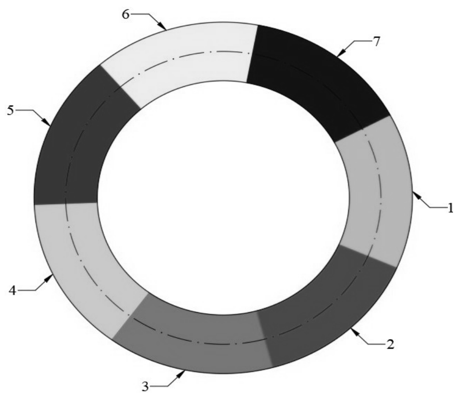

Fig. 1 – Proposed experimental sectors.

The materials and the road construction technologies were different for each type of pavement system. Therefore, the experimental set-up procedures were run in phases, and each phase was separately described. Due to the complexity of the phases, the experimental set up is presented in a two-part paper. In the first part the set-up phases for the experimental sectors no. 1, no. 2, no. 4, no. 6 and no. 7 are described, followed by the further detailing of the set-up phases of sectors no. 3 and no. 5 in the second part of the paper.

The constitutive materials and the geometric configurations of the experimental sectors that are characterised in this paper are presented in Figs. 2,...,6.

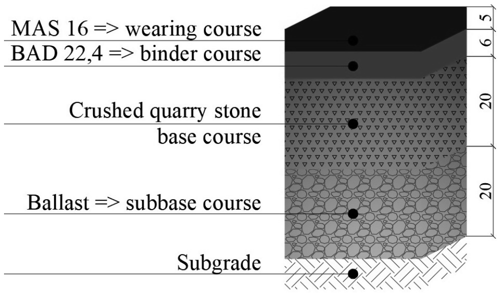

Fig. 2 – Experimental sector no. 1.

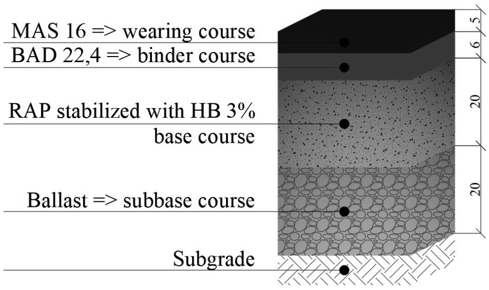

Fig. 3 – Experimental sector no. 2.

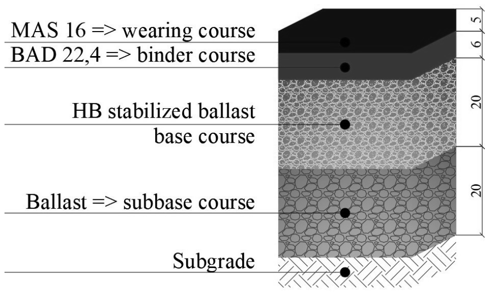

Fig. 4 – Experimental sector no. 4.

