EVALUATION OF SOME FACTORS INFLUENCE ON THE INTERLOCKING PAVING SYSTEM PERFORMANCE

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Summary

The stress field in the block paving systems depends on many factor. Among these there are: the block thickness, the stiffness of the sand joint connecting the blocks, the sand bed stiffness, the type of base used (bonded or not) and the interface conditions between adjacent layers. In this paper we report a study aimed to examine the influence of these factors. It has been carried out using a structural model very close to reality. In order to evaluate the sand joint stiffness required in the model we used an adequate experimental procedure.
The results obtained show that the most important factor is the type of base, then the blocks thickness. The other factors have a lower influence.

1 - Introduction

The block paving systems reach the end of life usually when the road surface shows excessive permanent deflections in the wheel path. The cause of this distress is the accumulation of permanent strains in the pavement layers and in the subgrade, produced by the repetition of the stresses induced by the vehicle load. Naturally the life decreases when the stresses magnitude and their repetition due to the traffic increase.
Inside the block paving system the stress field depends on many factors. Among these there are: the block thickness, the stiffness of the sand joint connecting the blocks, the sand bed stiffness, the type of base layer used (bonded or not) and the interface condition between adjacent layers.
In this paper we report a study aimed to examine the influence of the factors above said . To do this we used a structural model [1] of the block paving system that reproduces quite faithfully the real configuration. Particularly the model represents the surface layer as it is in the reality, a lot of blocks connected by the sand joints We did not represent this layer like an homogeneous and isotropic layer because we were interested to examine the influence of the blocks thickness and of the sand joints stiffness.

Besides this theoretical study we made an experimentation to evaluate, with an adequate test [1], the mechanical characteristics of the sand joint at different stress values.

2 - Pavements tested

The interlocking block system that we considered in our study is set up by 4 layers with the blocks in herringbone bond. It is like the pavement described by Houben e Jacobs [2], The mechanical characteristic and the thickness of each layer are reported in table 1.
In order to evaluate the different behaviour between the pavements with bonded base layer and those in which this layer is of u materials, we considered also the pavement reported in tab. 2, where the base course is in hot asphalt mix. (fig. 1)

Table 1 - Characteristics of the pavement with crushed concrete base layer

layer	element	dimension [m]	modulus E [MPa]	modulus G [MPa]	Poisson ratio
surface course	blocks	0.21x0.104x0.08	35000	15217	0.15
	sand joints	thickness 0.002	11 [1]	5 [1]	.35
sand bed		h = 0.05	130	48	.35
crushed concrete base		h = 0.20	110 [2]	41	.33
sand sub base		h = 0.9	66 [2]	25	.34
subgrade			120	45	.33

Table 2 - Characteristics of the pavement with bituminous concrete base layer

layer	element	dimensions [m]	module E [MPa]	module G [MPa]	Poisson ratio
Surface course	blocks	0.21x0.104x0.08	35000	15217	0.15
	sand joints	thickness 0.002	11 [1]	5 [1]	.35
sand layer		h =0.05	130	48	.35
bituminous concrete		h= 0.25	3000*	1154	.3
sand sub base		h=0.4	66 [2]	25	.34
subgrade			120	45	.33

* evaluated for t≈20°C and f≈5 Hz

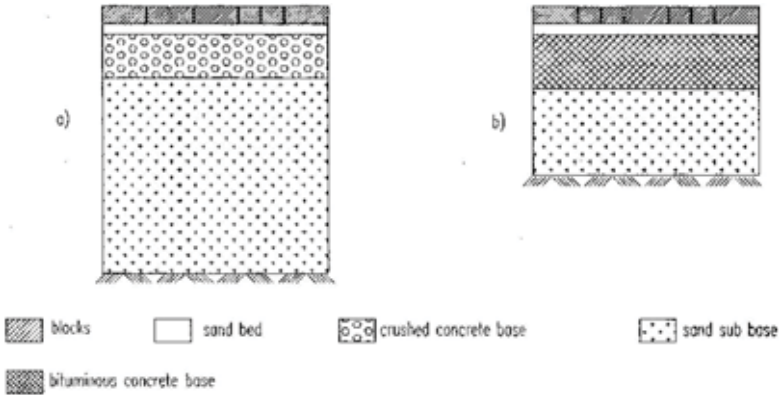


Fig. 1 - Pavements tested: a) with crushed concrete base, b) with bituminous concrete base.

