CONTINUOUSLY REINFORCED CONCRETE PAVEMENT IN THE A-7 MEDITERRANEAN MOTORWAY OF SPAIN

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ABSTRACT

Long-life concrete pavements require less frequent repair, rehabilitation, and reconstruction, and therefore contribute to improving highway safety and mitigating congestion. Experience with these pavements, including examples of concrete pavements that have remained in service for more than 35 years.

CRCP set out to offer the market a new alternative in the use of comfortable concrete pavements, with very few contraction joints, where it is possible to predict the design stresses (loads, shrinkage, etc.), and monitor cracking as in any other reinforced concrete structure and which has the advantages of safety, cost and compatibility with existing asphalt mix or concrete pavement in poor condition.

Nowadays, the methodologies of life cycle cost analysis are already applied in the most advanced countries as potent tools in the selection of the type of pavement, endeavouring to reduce pollutant emissions.

This paper presents the lessons learned from the performance CRCP in the A-7. A motorway section, about 10.5 km long, has been constructed in the South of Spain, as a part of the so-called Mediterranean Motorway. The Spanish Ministry of Development and Ginprosa Engineering have looked for execute the work with high parameters of quality, investigating and innovating in this type of pavements.

KEY WORDS

CONCRETE ROAD / CONTINUOUSLY REINFORCED CONCRETE PAVEMENT (CRCP) / ANALYSIS OF LIFE CYCLE COST / LONG-LIFE CONCRETE PAVEMENTS

1. BACKGROUND

Concrete pavements have been constructed in Spain since 1920, and CRCP`s since 1976. the first CRCP was laid on the so-called Asturian “Y”, the Oviedo-Avilés-Gijón Motorway. The solution was adopted on account of three-fold circumstances: dense industrial and mining transport giving rise to very heavy traffic in the section, persistent humidity with very frequent rainfalls and, lastly, the plasticity and irregularity of the terrain. In spite of the unfavourable combination of traffic, climate and land, its performance has proved excellent.
2. DESCRIPTION OF THE PROJECT

The project consists of executing a section of motorway between Granada and Almería. The length of the new motorway is 10.558 m., with a practically mid-slope layout and a maximum gradient of 5.84 %. With a design speed of 80 km/h and a minimum radius of 450 m. The cross section defined is of two carriageways 7.00 m wide, with 2.50 m outer hard shoulders and 1.00 m inner ones.

The pavement for the trunk motorway is defined with concrete pavement (HP-45) on an subgrade with Ev>300 Mpa and a granular subbase and hot mix asphalt pavement in the relaying of minor roads. On the three existing viaducts the rolling surface is defined with hot mix asphalt pavement. The construction started in 2002 and finished in 2008, January, with a liquid budget of €74,811,556.80

- Reinforced concrete HP-45 27,771 m³
- Vibrated concrete HP-45 9,860 m³
- Steel used in pavements 1,780.727 Kg
- Lean concrete in pavements 20,892 m³

2.1. Pavement

The pavement planned for the trunk motorway was a concrete section of 21 cm (25 cm reduced by 4 cm through being reinforced) and a 15 cm subbase layer of lean concrete. The layer of reinforced concrete was composed of HP-45 concrete, i.e. a pavement concrete with a flexural tensile strength of 4.5 MPa. The pavement represented a total of €6,014,392.16, versus the material execution budget of €64,075,652.95 for the whole of the project, i.e. 9% of the total budget.

2.2. Geology and geotechnology

The motorway runs over materials of the Alpujarroide Complex of the Betic Mountain Chain, with a lithology predominantly composed of schists. The whole metapelitic series presents intense tectonization and fracturation.

The appearance of possible settlements caused on the one hand by the height of the embankments made with schists, more than 100 metres high, and on the other, the faults and joints in the rock mass gave rise to doubts as to good performance that might be displayed by a flexible pavement in this ground.

On account of its improved ground load distribution and its better performance with settlements it was decided to determine from what geotechnical point of view the CRCP pavement would offer a better result (Figure 1). In rigid pavement, the concrete absorbs a large proportion of the stresses applied on the pavement, while in flexible pavement this stress is transmitted to the lower layers. (Figure 2)
3. **PAVEMENT**

The reinforcement ratio of CRCP were 0.7% with HP-45 (4.5 Mpa) and 0.6% HP-40 (4.0 Mpa).

The abutments were designed at the ends of these slabs and in the special sections that so required. Also designed at the lane separation were warping and longitudinal construction joints, which would be executed by sawing, with a cutting depth of not less than a third of the thickness of the slab and, transversely to the joint and astride this, corrugated tie rods, 12 mm in diameter, 80 cm long and 1 m apart, would be placed.