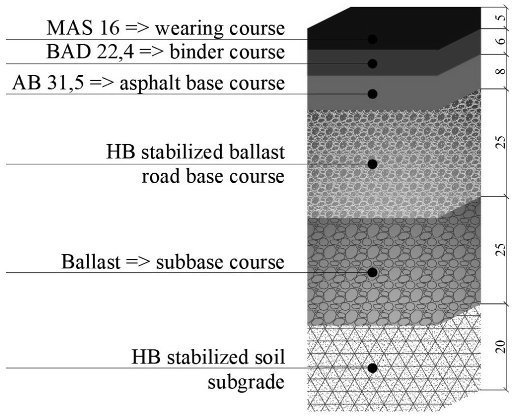

Fig. 5 – Experimental sector no. 6

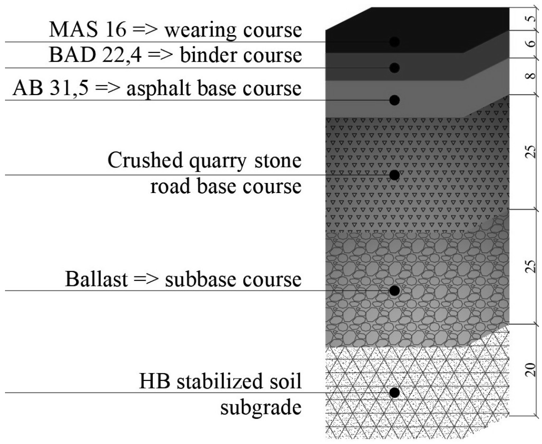

Fig. 6 – Experimental sector no. 7.

4. Materials Properties

4.1. Materials Used for the Subgrade Layer

According to Table 1b, taken from the Romanian Norm STAS 2914-1984, the soil used as subgrade for the experimental sectors no. 1, no. 2 and no. 4 falls into the type 4b category. In the same Norm it is specified that the quality of the materials included in the type 4b category is considered to be tolerable, but less than satisfactory for road construction. Although the Norms and the

Practice Guides do not recommend this type of soil as subgrade for roads, a large part of the Romanian national road network was developed on identical or similar soils.

The subgrades of the experimental sectors no. 6 and no. 7 were made with soils of type 4d. According to the Romanian Norm STAS 2914-1984, the quality of the materials that are included in the type 4d category is considered to be unacceptable for road construction. Thus, the subgrades made with this type of materials were stabilized with hydraulic road binder in percent of 3.00% reported to its total mass. By testing identical pavement systems built on different soils, the influence of the subgrade on the strain distribution may be analysed. The compaction characteristics of both soil types used as subgrade are presented in Table 1.

Table 1
The compaction Characteristics of the Subgrade

Compaction characteristics	Symbol	Unit	Value
Experimental sectors no. 1, no. 2 and no. 4			
Dry bulk density	$\rho_{d\max}$	g/cm^3	1.664
Optimum compaction moisture content	w_{opt}	%	15.90
Experimental sectors no. 6 and no. 7			
Dry bulk density	$\rho_{d\max}$	g/cm^3	1.821
Optimum compaction moisture content	w_{opt}	%	14.90

4.2. Materials Used for the Subbase Layer

The subbase course consists of a ballast layer made with materials extracted from the Cristeşti quarry. The compaction characteristics of the ballast are presented in Table 2.

Table 2
The Compaction Characteristics of the Subbase

Compaction characteristics	Symbol	Unit	Value
Dry bulk density	$\rho_{d\max}$	g/cm^3	1.970
Optimum compaction moisture content	w_{opt}	%	9.40

4.3. Materials Used for the Road Base Layer

The road base, also referred to as the base course, is defined as a layer or a combination of layers of bounded or unbounded materials that provide and assure the structural integrity of a pavement. In most of the cases, the base courses of the Romanian roads are made of well-graded materials, usually crushed stone. Thus, the road bases of the experimental sectors that were considered in this study were selected according to the most common materials used for the construction of Romanians roads, as follows:

For the experimental sector no. 1 and no. 7, the road base course was made with crushed quarry stone extracted from the Dornişoara quarry.

For the experimental sector no. 4 and no. 6, the road base course was made of stabilized ballast with hydraulic road binder in percent of 3.50% reported to its total mass.

For the experimental sector no. 2, the road base course was made by the RAP cold recycling technology, by stabilizing the material with hydraulic road binder in percent of 3.50%.

The compaction characteristics of the materials used as road base are presented in Table 3.

