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SRM - AXISYMMETRIC BIDIMENSIONAL DISCRETE MODEL FOR ANALYSIS OF ROAD STRUCTURES

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Abstract: In this paper is shown an axisymmetric discrete model for the analysis of pavements developed by the Faculty of Civil Engineering from Transilvania University of Braşov. The model was validated by comparing its results with those provided by other similar programs. The model is very useful for verification, analysis and design of new or existing layers of pavements.

Key words: finite element method, pavement, axisymmetric problem

1. INTRODUCTION

The optimization of pavements to ensure a sustainable development of this transport system is required due to the accelerated development of the road transport system, characterized by explosive growth in traffic, but also by a trend to increase the axle loads of vehicles, as well as new challenges resulting from increased pollution and global resource depletion.

Because the classical methods for optimization of pavements are involving a large number of in situ and laboratory tests, with significant cost and time-consuming, an increasing alternative used to eliminate these disadvantages is the modeling and simulation of pavements behavior using specialized computer programs, which results are verified experimentally for the calibration of models and for their validation.

The impediments due to numerical methods which are requiring large computational resources to ensure a satisfactory accuracy of results are removal in present days due to the rapid growth of computer speed and memory.

Because finite element method (FEM) is allowing the modeling of physical phenomena by meshing of complex structures in simple (finite) elements and using algorithms for rebuilding of the entire assembly so that the model behavior approximates well the real behavior of the structure [4], it is one of the most productive methods of numerical computation nowdays.

Worldwide efforts are significant for the development of numerical models to simulate the behavior of pavements; models based mainly either on analytical solution of layered structures or on the finite element modeling of these structures.

In this context, at the Civil Engineering Faculty from the Transilvania University of Braşov, Romania, was developed a software for pavements computation using six node axisymmetric triangle finite elements. The computer program was developed in Matlab and it was called **SRM** (**S**isteme **R**utiere **M**ultistrat = Multilayer Pavements) [8].

In the following there are presented the main features of the SRM model and the conclusions of a comparative analysis of the results provided by this program, the Romanian program CALDEROM 2000 [1], French Alizé program [5] and other programs [6, 7]. The comparisons have been made in order to validate the SRM model.

2. GENERAL ASPECTS ON AXISYMMETRIC PROBLEMS

An axisymmetric body generally results from rotating a planar figure around an axis of the plane figure. In the following it is assumed that the loads and the boundary conditions have the same symmetry axis and that the material is isotropic. On adopt a system of reference with three directions: r (radial direction), θ (circumferential direction) and z (axial direction) as in figure 1.

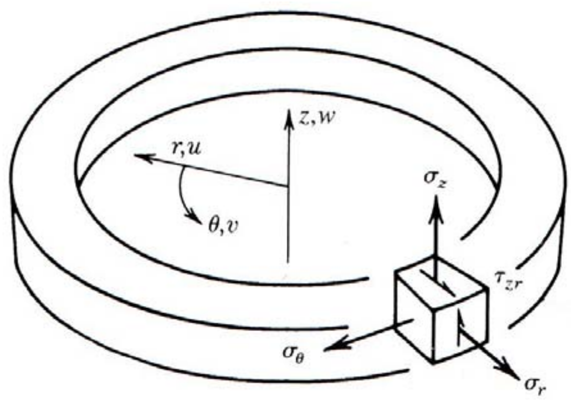

Fig. 1 Axisymmetric stresses

If the geometry, the elastic properties, the loads and the boundary conditions are all axisymmetric, nothing varies in the circumferential direction θ and the points have only the displacements components u and w in radial direction and axial direction, respectively. Thus, from mathematical point of view, the problem becomes two dimensional. Finite element formulations and program modules for plane elasticity problems can be adapted with minor changes to the axisymmetric issues. Because of this close relationship with the plane elasticity problems in formulating of elements and in software it is used a reference plane x and y corresponding to the r and z directions of the three dimensional theory.

The geometric shape of an axisymmetric finite element is a torus with nodal hoops, instead of nodes. The computing resource requirements (memory and time) are significantly reduced by avoiding division into elements in the circumferential direction, i.e. by using a plane mesh instead of a three-dimensional one.

