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Design Analysis Of Rigid Pavement In The Municipality Of Arauquita, Department Of Arauca

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1. Introduction

With the structural design proposed for the implementation of the rigid pavement (Islam, M. R., & Tarefder, R. A. 2020), it is desired to improve the quality of life and access to the sector under study, which is delimited from carrera 2A between streets 9 and 11 of the Araguaney neighborhood in the urban area of the municipality of Arauquita- Department of Arauca.

On the other hand, this pavement design seeks to improve the circulation of existing vehicular and pedestrian traffic (Heinrichs, K. W., Liu, M. J., Darter, M. I., Carpenter, S. H., & Ioannides, A. M. (1989) in order to reduce travel times from one place to another and to create a reliable, comfortable and safe environment for its users.

Rigid pavement has become a durable alternative (Huang, Y. H. (2004) and with low maintenance costs, which offers the community benefits in terms of safety and good rainwater drainage; in conclusion, these advantages make it more feasible when proposing it as a solution to this problem.

Today the country is at a very important stage of development, which is why it must invest in the road infrastructure of each of the Departments that make it up, as a strategy for mobility, communication, competitiveness and development (Lane, D. S. (1998).

Keywords: desing; pavement; via; structure; rods.

2. Method

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2.1. Sample

Rigid pavement design and analysis of race 2A between streets 9 and 11 in the municipality of Arauquita.

2.2. Instrument

For this research study we used tools such as: AutoCAD civil 3d software, Microsoft Excel, soil laboratory to perform geotechnical parameters, Invias Manual.

2.3. Parameters and design variables

2.3.1. Traffic

In this case, heavy traffic is considered, for which the respective transformations are made to equivalent axles for 20 years. Due to the volume of traffic projected to be supported by the structure, a number of equivalent load repetitions per single axle has been established (Arboleda Vélez, Germán).

2.3.2. Geotechnical Parameters

For the determination of the design CBR, a value of 3.66% is taken, taking into account that the calculations will be carried out with the critical conditions presented in the foundation soil (Gutiérrez, J. A. C., Carrascal, J. L. J., & Ortega, M. V. (2021).

2.3.3. Dimensions of the structure

The design is carried out using the INVIAS method:

- Category of the road according to traffic
- Class type of road according to soil
- Transfer system
- Granular base, INVIAS type
- Flexural tensile strength values of concrete (modulus of rupture).
- The design of the pavement structure is carried out according to the INVIAS design manual.

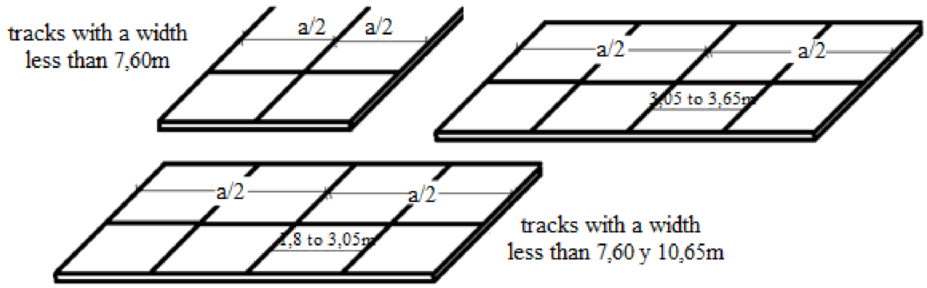
2.3.4. Slab Modulation

- Longitudinal joints

Since the roads of the present design are traveled in both directions and the pavement width is less than 7.60 m, a longitudinal joint should be built to divide the pavement into two strips or lanes of equal width (Cavero Castillo, P. G., & Estrada Durand, L. L. (2022).

However, if for any situation the roads are built with a width between 7.60 and 10.65 m, a longitudinal joint should be built in the center, and on each side of this, another one that is separated between 1.8 and 3.05 m from the central one. And for 10.65 and 14.65 m wide lanes, a joint should be made in the center and on each side of it, another one separated between 3.05 and 3.65 m from the central one. As shown in the following figure (Huang, Y. H., & Wang, S. T. (1973):

Figure 1. Location of the two-way longitudinal joints and width A



Source: Concrete pavement design manual for roads with low medium and high traffic volumes.