Table 3

The Compaction Characteristics of the Road Base

Compaction characteristics	Symbol	Unit	Value
Experimental sectors no. 1 and no. 7			
Dry bulk density	$\rho_{d\max}$	g/cm^3	2.227
Optimum compaction moisture content	w_{opt}	%	6.20
Experimental sectors no. 4 and no. 6			
Dry bulk density	$\rho_{d\max}$	g/cm^3	2.159
Optimum compaction moisture content	w_{opt}	%	5.50
Experimental sector no. 2			
Dry bulk density	$\rho_{d\max}$	g/cm^3	2.005
Optimum compaction moisture content	w_{opt}	%	5.10

4.4. Materials Used for the Asphalt Base

In the case of the experimental sectors no.6 and no.7, the base layer consists of an asphalt course made with bituminous mixture. According to the Romanian Norms AND 605-2016 and SR EN 13108-1/AC-2008 this material falls into the type AB 31.5 category. The bitumen volume was set at 4.50%, value based on the weight of the mixture.

4.5. Materials Used for the Binder Course

On all the experimental sectors, the binder course was made of an asphalt mixture. According to the Romanian Norms AND 605-2016 and SR EN 13108-1/AC-2008 this material falls into the type BAD 22.4 category.

4.6. Materials Used for the Surface Course

The surface course consists in an asphalt mixture and was kept the same for all the experimental sectors. According to the Romanian Norms AND 605-2016 and SR EN 13108-1/AC-2008 this material falls into the type MAS 16 category. The bitumen volume (5.60%) was determined based on the weight of the mixture and the fibre volume was set at 0.50%.

5. Experimental Sectors Set-up

The designed pavement thickness for the experimental sectors no. 1, no. 2 and no. 4 was 51 cm, while the experimental sectors no. 6 and no. 7 were designed with a total thickness of 89 cm. As mentioned before, in case of the experimental sectors no. 1, no. 2 and no. 4 the earth work construction (subgrade), beneath the pavement, consists in layer of 20 cm of compacted natural soil. For the experimental sectors no. 6 and no. 7, the subgrade consists in a stabilized soil with hydraulic road binder in percent of 3.00% with a total thickness of 20 cm. The earth work construction was performed by progressively bedding and compacting the soil layers, until the designed thickness was achieved.

The next stage in the preparation of the experimental sectors was the execution of the sub-base course made of ballast. For the experimental sectors no. 1, no. 2 and no. 4 the designed thickness of the ballast layer was determined as 20 cm. In the case of the experimental sectors no. 6 and no. 7, due to the imposed high traffic volume (over 1.00 m.s.a), the designed thickness of the ballast layer was 25 cm. The sub-base was constructed by bedding two ballast layers. Immediately after the layers had been spread and shaped to the cross section required, each of them was compacted with suitable and adequate compaction equipment, as specified in Romanians Norms and Practice Guides (CD 148-2003).

Once the sub-bases of the experimental sectors had been completed, the execution of the road bases started. The primary goal of these layers is to assure the structural integrity of the pavements.

For the ’’benchmark sectors’’, the road bases consisted of a layer of crushed quarry stones with a thickness of 20 cm on the first experimental sector and a thickness of 25 cm on the final one. For the experimental sector no. 2, the road base consisted of a layer of 20 cm made of stabilized RAP with hydraulic road binder in percent of 3.50% reported to its total mass. In the case of the experimental sector no. 4, the same thickness was kept but the material was replaced by a stabilized ballast with hydraulic road binder in percent of 3.50%

reported to its total mass. The same material was used for the road-base of the experimental sector no. 6, yet, in this case, the thickness was increased to 25 cm. The road bases of all the experimental sectors were bedded in two layers and each of them was compacted to assure an adequate mechanical strength.

The experimental sectors no. 6 and no. 7 were designed to include an asphalt base course made of a bituminous mixture of type AB 31.5 with a thickness of 8 cm. This base was bedded in a single layer by keeping a temperature between 110,...,140ºC, as recommended in the AND 605-2016 Norm, and compacted to ensure an adequate mechanical strength.

The binder course for all the experimental sectors consisted of an open-graded asphalt concrete of type BAD 22.4 with a thickness of 6 cm. Similar to the case of the asphalt base course, the binder course was bedded in a single layer and compacted to ensure an adequate mechanical strength.