3. ON SRM MODEL

Because in the Romanian regulations for the layers size calculus of pavements [1] the two real areas of contact between tire and pavement of the standard half axle with twin wheel are replaced by a circular equivalent area of the tire- pavement surface contact, with uniformly distributed loads, the problem of the stress and strain distribution state in pavement is axisymmetric one. Because of this, SRM is an axisymmetric finite element model. The 3D analysis can be reduced to 2D, also due to the symmetry.

Axisymmetric solid modeling in SRM is achieved by means of axisymmetric triangular finite elements with six nodes (figure 2).

The model computing assumptions in SRM model are similar to the Burmister model. Therefore, just as in the CALDEROM 2000 program [1], the interfaces between layers are considered fully adherent.

The characteristics of the pavement required by the SRM model are similar to programs CALDEROM 2000 [1] and Alize [5], i.e. the thickness of pavement layers, dynamic modulus and Poisson's ratio of the material that makes up each layer. It is considered that the materials of the pavement have a perfectly linear elastic behavior under the action of the standard half axle load.

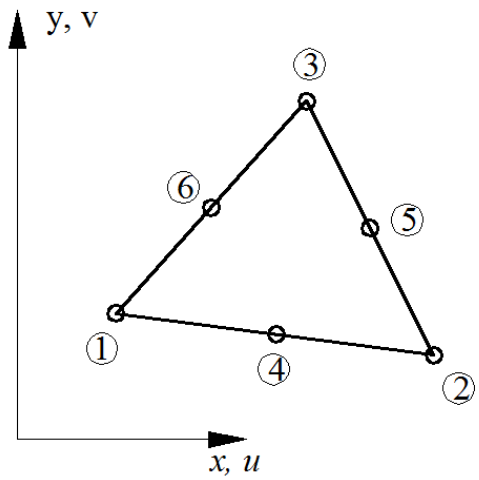

Fig. 2 Six nodes triangular axial finite element

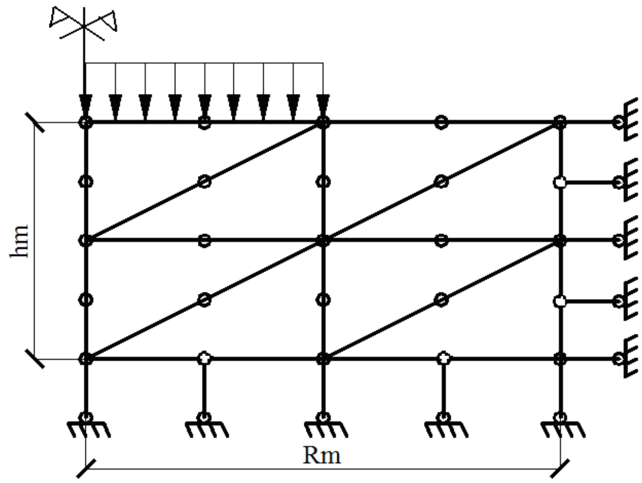

Fig. 3 Meshing of structure and bearing conditions on boundary

The mesh network uses a rectangular mesh obtained by dividing the area studied in n_x vertical lines and n_y horizontal lines, as in figure 3.

To ensure an acceptable accuracy of the results it is recommended to use a finer mesh in the areas near the axis of symmetry, near the contour of the load and in the areas of interfaces between the layers of pavement, where high stress and strain gradients are expected.

The dimensions of the model should be determined by the user of the SRM program in such manner that the stresses and strains near the boundaries of the model become small enough and their influence on the overall solution can be neglected.

The SRM model allows the consideration of any combination of the radius of the contact surface and the load on the twin wheels half axle.

The results provided by the program are strains and stresses.

The program provides both numeric results and graphical representations of stresses and strains.

4. A COMPARISON OF SRM MODEL RESULTS WITH THOSE PROVIDED BY CALDEROM 2000 AND ALIZÉ PROGRAMS

CALDEROM 2000 program is part of "Normative for flexible and semi-rigid pavement dimensioning" [1] and it is currently used in the design and verification of semi-rigid and flexible pavements.

The ALIZÉ program is the reference program used in the "French method for dimensioning of pavements" (LCPC, 1994) [2].

Both programs are based on the analytical solution of stresses and strains under loading of pavement layers, with the Burmister elastic multilayer model [3].

Unlike CALDEROM 2000 program, the program ALIZÉ allows the user to choose whether interfaces between layers are considered perfectly bonded or unbonded and loading of pavement can be achieved both with the single axle load and with loads of multiple axles [4].