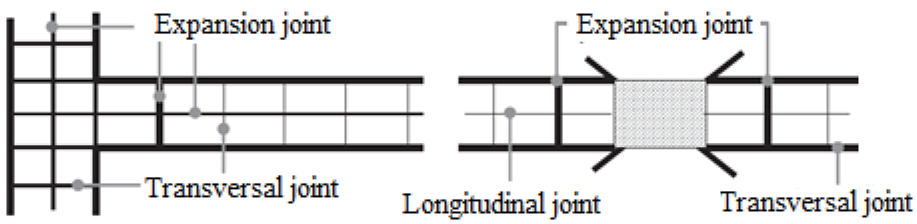
- Transverse joints

The spacing between transverse joints should be between 3.60 m and 5.0 m and the ratio between the length and width of the slabs should be between 1 and 1.3. As a general recommendation, slabs that are as square as possible will have better structural performance.

- Expansion joints

The geometric distribution of the joints begins with the definition of the places where the expansion or isolation joints are placed, which as a general rule are located in the slab before the point where the particularity occurs, as shown in the figure (Tayabji, S. D., & Colley, B. E. (1983):

Figure 2. Expansion joints at intersections and near some obstacle.



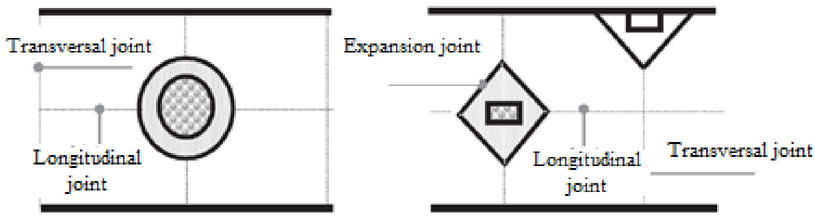
Source: Concrete pavement design manual for roads with low medium and high traffic volumes.

In the case of intersections, it is recommended that the expansion joint be built on the minor roadway (Tavara Lizama, G. A. 2022).

If other existing concrete structures such as drains, inspection chambers or boxes are present at the work sites, expansion joints should be made at least 0.30 meters from the edges of these elements and their shape should be polygonal, circular or semicircular.

The joint opening shall be at least 10 to 15 mm wide.

Figure 3. Expansion joints around elements incorporated within the pavement.



Source: Concrete pavement design manual for roads with low medium and high traffic volumes.

In the case of expansion or isolation joints with a polygonal shape, longitudinal or transverse contraction joints must be constructed at each of the vertices of the polygon (Villanueva Eduardo, S. C. (2021). If the isolation joint has a circular or semicircular shape, at least one longitudinal or transverse contraction joint must come out of it.

2.4. Data analysis

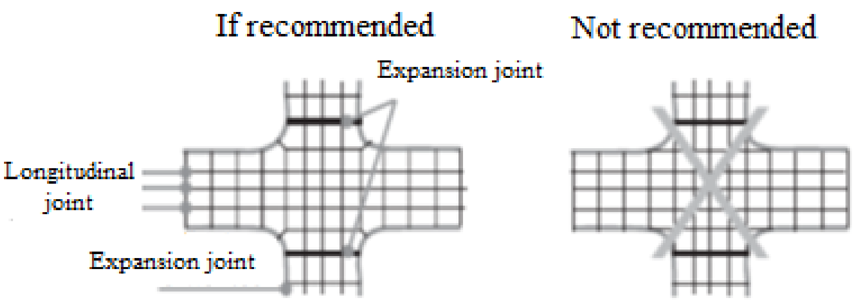
The installation of an NT-2400 woven geotextile to prevent mixing between the subgrade soils and the materials that make up the granular layers of the pavement (art. 231 of the 2012 INVIAS Road Materials Testing Standards).

It should be noted that in places where there is soil cushioning, these failures should be repaired with ball stone material or raw material with a maximum size of 4".