The two reported pavements are equivalent for the flexural stiffness and therefore for load spreading capacity on the subgrade.

The structural model that we used for the pavements is like the one we presented at the Fourth International conference on Concrete Block Paving [1], It represents the surface course in a very close way respect to reality and take account of the interface condition between adjacent layers using some fictitious layers 0.01 m thick. The first characteristic allows to evaluate the tensile stresses in the sand joints and thus to understand if the surface course, due to the interlocking compressive stresses, works like a layer with tensile strength. Moreover it permits the evaluation of the stress-strain field inside the pavements using parameters set up only with laboratory tests.

The model that we consider is 2.5x2.5 m^2 wide in plant and has the section reported in figure 2. In this figure we can see three fictitious layers: the first one is between the surface course and the sand layer, the second one is between the sand layer and the base and the third one is between the base and the foundation.

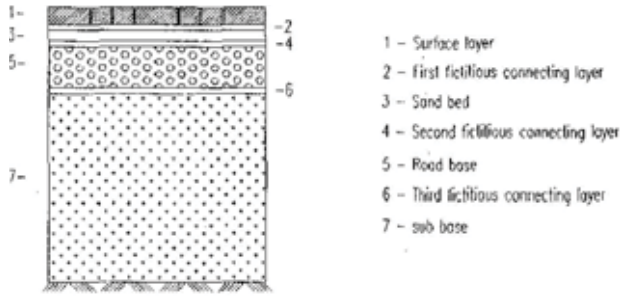


Fig. 2 - Section of the pavement with the fictitious layers

The mechanical characteristics of these layers are in table 3. They have been chosen so that they cannot give any inaccurate structural contribute [1]. The relationship between the spring stiffness representing the interface conditions and the Gxz-Gyz values is:

$$G = K * s$$

where K [MPa/m] is the stiffness, for unit area, of the springs connecting the adjacent layers and "s" is the thickness of the fictitious layers.

Table 3 - Mechanics characteristics of the fictitious connecting layer

fictitious layer	bond layer	[MPa]	[MPa]	[MPa]
1	surface coarse	Ex = 10	Ey = 10	Ez = 100000
	sand layer	Gxy = 0.1	Gxz = 100	Gyz = 100
2	sand layer	Ex = 10	Ey = 10	Ez = 100000
	road base	Gxy = 0.1	Gxz = 150	Gyz = 150
3	road base	Ex = 10	Ey = 10	Ez = 100000
	foundation	Gxy = 0.1	Gxz = 150	Gyz = 150

The load applied on the pavement is a wheel of 60 KN having a circular contact area with a radius of 0.165 m.

3 - Mechanical characteristics of the sand joint

The E and G moduli that characterise the mechanical behaviour of the sand joint are evaluated by the laboratory tests that reproduce the scheme described in figure. 3
The procedure was set up in a previous work [1], It take into account the block shape and let us represent the blocks and the sand joints in the structural model before described as bricks. This fact makes the results dependent on the block shape. The sand grading is reported in figure 4, while the tested blocks are in figure 5.