For a comparative analysis of SRM model results with those of the Romanian program CALDEROM 2000 and the French program ALIZÉ, it was considered the pavement by [3] (presented in table 1).

The characteristics of standard axle load of 115 kN are as follows [6, 7]:

- twin wheel load: 57.5 kN;
- contact pressure: 0,625 MPa;
- radius of contact area: 17,1 cm.

Tab. 1 Characteristics of pavement [3]

Material in layer of pavement	h [cm]	Dynamic modulus E [MPa]	Poisson's ratio ν
Asphalt BAR 16	4	3600	0,35
Binder BAD 25	5	3000	0,35
Bituminous layer AB 2	8	5000	0,35
Ballast	15	300	0,27
Foundation soil type P5	∞	70	0,42

According to the regulations in force [1], it was followed to estimate the structural response of pavement in his critical points:

ε_r = horizontal strain at the bottom of the asphalt layer;

ε_z = vertical strain at the surface of the foundation soil.

The results of the pavement analysis in linear elastic behavior stage with the under mentioned three computer programs are presented in table 2.

Tab. 2 The results comparison of the SRM, ALIZÉ and CALDEROM 2000 programs [8]

Name of program	The method used in the model	Horizontal tensile strain at the bottom of the asphalt layer, ε_r, μS	Vertical compression strain at the surface of the foundation soil, ε_z, μS
SRM	Axisymmetric Finite Element	193,867	684,737
CALDEROM 2000	Multilayer	194,00	687,00
ALIZÉ	Multilayer	193,10	683,60

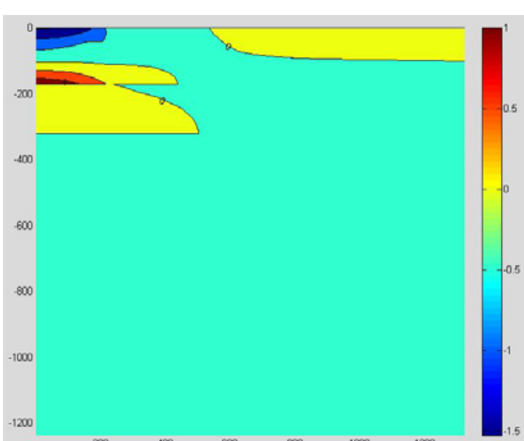

Fig. 4 The σr radial stress state

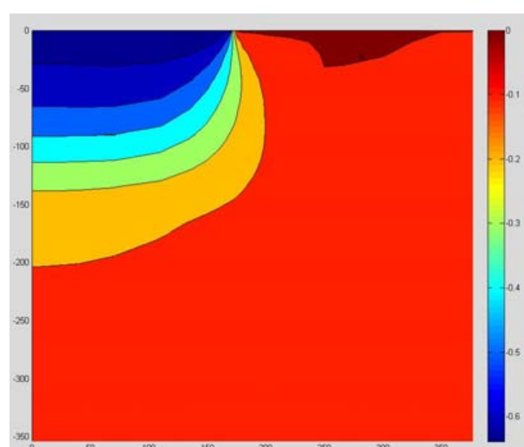

Fig. 5 The σz vertical stress state

Figures 4, 5, 6, 7, 8, 9, 10, 11 and 12 are graphical results provided by the SRM program for the analyzed case to compare the results. Except the figure 12, in all others in the abscissa is the horizontal distance from the axis of symmetric loading and ordinate is the depth from the surface of pavement.