The wearing course, also referred to as the surface course, consisted of a stabilized asphalt mixture of the MAS 16 type with a thickness of 5 cm, bedded in a single layer, for all the experimental sectors.

6. Experimental Procedure

The APT facility used in this study is an indoor facility located at the Faculty of Civil Engineering and Building Services in Iasi (Fig. 7). This road-testing facility, called Accelerated Loading Test (ALT) ”Laboratorul de încercări rutiere accelerate” (LIRA), abbrev. ALT-LIRA, consists of a circular track (Fig. 8) having a width of 3.00 m and a diameter in the wheel set axle of 15.00 m.

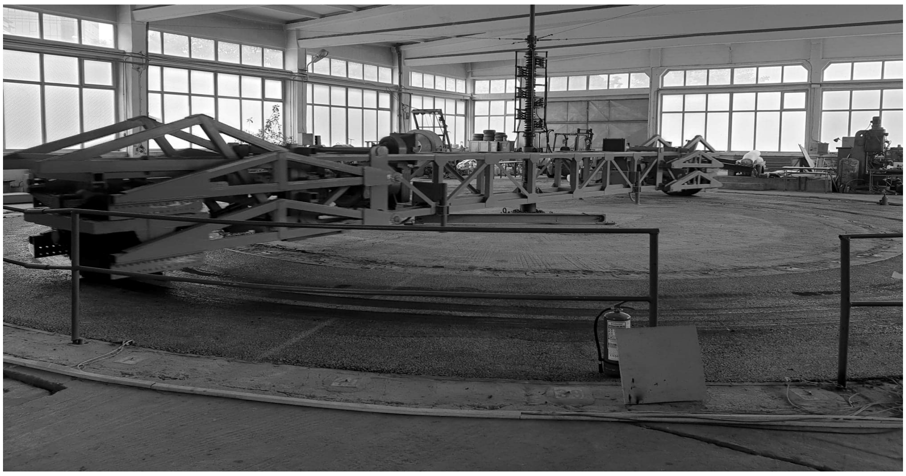

Fig. 7 – The ALT-LIRA Testing facility.

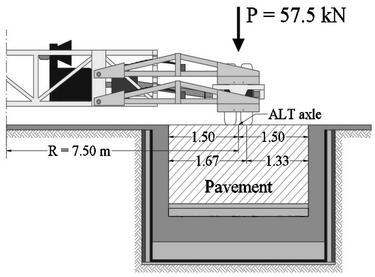

Fig. 8 – ALT-LIRA – General configuration.

The experimental tests were designed taking into account the standard axle load in Romania (115 kN). Each set of wheels of the ALT-LIRA facility was set to develop a force of 57.5 kN. The speed of the wheel load was set to approximately 20 km/h with a load frequency of 2500 passes/day.

Based on the preliminary results of this experimental study, the authors will decide whether it is feasible or not to boost the traffic load from moderate to heavy, by increasing the testing load to 150 kN.

After the experimental sectors were completed, the pavement systems have been prepared for the loading stage. Strain and pressure gauges were installed at various levels, aiming to measure the strain and load variations. The application of the gauges was performed in laboratory conditions, respecting the specifications provided by the norms and producing company. The locations of the gauges corresponding to each experimental sector are presented in Figs. 9,...,10.

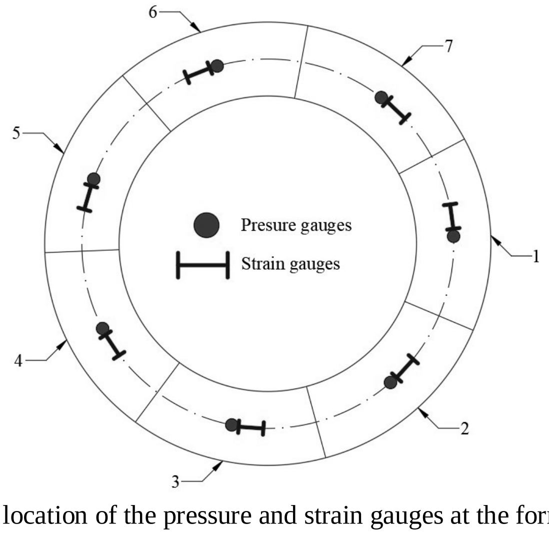

Fig. 9 – The location of the pressure and strain gauges at the formation level.