3.1. Selection criteria. Solution adopted

The choice of the optimal design solution was qualified by two main criteria:

On the one hand, strictly economic. In the project a detailed study was made of all the pavement solutions for flow rates upper 800 heavy vehicles. The rigid pavement solution proved considerably more expensive than other flexible pavements. This study was supplemented, however, with the conduct of pavement life cycle cost analysis, including in this the costs stemming from upkeep and maintenance, and the conclusion was reached that this total cost represented a saving of up to 30% in respect of other more common solutions. (Figure 3)

![Figure 3. Comparative Cost Analysis.](image)

The numbers mean:
- First number (1): Traffic between 1999 vehicles per day to 800 vehicles per day.
- Second number (3): Embankment with Young’s modulus E>300 MPa.
- Third number (1, 2, 3, 4, 6 o 7): 1, 2 and 3 flexible pavements, 4 semi-rigid pavements, 6 and 7 rigid pavements with a base of 15 cm of lean concrete base (6) or 15 cm of Soil-cement base (7)

Although the last solution (137) proved to be more economical, section 136 was the final choice, mainly due to the better performance of lean concrete base compared with cement-bound granular material. The principal benefits offered by this base are:

- Lower pavement erodibility.
- Easier compaction (vibration) on platform with lower bearing capacity.
- Guaranteed thickness and regularity.
- Possibility of make adjustments in the Concrete Plant and the placement equipment.

On the other hand, the choice of a rigid pavement was qualified by the intention on the part of the Ministry of Development Technical Directorate in Madrid executing an experimental continuously reinforced concrete pavement in the “Dry Spain” so as to be able to study its performance in climates different from those where it is usually used (Asturias, Canada, UK, Belgium, etc)

3.2. Design

The standard section was a 25 cm concrete pavement, reduced by 4 cm due to being Continuously Reinforced Concrete on a 15 cm Lean Concrete base, i.e. identical aspects to those considered in
the old standards. The Concrete HF-4.5 (4.5 Mpa flexural strength) corresponding to the former HP-45 was used and reinforcement ratio was adjusted so that it represented 0.7% versus 0.86%, which could be considered too high.

The arrangement of the traverse reinforcement was designed both in its type and distribution. Steel meshes were now used consisting of a Ø10 bars at the top and Ø6 bars at the bottom joined by Ø4 electrowelded bars. (Figure 4) In this way, the spacers were replaced to facilitate the placement. In addition, the Ø10 bars was extended as a through-reinforcement.

![Figure 4. Close view of Mesh.](image)

![Figure 5. Arrangement of Reinforcements.](image)

It was decided to arrange the transverse reinforcement perpendicular to the longitudinal due to the slight frost risk in the area and the added difficulty in its on-site placement entailed in this arrangement. Longitudinal reinforcement was done with 54 Ø16 bars arranged every 14 cm, which represented a quantity of 0.7%, as already mentioned. (Figure 5). A 20 cm lean concrete extrawidth was executed in respect of the vibrated. This represented a total of 7.80 m of lean concrete, laid with a thickness of 15 cm. In addition, it coincided with the width of the paving, with standard 7.31 m extensions, plus the 50 cm implementation.

3.3. Working Formula.

The quality of a concrete pavement obtained not only depends on the intensity of the tests performed but fundamentally on a good prior study of the materials and their homogeneity, and on concrete batching in keeping with the equipment available on site.

The prior study for the concrete batching was done by adapting Fuller’s curve. During the spreading of the lean concrete numerous initial formula adjustment tests were conducted, so that it was fully adjusted and proven when execution of the concrete pavement started. It may be observed that the real mix, actually made on site, including the cement as aggregate, it was more close to the Bolomey’s curve than the Fuller’s curve. (Figure 6)
Although different batches were tested with higher water-cement ratios and a larger amount of cement, it was observed that workability was below standard and strengths were achieved too quickly, so an initial cracking problem could arise. The formula adopted, therefore, had a water-cement ratio of 0.36 and 400 kg of cement.

We should recall that the quotient between the weight of the water and that of the cement should not be higher than 0.55. As concretes with higher w/c ratios normally present a higher risk of shrinkage cracking and poorer mechanical properties and surface wear strengths, degradation could occur even in the medium term.

The cement used was V 32.5 type with a view to reducing shrinkage cracking. The percentage of andesite aggregate to fine aggregate was higher than that required, with use of a proportion as high as 55%, when the percentages recommended are above 35%. Improvements in the workability of the concrete were obtained by including plasticizing additives.

4. ON-SITE PLACEMENT

During the construction stage other characteristics different from those pointed out above had an effect on the design parameters that have been specified.

First of all, we should mention the proximity of the aggregate borrow pits. This circumstance is of fundamental importance in the end cost of the pavement. The different borrow pits and their characteristics were therefore assessed, along with their compliance with the project requirements.