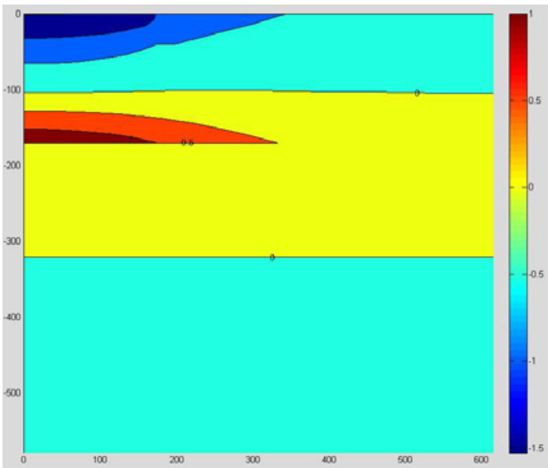

Fig. 6 The σ_θ circumferential stress state

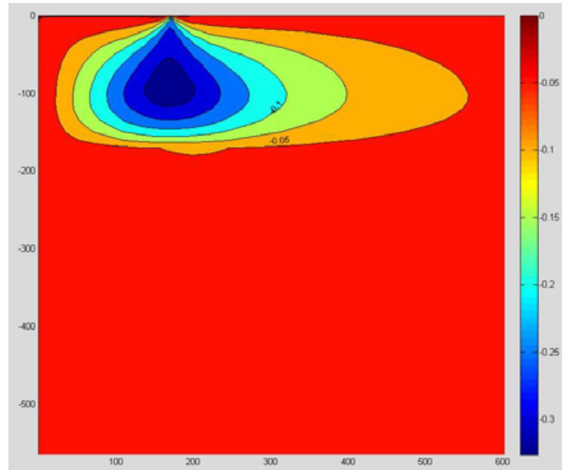

Fig. 7 The τ_{rz} shear stress state

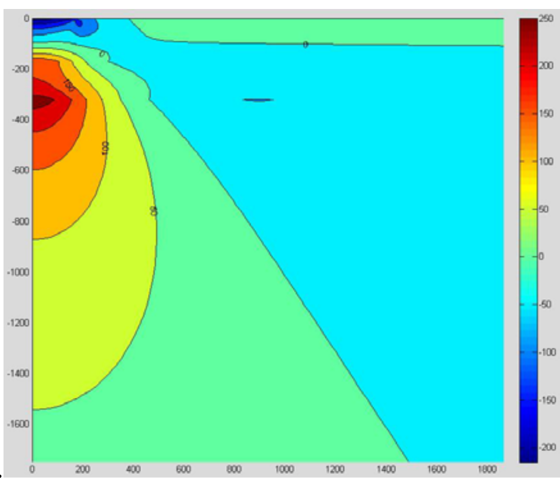

Fig. 8 The ε_r radial strain state

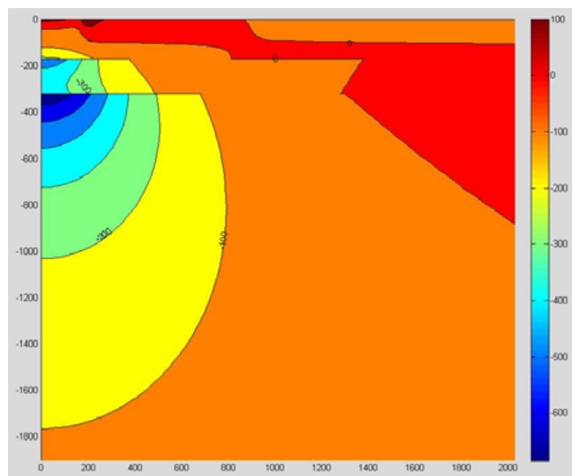

Fig. 9 The ε_v vertical strain state

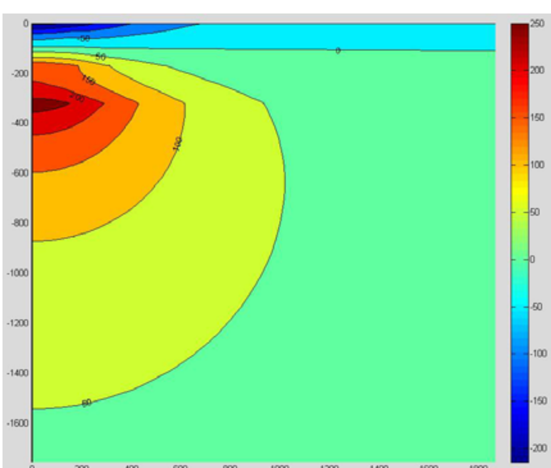

Fig. 10 The ε_θ circumferential strain state

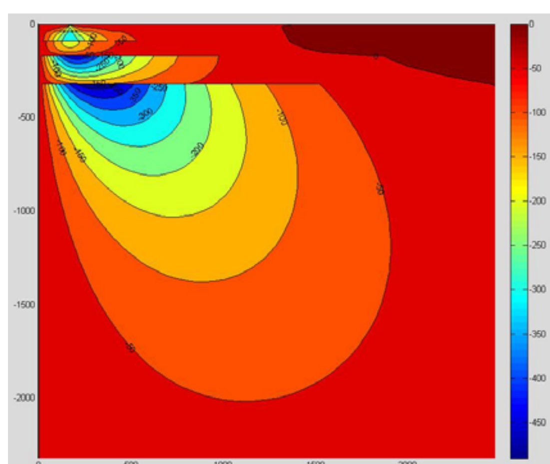

Fig. 11 The γ_{rz} shear strain state