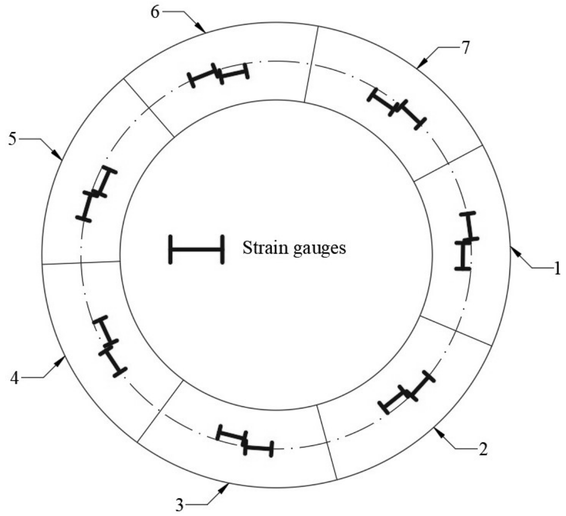

Fig. 10 – The location of the strain gauges at the level of the base and the bituminous courses.

7. Conclusions

For road engineering, the CE model and the sustainability concept are associated with the idea of developing new recycling materials that can be used to construct an efficient, safe and cost-effective pavement system.

The structural behaviour of a prototype pavement system can be characterized by performing an Accelerated Pavement Test. The European and National Norms defined APT as a controlled application that can simulate the traffic conditions by imposing a specific wheel loading. Thus, it can be concluded that the APT constitutes a link between the laboratory evaluation techniques of pavement materials and the full-scale field behaviour of these materials within a pavement structure.

This paper presents the experimental set-up of a study aiming to describe the behaviour of various classical and modern pavement systems. The preparation and instrumentation of the experimental sectors were extensively detailed. The experimental program focuses on the main parameters that describe the behaviour of a road structure subjected to moderate and heavy traffic conditions, such as the normal strain variation at the formation level, the stress distributions at the level of the stabilized based courses, the shear strain distributions at the level of the bituminous courses and the total displacements of the pavements.

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ÎNCERCAREA ACCELERATĂ A STRUCTURILOR RUTIERE REALIZATE DIN MATERIALE TRADIȚIONALE ŞI RECICLABILE
Organizarea programului experimental

(Rezumat)

Se prezintă modul de organizare a programului experimental realizat în scopul studierii structurilor de drumuri clasice, a sistemelor rutiere realizate cu agregate naturale stabilizate cu lianți hidraulici rutieri şi a structurilor de drumuri realizate prin reciclarea la rece a mixturilor asfaltice. În acest sens, au fost proiectate şi construite şapte sectoare experimentale, în cadrul Stației de Cercetări Rutiere a Facultății de Construcții şi Instalații din Iaşi. Sectoarele experimentale au fost instrumentate cu traductori rezistivi de monitorizare a deformațiilor specifice şi a presiunilor pentru captarea şi prelucrarea datelor referitoare la stările de tensiuni-deformații specifice din straturile principale. Fiecare sector va fi testat prin aplicarea unei încărcări prin intermediul unui sistem de rulare, în condiții de laborator. Prin efectuarea acestui program experimental se pot analiza diferite aspecte referitoare la comportamentul structurilor rutiere, cum ar fi: variația deformațiilor specifice normale la nivelul patului drumului, variația tensiunilor la nivelul straturilor din agregate stabilizate, variația deformațiilor specifice tangențiale la nivelul straturilor bituminoase şi deformația remanentă la nivelul îmbrăcăminții rutiere.