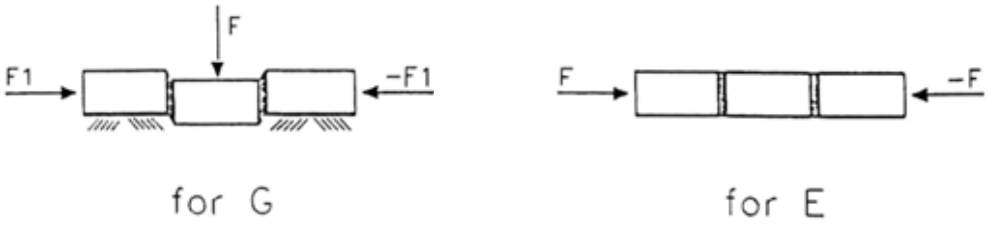


Fig. 3 - Schemes to evaluate E and G modulus

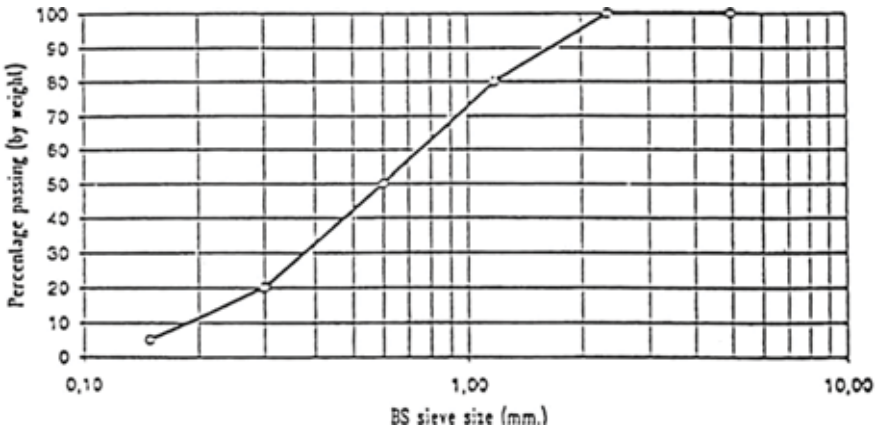


Fig. 4 - Grading curve of the sand joints

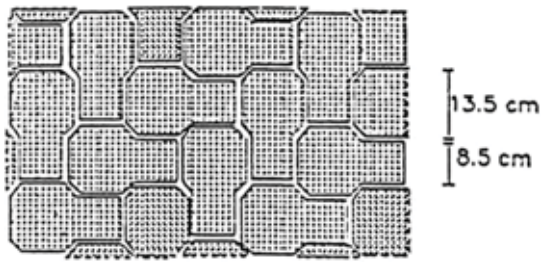


Fig. 5 - Type of block used in the test

The moduli G and E obtained with the test on the sand joints between the blocks showed in figure 5 are influenced by the confining stress and are showed in figure 6. We can see in the diagram of modulus G that it increases its value until the confining stress reaches a value of 28 Mpa and after it becomes constant. The modulus E has the same behaviour and becomes constant for an higher value of confining stress.
The breakdown test reproducing the scheme in figure 5 pointed out that with the kind of sand used the angle of the friction in the joints moved from 38° to 42°.

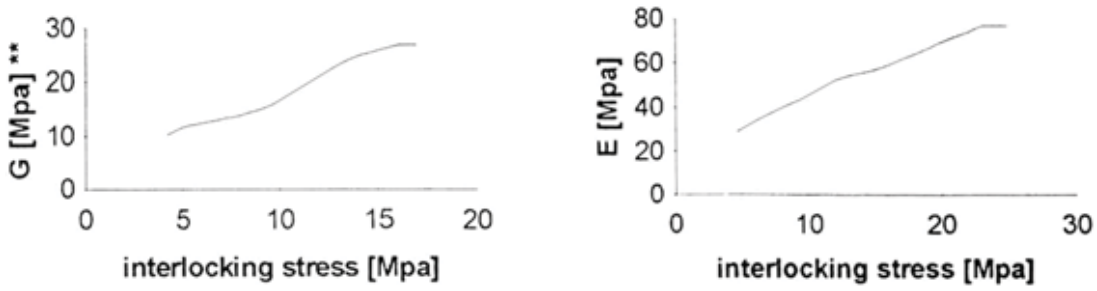


Fig. 6 - Relationship between the interlocking stress and G and E modulus

**The test was carried out for shear stresses ranging from 0.175 to 0.35 Mpa

4 - General behaviour of the loaded pavements

The load applied on the our structural model causes a superficial deflection reported in figure 7. It concerns the blocks on the ine a-a of figure 8.