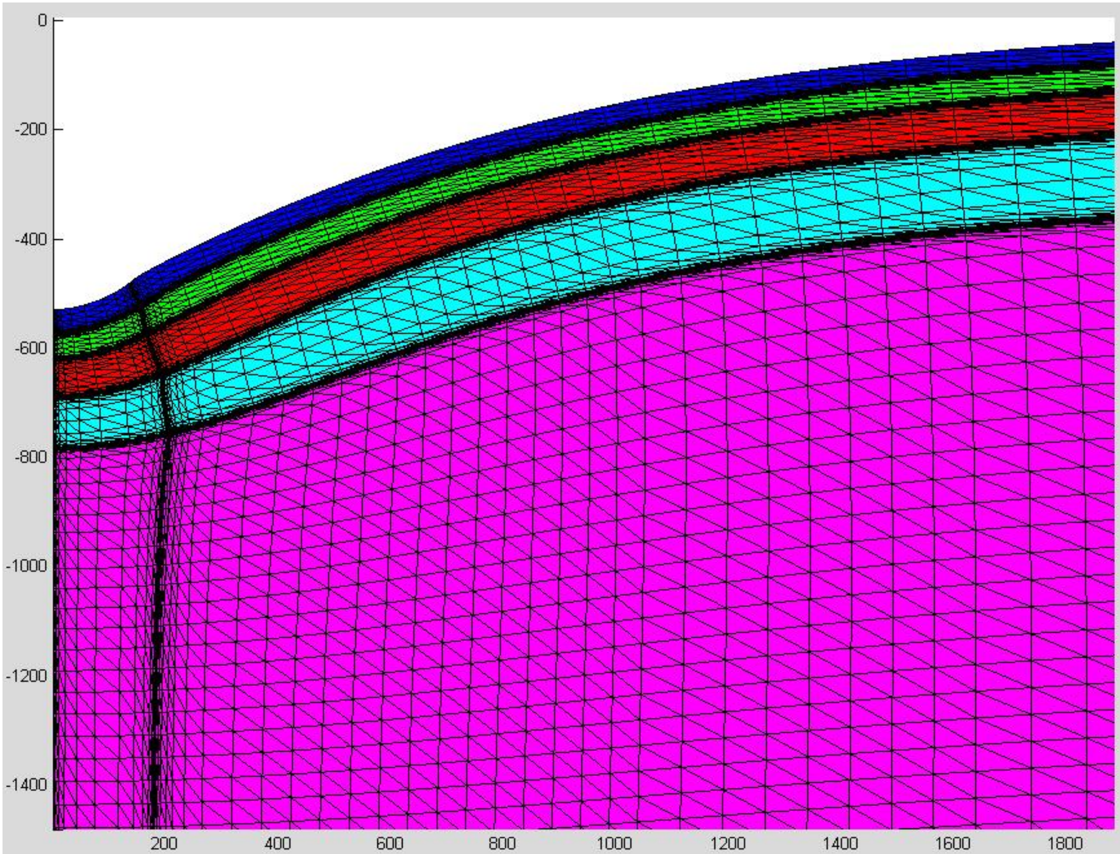

Fig. 12 Pavement and its deformed mesh (in mm sc 1:1000)

5. ANOTHER COMPARISON OF SRM MODEL RESULTS WITH THOSE PROVIDED BY OTHER PROGRAMS

The next pavement (presented in table 3) was considered for a comparative analysis of the SRM model results with those of programs presented in [6] and [7], and in addition with those of ALIZÉ program.

The characteristics of load are as follows [6, 7]:

- wheel load: 50.0 kN;
- contact pressure: 0.7 MPa;
- radius of contact area: 15.08 cm.