Special conditions

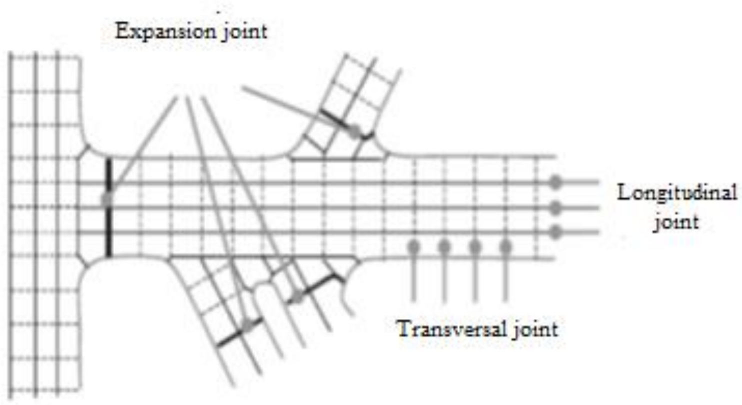
In order to avoid the formation of slabs with little area, especially in changes of direction (Davila Barbaran, W. L., & Saldaña Gomez, D. A. (2022), in intersections or in approaches to existing structures, the geometry of uncertain slabs can be modified to include in them the other slabs with little area as shown in the following figure:

Figure 4. Location of joints at a track crossing



Source: Concrete pavement design manual for roads with low, medium and high traffic volumes.

Figure 5. Example of joint design



Source: Concrete pavement design manual for roads with low, medium and high traffic volumes.

3. Results and discussion

- Total, design traffic: 603,690,563 Axles of 80 KN
- Design CBR: 3.66%.

Table 1. Traffic category for the selection of thicknesses by the Invias method

“Category	Type of road	TPDs	Cumulative axes of 8.2 t
T0	(Vt) – (E)	0 to 200	<1’000.000
T1	(Vs) – (M ó A) – (CC)	201 to 500	1’000.000 to 1’500.000
T2	(Vp) – (A) – (AP-MC-CC)	501 to 1.000	1’500.000 to 5’000.000
T3	(Vp) – (A) – (AP-MC-CC)	1.001 to 2.500	5’000.000 to 9’000.000
T4	(Vp) – (A) – (AP-MC-CC)	1.501 to 5.000	9’000.000 to 17’000.000
T5	(Vp) – (A) – (AP-MC-CC)	5.001 to 10.000	17’000.000 to 25’000.000
T6	(Vp) – (A) – (AP-MC-CC)	More than 10.001	25’000.000 to 100’000.000”

Note: The data obtained from the table were taken according to the traffic study by means of a daily vehicle count, where the total equivalent axles and TPDs are obtained.

Source: Concrete pavement design manual for roads with low, medium and high traffic volumes.

- The road type class according to the soil is: S2.
- Transfer system: segments and berms (DB).
- Granular base, type INVIAS: BG = 15cm
- Modulus of rupture: MR = 40 Mpa

Table 2. Variables used in pavement design analysis.

Soils	Transit	Transfer and containment	Support	Concrete

S1 (CBR < 2)	T0 (EALS<1E6)	D and B (Voussoirs and Berms)	SN (subgrade)	MR1=38Mpa
S2 (2 <CBR < 5)	T1 (1E6<EALS<1.5E6)	D and not B (Voussoirs and not Berms)	BG (15 cm BG)	MR2=40Mpa
S3 (5 <CBR < 10)	T2 (1.5E6<EALS<5E6)	Not D and B (No Voussoirs and Berms)	BEC (15cm BEC)	MR3=42Mpa
S4 (10 <CBR < 20)	T3 (5E6<EALS<9E6)	Not D and Not B (No Voussoirs and no Berms)		MR4=45Mpa
S5 (CBR > 20)	T4 (9<EALS<17E6)			
	T5 (17E6<EALS<25E6)			
	T6 (25E6<EALS<100E6)			

Source: Concrete pavement design manual for roads with low, medium and high traffic volumes.