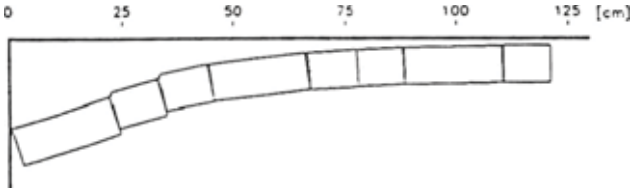


Fig. 7 - Superficial deflection



Fig. 8 - Surface course of the model

The figure 7 shows that the deflection is characterised by the rigid displacements of the blocks and by the deformation of the sand joint The same figure shows that the deflection is due mainly to the relative rotation of the blocks rather than their relative sliding.
The deformed shape shows also that the bending moment changes its sign from the first to the second block We have the same effect in the shape of horizontal stress in the surface layer.

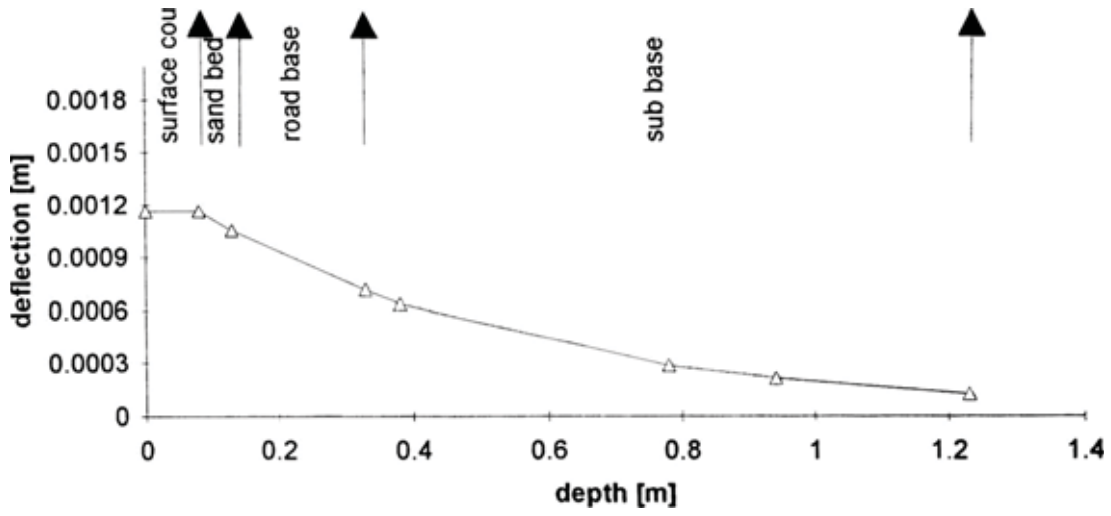


Fig. 9 - Vertical displacements under the load

The vertical displacements of the points under the load, described in figure 9, shows that the deflection is due mainly to the vertical deformation of base and foundation layers. The displacement on the subgrade layer is about 10 % of the total. This last data shows the good load spreading capacity of the pavement and that the whole deflection can be reduced in a significant way only increasing the layers moduli, so that they reduce their vertical strain.
The slope of the different segments of the diagram shows, as expected, that the strain decreases moving from the sand to the foundation layer

In figure 10 we report the horizontal stress at the lower edge of the blocks on to the section line described in figure 8 In it we can see how we previously observed, the change of the sign of the stress and therefore of the bending moment in this layer This shows that the spreading load capacity of the surface layer do not go beyond the block directly loaded.
The knowledge of the magnitude of the tensile stress in the sand joints is very useful because it makes us able to know if the surface course will be or not completely reacting. If the absolute value of this stress is less or equal to the interlocking compression stress the layer will be completely reacting
By the pull-out tests results reported by K. C Malvin [3] and by Ir. Molenaar and others [4] we can deduce that the angle of the friction in the joints between the blocks is about 36° and that we need a load of about 18 KN to pull out a block with the dimension of 0,215x0.105x0 09 m from a pavement that had been opened to the traffic for 6 month Using these values we can understand that the interlocking stress is about 0.44 MPa