Secondly, homogeneity is known to be an essential condition for achieving good quality in a pavement. This is partly due to the fact that the on-site placement and slip-form equipment is extremely sensitive to variations in the homogeneity of the fresh concrete.

Thirdly, we should underscore workability, a characteristic linked to thixotropy, i.e. to its ease of placement and vibration compaction, combined with end stability at rest and its cohesion. Stability was a very important characteristic in this case, as use of slip-form machinery required the edges to be left free but without crumbling.

Lastly, it should be pointed out that shrinkage is one of the problems of these pavements; this is reflected in cracks appearing in the concrete at the outset. The general intention, therefore, is for the concretes to be low shrinkage. This must not be accompanied by impairment of their initial strength, quite to the contrary, the objective is for this to be high; i.e. it is beneficial for the strengths to be able to be attained after three or at the most seven days, providing that they are high enough. The aim therefore was to strike a balance between initial strength and shrinkage.
The proportion of siliceous particles of this aggregate was limited. As the intention is to control the surface wear of the pavement, this percentage has to be higher than 35%. In addition, this aggregate has to come from a coarse that has an accelerated polishing coefficient that is higher than 0.50, for these traffics (more than 800 heavy vehicles/day). For other traffic the proportion of siliceous aggregate has to be at least 30%, with an accelerated polishing coefficient of more than 0.45. As already mentioned above, this condition was met more than adequately.

### 4.1. Planning

Planning the on-site placement of the concrete appeared complicated, largely predetermined by:

- The strict dimensions of the trunk motorway, with a small median strip in most of its layout
- The site truck traffic, which represented a drawback when it came to organizing and planning the on-site placement of the concrete.
- The minimum strength required of the concrete, i.e. a strength of 75% of the end value, which meant waiting 7 days, in the best of circumstances, in order to be able to walk on the concrete.
- Delay in the execution of some embankments, specifically the highest one included in the project, with a height of 109 m.

All this hampered spreading, which prevented it from being carried out on a continuous basis, with the result that the spreader often had to be at different places on the site.

The maximum and average performance ratings, however, were quite acceptable. The maximum length spread in one day, on a concrete roadbed, was 743 lm, which represented the on-site placement of 1310 m³ on that day, giving an average of 440 lm/day, i.e. 770 m³/day. For its part 950 lm of lean concrete was laid in a single day, which represents a total of 1112 m³ per day, giving an average of 500 lm/day, i.e. 590 m³/day.

### 4.2. Base. Lean concrete

Execution of the base with lean concrete proved to be one of the most successful decisions taken at the pavement design stage, as it enabled the on-site placement equipment to be finally adjusted and tested, besides permitting the training of personnel in their handling and pavement termination. Furthermore, it meant that the concrete plant equipment could be adjusted and put into operation. In addition, lean concrete sections acted as testing sections for the reinforced concrete and were used to adjust and try out the working formulas and on-site placement mechanisms.

### 4.3. CRCP.

#### 4.3.1. Materials

The aggregates used in the concrete originated from two different quarries. On the one hand, the siliceous aggregate used was extracted by crushing andesite rocks and, on the other, their aggregate was of limestone origin. The tests conducted during the execution of the project showed that the aggregates were fairly consistent.

The longitudinal reinforcement bars used were 16 mm in diameter, with a yield strength of 500 MPa, and they were placed 14 cm apart. They were joined by tying, with an overlap length of some 40 diameters, i.e. 65 cm. The aim was for there to be less than 20% of overlaps in the same section. Oblique overlaps were therefore adopted. Fifty-four 16 mm rods were used, which represented a total amount of 0.7%.

The transverse reinforcement was made up of corrugated Ø=10 diameter bars mm alternating with electrowelded meshes (Figure 4) containing Ø=10 mm bars at the top, with an 80 cm spacing. This entailed a total amount of 0.05%. The steel used in the pavement was more than 1700 t.

The concrete had a 0.36 W/C ratio, and 3.5% of occluded air. . The batching finally used in the continuously reinforced concrete was as follows:
Table 1. Batching

<table>
<thead>
<tr>
<th>Materials</th>
<th>Calculation</th>
<th>Batching</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>Volume</td>
</tr>
<tr>
<td>Cement</td>
<td>100%</td>
<td>126.23</td>
</tr>
<tr>
<td>Additive (Weight)</td>
<td>0.80%</td>
<td>3.00</td>
</tr>
<tr>
<td>Additive (Volume)</td>
<td>0.68%</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td>145.0</td>
</tr>
<tr>
<td>Aggregates</td>
<td>12-25</td>
<td>28.97%</td>
</tr>
<tr>
<td></td>
<td>6-12</td>
<td>27.85%</td>
</tr>
<tr>
<td></td>
<td>0-6 Andesite</td>
<td>26.44%</td>
</tr>
<tr>
<td></td>
<td>0-4 Limestone</td>
<td>19.95%</td>
</tr>
<tr>
<td>Total Weight</td>
<td>1846.0</td>
<td>Kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Theoretical dₕ</td>
</tr>
</tbody>
</table>

The most noteworthy characteristic that differentiate concrete for pavements is primarily that the strength defining it is its flexural tensile strength as, owing to the manner of working of the slabs, they "confine themselves" to passing on the loads produced by traffic.