According to Table 5-3 of the INVIAS rigid pavement manual, the design of the pavement structure is as follows

Table 3. Thickness of concrete slab (cm) according to the combination of variables T1

		"Transit T1																			
		S1				S2				S3				S4				S5			
		D and B	D and not B	Not D and B	Not D and not B	D and B	D and not B	Not D and B	Not D and not B	D and B	D and not B	Not D and B	Not D and not B	D and B	D and not B	Not D and B	Not D and not B	D and B	D and not B	Not D and B	Not D and not B
SN	MR 1			24	28	23	27	23	27	21	25	21	25	21	24	21	24	20	23	20	23
	MR 2			23	27	22	26	22	26	21	24	21	24	20	23	20	23	20	23	20	23
	MR 3			22	26	22	25	22	25	20	23	20	23	19	22	19	22	19	22	19	22
	MR 4			20	25	21	24	21	24	19	22	19	22	18	21	19	21	18	21	19	21
BG	MR 1			23	26	22	26	22	26	21	24	21	24	20	24	20	24	20	23	20	23

	MR 2	22	26	22	25	22	25	20	23	20	23	20	23	20	23	19	22	19	22
	MR 3	21	25	21	24	21	24	19	23	19	23	19	22	19	22	19	22	19	22
	MR 4	20	24	20	23	20	23	18	22	19	22	18	21	18	21	18	21	19	21
	MR 5	20	23	20	23	20	23	18	21	18	21	18	21	18	21	18	20	18	20
BEC	MR 6	19	22	19	22	19	22	18	20	18	20	17	20	18	20	17	20	18	19
	MR 7	19	22	18	21	19	21	17	20	18	20	17	19	18	19	16	19	18	19
	MR 8	19	21	17	20	19	20	16	19	18	19	16	18	18	19	15	18	18	18 ”

Source. Invias Manual

Note: These data are obtained according to the type of soil obtained from the soil study and the traffic study by the Invias method.

Next, once these data are available, a simulation of the layers of the rigid pavement structure is made in the following image (Paredes Bocanegra, L. J., & Ramos Bermudez, I. G. (2022).

Figure 6. Rigid pavement structure

Wearing course – Concrete MR = 40 kg/cm2	22 cm
BG-1	15 cm
Woven geotextile NT-2400	
Subgrade	

3.1. Concrete slab reinforcing steel

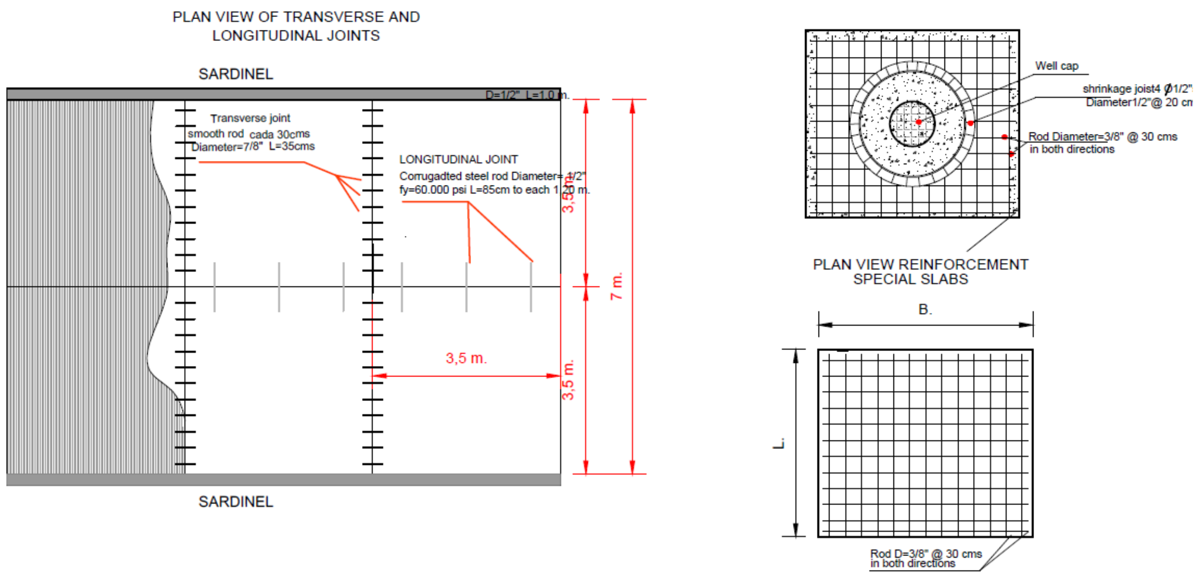
3.1.1. Anchor bars

The longitudinal construction joint will have ½" diameter corrugated anchor bars, 85 cm long and spaced every 1.20 m (5 ft).