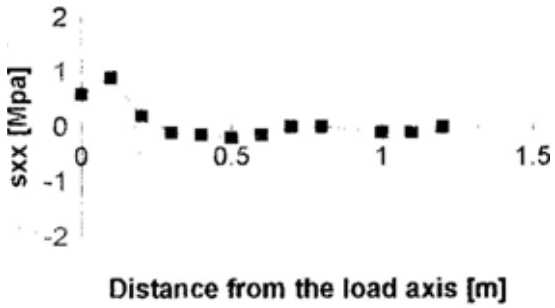


Fig. 10 - Horizontal stress at lower edge of surface layer

5 - Comparison between the two pavements.

The two type of pavements described in the paragraph 2 show the vertical displacements reported in figure 11 They were evaluated in many points under the load. In the figure we can observe that the two pavements are practically equivalent as far as the deflection of subgrade, represented by point A for the first pavement and by point B for the second pavement. This fact was expected because the two pavements are equivalent as far as bending stiffness. We observe the differences taking in account the surface deflection: the deflection of the second pavement is about 1/3 compared to the first one. This fact happen because the bonded base course suffers only a small vertical strain and because this course spreads very well the load coming from the upper layer. In the second pavement furthermore the vertical deformation of the sand bed i.s. a little larger than the first one and it is about an

half of whole strain of pavements. This fact pointed out that the surface course, in the second type of pavement, spreads less the loads, even though slightly.

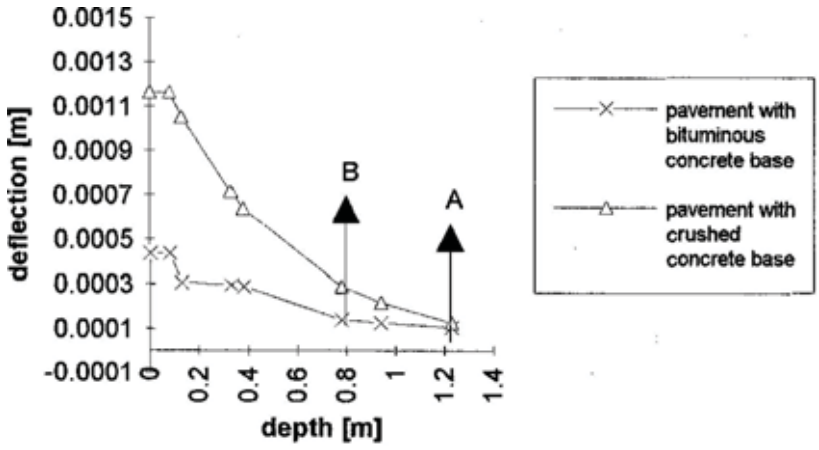


Fig. 11 - Comparison of the vertical displacements of the two pavements

6 - Evaluation of the influence of some factors

The influence is evaluated for the pavement with the crushed concrete base. The factors that we take into account in the study are: the block thickness, the stiffness of the sand joints, the thickness and the modulus of the sand bed and the friction between the layers. The comparison of the behaviour was carried out changing one by one the listed factors and evaluating for each one of them the deflection under the load and the deviatoric stress (s11-s33) in the middle of the base layer. This last one is very useful to evaluate the magnitude of the permanent deflection. Beside those two parameters we used some others when was useful.

6.1 - *Blocks thickness and sand joint stiffness*

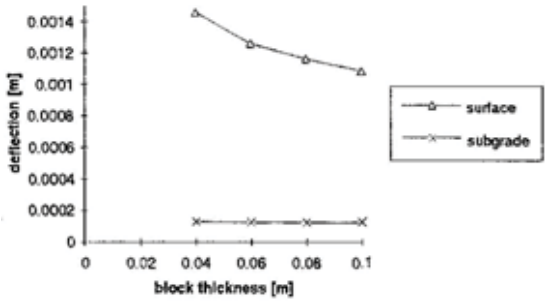


Fig. 12 - relationship deflection - block thickness.