It was considered a comparative analysis of the SRM model results with those of programs presented in [6] and [7], and in addition with those of ALIZÉ program, because the AMADEUS study [6] and paper [7] studies and compares a large number of response models applied worldwide. It was aimed to determine the values of the following parameters on the axis of symmetry of the uniform distributed circular loading and on its edge:

Tab. 3 Characteristics of pavement [6, 7]

Material in layer of pavement	h [cm]	Dynamic modulus E [MPa]	Poisson's ratio ν
Bituminous layers	26	5000	0.35
Ballast	50	200	0.40
Subgrade (Road bed)	∞	50	0.45

σ_{z1} = vertical stress on the surface of the pavement (the equivalent stress σ_z from SRM program)
ε_{t1} = horizontal strain at the bottom of the asphalt layer (the equivalent strain ε_r from SRM program)
ε_{z2} = vertical strain on the surface of granular material layer (equivalent strain ε_z from SRM program)
ε_{z3} = vertical strain at the surface of the soil (equivalent strain εz from SRM program) and the results are summarized in table 4.

Tab. 4 Comparison of SRM results with those of other programs

Programs	The symmetry axis of loading				At the edge of loading			
	σ_{z1}	ε_{r1}	ε_{z2}	ε_{z3}	σ_{z1}	ε_{r1}	ε_{z2}	ε_{z3}
	MPa	µS	µS	µS	MPa	µS	µS	µS
SRM	0,700	-100,5	251,7	184,7	0,349	-61,9	192,2	177,1
APAS	0,700	-100,4	251,8	185,1	0,000	-61,8	192,0	177,5
AXIDIN	0,723	-116,0	212,0	163,0	0,386	-68,1	167,0	176,0
MICHPAVE	0,700	-91,6	238,9	129,0	0,000	-38,0	177,0	119,0
BISAR	0,700	-100,5	251,7	185,0	0,350	-61,9	192,2	177,5
CIRCLY	0,700	-94,0	246,7	185,1	0,350	-62,9	193,1	177,5
ELSYM5	0,700	-99,7	250,1	176,0	0,342	-61,1	190,7	168,3
KENLAYER	0,817	-100,5	251,6	185,3	0,319	-62,0	192,2	177,0
NOAH	0,700	-100,5	251,6	185,0	0,000	-61,9	192,1	177,4
VAGDIM	0,700	-100,5	251,6	185,1	0,327	-61,9	192,0	177,4
VESYS	0,700	-99,4			0,372	-61,5		
WESLEA	0,700	-100,4	251,5	185,0	0,000	-61,9	192,0	177,4
CHEVRON 15	0,700	-99,7	250,2	176,0	0,000	-63,1	194,0	169,0
Rubicon Toolbox	0,700	-100,0	252,0	176,0	0,000	-61,8	192,0	177,0
me-PADS (GAMES)	0,700	-100,5	251,6	185,1	0,345	-61,9	192,2	177,5
me-PADS (ELSYM5M)	0,700	-97,9	249,2	169,2	0,327	-59,4	189,6	161,4
FEMPA 2D	0,700	-99,1	250,4	181,6	0,000	-60,8	190,8	173,9
FEMPA 3D	0,701	-100,9	247,4	181,4	0,179	-59,9	190,3	173,4
ALIZÉ	0,700	-100,5	251,7	185,1	0,350	-56,4	192,2	177,5

Comparative analysis of the results shows a good correlation between them. Differences that arise are, in general, due to different calculation assumptions. It is noted, however, that the SRM results are close to the average of the results of the other programs considered in the analysis.

6. CONCLUSIONS

The analysis of above comparisons shows that the SRM model provides results very close to those obtained by programs CALDEROM 2000 and ALIZÉ, these results ranging between results from the two programs above mentioned.

More extensive parametric studies, which are not presented in this paper, have shown that for pavements the SRM program provides results that are very close to those obtained with the above-mentioned programs. Given this, it follows that 2D axisymmetric finite element model called SRM is a useful tool of analysis flexible and semi flexible pavements.

It should be noted that, unlike CALDEROM 2000 program, the SRM program allows the analysis of multilayer pavements for other values of axle loads and dimensions of the contact circle than the typical equivalent standard axle. In addition, it allows the estimation of stresses and strains on any point of pavements, a fact which makes it particularly useful in carrying out numerical experiments to verify and to design the layers of pavements.

The development of SRM program should allow consideration of unbonded contact between the various layers of pavement, the nonlinear behavior of materials in the composition of pavement and the possibility of analyzing stress and strain state in the pavement under multiple loads, these new facilities allowing a better approximation of the reality, like ALIZÉ program and other programs that have these computing facilities.

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