3.1.2. Load transfer rods (voussoirs)

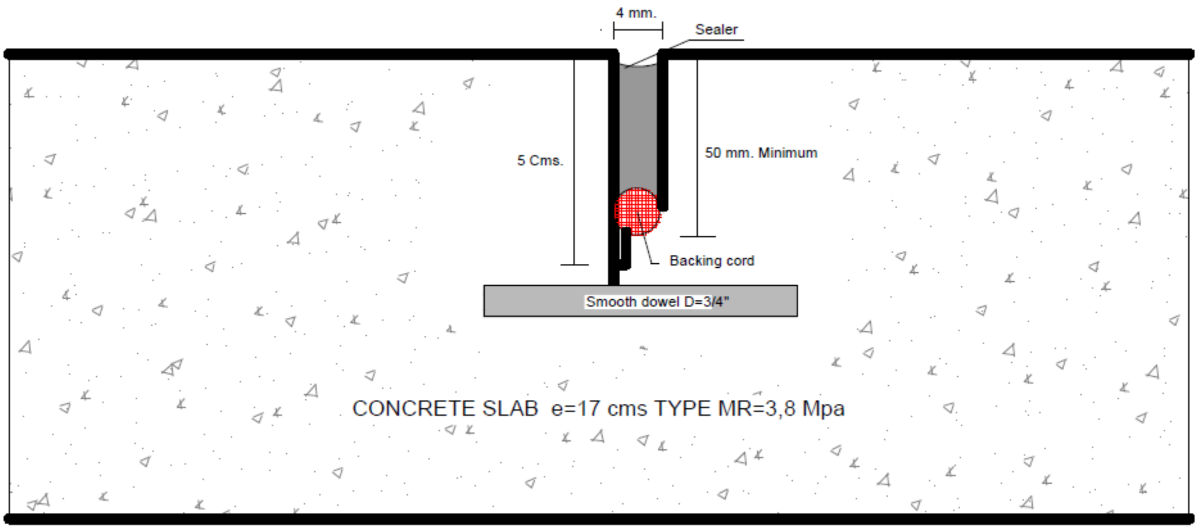
The load pins are located on the transverse joint will be 7/8" diameter smooth steel bars, 35 cm long and spaced every 30 cm. In case this diameter is not commercially available, it can be replaced by smooth steel of 1" diameter, 35 cm long and spaced every 30 cm.

Figure 7. Structural design of the pavement



Source. Own elaboration

Figure 8. Detail of joint cutting



Note: first cut is made at h/3, then enlarged to 4mm, to introduce backer rod and sikaflex.