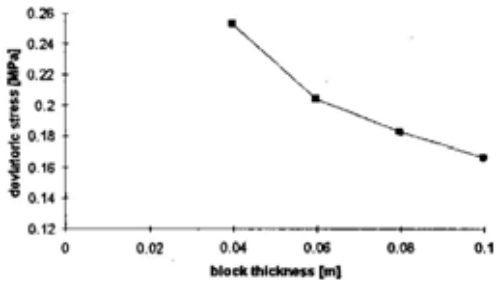


Fig. 13 - relationship deviat stress - block thickness.

In the comparison we used four block thicknesses: 0.04, 0.06, 0.08 and 0.1 m. The others characteristic are those listed in table 1 e table 3. In figure 12 we reported the superficial and the subgrade deflection. In this figure we can see that the superficial deflection, like expected, decreases with the increment of blocks thickness. However the reduction is not linear.

Furthermore the same figure shows that the thickness of surface course has only a very little influence on the deflection of the subgrade and therefore on the spread on th subgrade of the load applied on the surface. The reduction of the surface deflection is due to the lower stress field in the layers, in particular in the sand bed and in the base layer (see fig 13).
The figure 14 shows the horizontal stress at the bottom of the blocks on the line section in figure 8 In this figure we can see that the maximum tensile stress in the sand joint decrease sensibly passing from 0.04 m to 0.08 m up to reach values comparable with those of compression due to the interlocking.

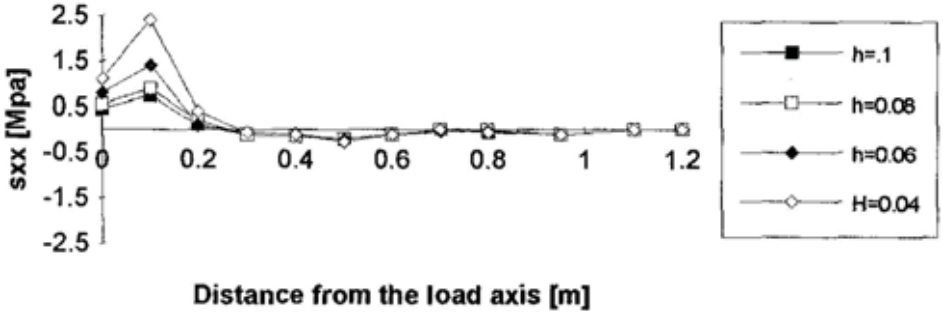


Fig. 14 - Horizontal stress at lower edge of surface layer for different block thickness

The values E and G used to evaluate the stiffness influence of the sand joint were respectively: 11 and 5, 22 and 10, 33 and 15, 75 and 30 Mpa. The last couple of values represent a borderline case impossible to obtain with the used sand and blocks. As far as what we need it would be an interlocking stress higher of 2 Mpa corresponding to a pull out load of 83.7 KN. This last one is higher than the maximum value given by Molenaar and others [4]. The figures 15 and 16 show that the pavement deflection and the deviatoric stress evaluated in the middle of base course decrease with the increase of joint stiffness. This reduction caused by block thickness is not linear.

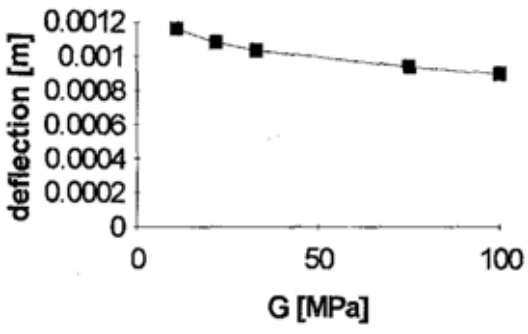


Fig. 15 - Relationship deflection - joint stiffness

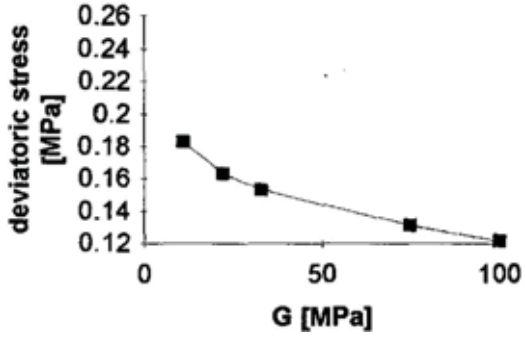


Fig. 16 - Relationship deviat. stress - joint stiffness

Between the two factors studied, block thickness and sand joint stiffness, the first one is more useful to improve the behaviour of these pavements. To validate this assertion it is sufficient to consider that to obtain a deflection reduction like the one we would have changing the thickness from 0.06 to 0.08 m we need to change G from 10 to 20 Mpa. This last value

correspond to an interlocking stress of about 1 MPa and it is more than double what was found by Molenaar and others in an interlocking pavements six month after its construction.

6.2 - *Thickness and modulus E of the sand bed*

In order to evaluate the influence of the sand bed thickness we considered 3 cases: 0.03, 0.05, and 0 07 m. In figure 17 we reported the variation of the superficial and base deflection In this figure we can note that the behaviour improves and that the curves of the two deflections are not parallel. This happens because the increment of the layer thickness increase the vertical deformation of the same layer. The better behaviour related to the spread of the vehicle load on the bottom layers is evident in the diagram plotted in figure 18 were is reported the deviatoric stress in the middle of the base course.

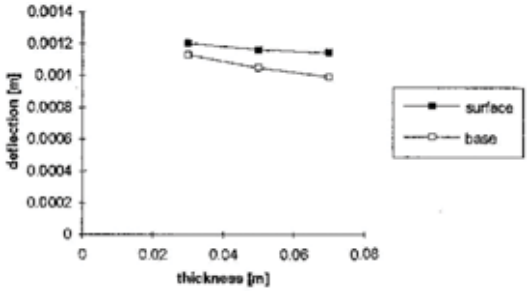


Fig. 17 - Relationship deflection - sand bed thick.

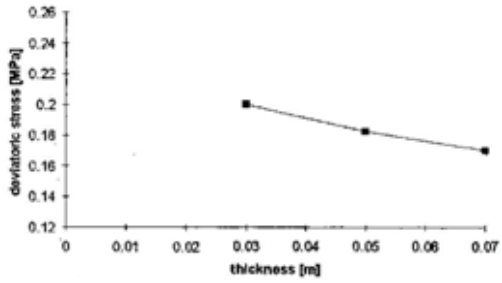


Fig. 18 - Relationship deviat stress-sand bed thick.

The moduli E that we considered to evaluate the influence of the sand layer material are 50, 110, 130 and 150 Mpa. In figure 19, where we reported the deflections of the sand layer at top and bottom, we see clearly that nothing change under this layer and that the decrease of the whole deflection comes only from its higher stiffness. The results in figure 20 confirm that the strain field in the bottom layer stands practically equal when the modulus E of the sand layer increases.

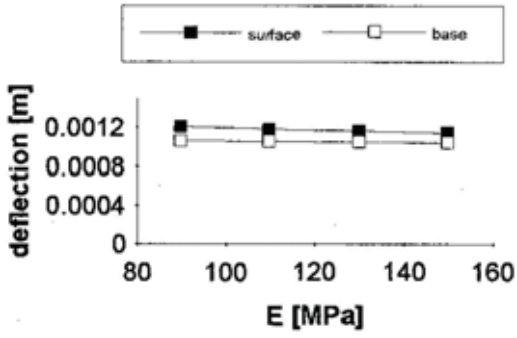


Fig. 19 - Relationship deflection - sand bed stiff.