Source: Own elaboration. Own elaboration

Figure 9. Basket of height h=7.5 cm. Support of transversal joints

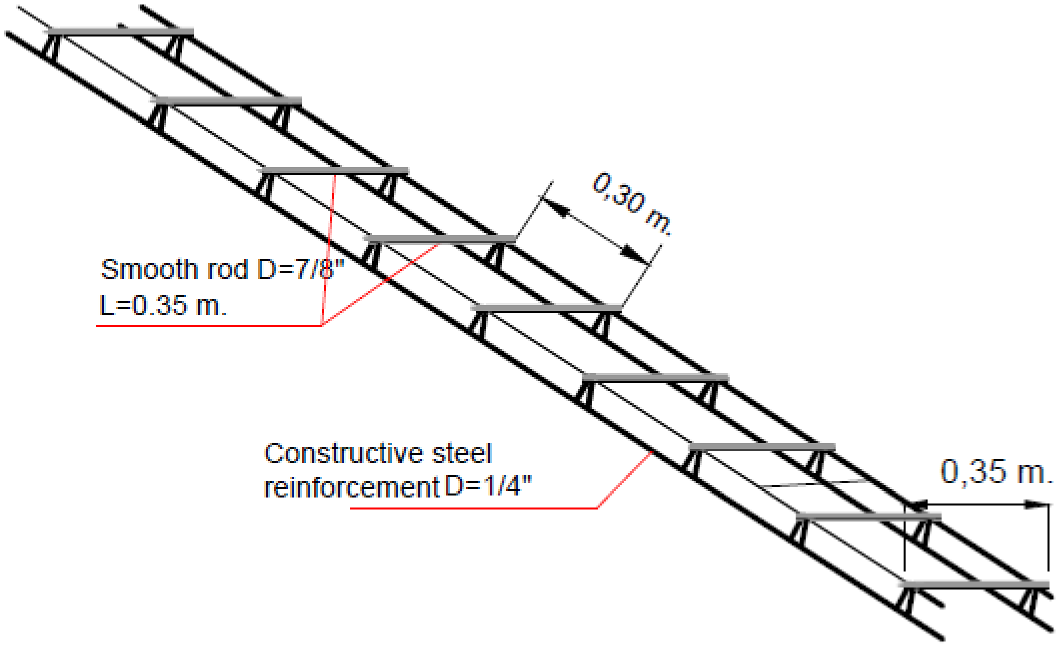
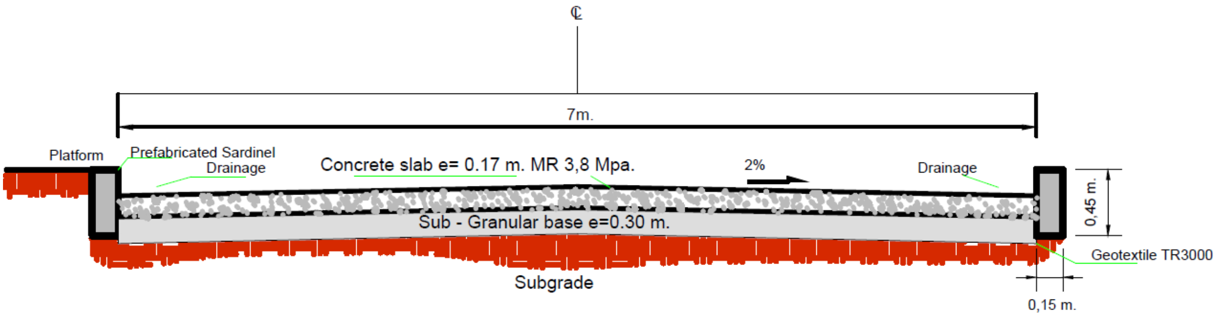


Figura 10. Sección transversal típica, pavimento



3.2. Construction process

3.2.1. Concrete slab and pavement structure

In order to obtain the expected results of the calculated structure, the following recommendations must be followed:

- The builder should acquire good quality materials that comply with current Colombian technical specifications for pavement construction.

- It is very important that the specifications of the Instituto Nacional de Vías (INVIAS) be adopted in the construction of the granular layers and rigid concrete.

- The construction of the granular layers and the wearing course should be done in the following manner:

Excavate to the design depth (Seeds, S. B., McCullough, B. F., & Hudson, W. R. (1982).

Shape and compact the subgrade to give it a better bearing capacity.

Installation and shaping of the granular material (Bravo Ramírez, F. (2021) in the recommended thickness, raw material with a maximum size of 4 inches will be installed to improve the subgrade with a thickness of 30cm. Taking into account that the bearing capacity of the subgrade is low and it is considered necessary to improve it.

Install the T-2400 geotextile, which has the function of preventing fines from migrating to the granular layer of higher quality to avoid contamination due to the migration of fines to the upper layers, this geotextile will also provide reinforcement to the structure.

Installation and shaping of the granular base (Hall, K. T. (2000), will be installed on the T-2400 geotextile, which must comply with INV specifications. The layer of this material will be 15 cm according to design.

The wearing course will be made of rigid concrete (Lane, D. S. (1998), and will be constructed with quality materials that comply with the INV standard. The thickness of the layer will be 22 cm according to the design.

For the installation of the load pins, these shall be smooth and greased in half of their length, so as not to restrict the movement of the adjacent plates. As for their position, this shall be in the middle of the thickness of the slabs, guaranteeing parallelism between the longitudinal axis of the track in the base plane and the bars, which in turn shall be parallel to each other.

Metal frames or baskets should be used, well anchored to the base and immediately before pouring, concrete should be placed on top to prevent displacement (Papagiannakis, A. T., & Masad, E. A. (2008)...).