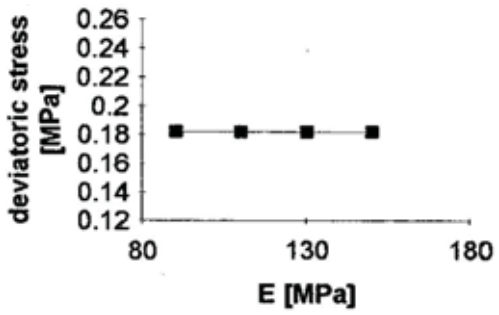


Fig.20 - Relationship deviat. stress-sand bed stiff.

The previous figures show that the thickness of the sand bed is more influent than the elastic modulus as far as the better behaviour of these pavements with crushed concrete base

6.3 - *Interface condition between the adjacent layers*

The spring stiffness values used to evaluate the influence of the interface conditions are 1000, 1500, 2000, 3000, 5000, 10000, 15000, 20000 Mpa/m. The figures 21 and 22 show that this factor has a slight effect and only as far as the spring stiffness value of 5000 MPa/m. This borderline value depends on the materials stiffness of the layers (increase with them) and besides it we can suppose that the connection between the layers is perfect.

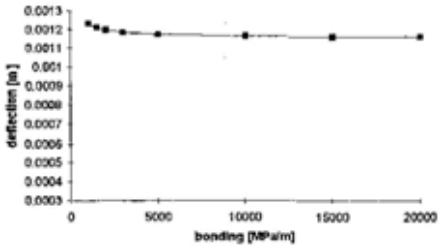


Fig.21 - Relationship deflection- interf. cond.

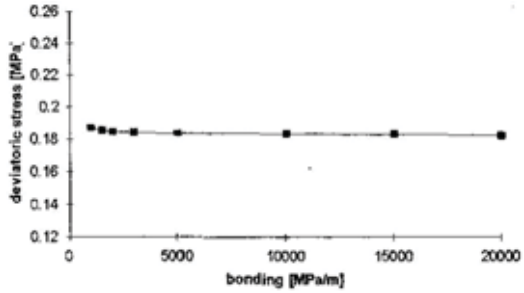


Fig.22 - Relationship deviat. stress-interf. cond.

7 - Conclusions

The study concerning the influence of the different factors on the behaviour of the block paving systems has shown that the type of base layer is the most important factor. The surface deflection of a pavement with a bituminous concrete base course is about 1/3 of the one of a pavement with a crushed concrete base course. Besides this factor the other that shows a good influence is the blocks thickness. The sand joints stiffness, the interface conditions between the layers, the thickness and E modulus of the sand bed have a little influence.

The minimal block thickness needed to have almost everywhere compressive stress in the sand joints is 0.08 m.

The experimental procedure carried out on the sand joint stiffness show that the G and E modulus are confining stress dependent. The first increase its value until the stress reaches a value of 28 Mpa and after it becomes constant. The second has the same behaviour and becomes constant for an higher value of confining stress.

The breakdown test conducted to evaluate the sand joints strength pointed out that the angle of the friction moved from 38° to 42°.

References

1. B.Festa, P.Giannattasio, M Pernetti "Contribution to the rational calculation of the block paving system" Proceedings of the Fourth International Conference, Auckland, February 1992 (Pave New Zealand, Porirua, 1992)pp 309-324
2. Houben, M.M. J Jacobs "Wheel track testing and finite element analysis of concrete block pavements"Proceedings of the Third International Conference, Rome, May 1988 (PAVITALIA, Treviso,1988) pp. 102-113
3. Malvin "Site and laboratory testing of interlocking concrete block pavements" Proceedings of the Third International Conference, Delft, April 1984. pp.55-60
4. Kellersmann, J. Klooster, G.R. Bosch, E. Beuving, A. A. A. Molenaar, H O. Moll "Design method for concrete block pavements" Proceedings of the Third International Conference, Delft, April 1984. pp. 100-114