It is recommended not to deepen the excavations more than 1.00 meter, due to the presence of the water table established in the stratigraphic profiles (Lin, J. H., & Weng, C. C. (2001).

3.3. Cutting and sealing joints

In both longitudinal and transverse joints made on adjacent rails, it is essential that the joints be properly aligned in the extension of each other, even if it is a new pavement in contact with an old one (Yoder, E. J., & Witczak, M. W. (1991). .

A cut equivalent to 1/3 of the thickness of the slab should be made with a diamond disc machine. The moment of the cut is determined by the characteristics of the concrete and the atmospheric conditions. It is recommended that it be done in the first hours of setting between 4 to 10 hours (WooLee, S., & Stoffels, S. M. (2001).

An initial cut is made with a width of 3 mm to induce controlled failure. Subsequently, a widening of the cut is performed to accommodate the seal material. The depth of the cut is one third of the thickness of the concrete slab, in this case it would be 6 cm.

- The seal must guarantee
- The tightness of the sealed space.
- Adherence of the seal to the joint faces.
- Resistance to tensile and compressive fatigue.
- Resistance to the action of water, solvents, ultraviolet rays, the action of gravity and heat.

The joint space to be sealed must be dry and completely clean, this can be achieved by washing, sweeping and then blowing with a compressor.

Prior to pouring the filling compound, a backer rod is placed and pressed into the joint with a suitable setter (Majidzadeh, K., Ilves, G. J., & McComb, R. A. (1981, April, 1981).

Joint sealing should be done during periods when the pavement is not in use. The first 3 to 5 days, but temporary protection should be provided.

With this project the inhabitants of the Araguaney neighborhood will solve the inconveniences presented with respect to the access to Cra 2ª between 9th and 11th streets, with an adequate pavement design and economically viable.

The pavement structure is 22 cm of concrete slab with a Mr= 40Kg/cm2 (after 28 days, tests must be performed on beams with load in thirds of the span) and 15 cm of granular base (compacted to 95% of the maximum dry density of the Modified Proctor).

To improve the subgrade, a maximum size of 4" ball stone or raw material will be used. For the construction of the proposed design, the general and particular specifications set forth in this report should be followed.

A very wide range of aggregates and sands can be used in concrete pavements, if they comply with certain minimum conditions that are especially related to granulometry (INVIAS E-123-12). It is possible to work with coarse aggregate whose maximum size can be equal to one third of the thickness of the slab.

For the quality of the concrete, joists will be taken in each casting, for concrete flexural strength tests, simple beam method loaded in the thirds of the span, to determine if the modulus of rupture of the concrete is complied with. As verification, concrete molds will be taken for the 28-day compression test. The water must be potable, free of sugars and other contaminants.

The builder must verify before construction, all interferences with other utility networks. If unavoidable interference is evidenced, modifications to the designs must be made with prior authorization from the contracting entity and in compliance with the regulations of Resolution 330 of 2017. The distances and diameters according to design must be verified by the constructor.

4. Conclusions

The modulus of rupture of the concrete used for the construction of the slabs must comply with a value of 40Kg/cm2 or 4.0 MPa.

The installation of an NT-2400 woven geotextile to prevent mixing between the subgrade soils and the materials that make up the granular layers of the pavement (art. 231 of the 2012 INVIAS Road Materials Testing Standards).

The granular base, considered in the design, must comply with the requirements of the INVIAS standard Articles 300 and 330 of 2012.

This design does not contemplate the use of steel to reinforce the slabs; steel will only be used in the segments and in the anchor bars, when required.

In the case of concrete pavements, joint and crack sealing activities are necessary, and in some cases, superficial and deep repairs may be required.

The contractor may carry out any complementary activity that has not been foreseen in the proposed alternatives and that is necessary for its correct functioning and preservation, after consulting the contracting entity.

The method selected for estimating the design flow is the rational method, which applies to the particular conditions of the project and according to recommendations given by the RAS-2000 in Chapter D.4.3.2.

Excess storm runoff from the sector can be satisfactorily evacuated without increasing the maximum flows discharged under the current existing conditions if storm drainage design measures are implemented through pipes and/or ditches.

In the event of differences between the design and field findings, modifications may be made with the prior authorization of the contracting entity.

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