The second important characteristic of paving concrete is its fatigue strength, as this is directly related to its performance versus repeated loads. This variable has not been tested sufficiently, as most of the studies on repeated loads in concrete have been carried out on compression strength, so that the approximations existing now are extrapolations to flexural tension of the former.

As an experimental analysis, an attempt was made to seek a correlation between the compressive strengths obtained at 7 and 28 days with the flexural strengths values obtained in identical data collection procedures. The expected strength at 28 days for HF 4.5 should be around 35 MPa, which is very approximate, as may be observed in Figure 7.

However, due to the great dispersion that was obtained in the results, it proved impossible to adopt any reliable conclusion.

![Figure 7. Correlation at 28 days.](image)

Furthermore, the tendency was to achieve the stipulated strengths with relative ease and the flexural strengths were exceeded at both 7 and 28 days, barring an initial setback, corresponding to the test sections and a drop in strengths around the middle of the works due to problems in the mixing plant.
It is worthwhile underlining this point. The decision made by the Project Manager not to permit opening to site traffic until reaching 75% of the flexural strength, i.e. 3.7 MPa, which interfered with on-site placement even more in some cases.

4.3.2. Concrete making

The Plant used on site for making the concrete was an Intrame Ross-600, with an output according to the cycle of between 150-250 m³/h and a power rating of 430 KW, while the cement storage capacity was 110 m³. (Figure 8). This capacity had to be supplemented with two mobile cement silos, which proved inadequate at some production peaks. It was installed specifically to supply the paver and its performance was quite good throughout the whole laying process.

This plant had two mixers each with a capacity of 18 m³, which gave an overall mixing capacity of 6.11 m³. Despite having that capacity, mixes of 5 m³ per cycle were made due to the overflow of concrete in some cases and the fact that the capacity of the trucks was practically 10 m³. The plant batched the aggregates and cement by weight, with a central discontinuous mixer. The mixing time was around.

Obtaining homogeneous concrete is crucial for good on-site placement. Continuous monitoring of the slumps in the Abrams cone proved to be a complicated task. To assist on-site placement fine-grain limestone sands were used that helped to correct the working formula.

The slump in the Abrams cone of the concrete to be used ranged from 2 - 5 cm (plastic concrete) in the test conducted at the central plant. Performed on site, the same test gave lower results and the cone value almost reached zero. The paver forward speed ranged between 0.8 and 1.5 m/minute and in some cases reached a peak production of 1.6 m/minute, so it is vital to obtain appropriate continuous outputs.

4.3.3. Transport

The transport equipment was made up of dumper trucks, mainly owing to the advantages of speedy offloading, besides their simplicity, versatility and availability of use. They can be easily adapted to the rocking that occurs in production, without overlooking the economic advantages offered to the contractor. (Figure 9)

The pouring onto the slipform paver was done by tipping the various trucks a regular distances from the paver. A backdigger was used for preliminary spreading during the on-site placement of the lean concrete, which was helped with a mini back hoe during the spreading of the reinforced concrete. In this way, better concrete distribution was achieved and the output of the paver was increased. Transport was controlled in such a way that time between making and spreading was always less than 1 hour and preferably less than 45 minutes.
4.3.4. Spreading

For the execution of the concrete pavement we used a Terex make, CMI SF model slip-form paver, with a Carterpillar with a 10.5-litre engine and four independent hydrostatic-drive crawlers and a speed of up to 10 metres/minute. It has a standard paving width of 12 feet (3.66 metres) to 24 feet (7.32 metres), so it had to be supplemented with a 50 cm section. (Figure 10)

![Figure 10. Slipform Paver.](image)

It is necessary first of all to position topographically the wires used for ground plan and elevation guidance of the machine feelers. In this case, a wire was placed on either side of the machine, which the spreader was using for both ground and elevation guidance purposes. (Figure 11). Sensor line and sensors provide the grade and steering information linked to the digital operating system, located on the operator panel.

![Figure 11. Level Plotting.](image)

On these slip-form paving machines the concrete spreading, vibrating and screeding operations are performed in a single pass, so that the slab is practically at the output from the paver, barring the curing and texturing operations. Speeds of up to 1.5 m/min and averages of 0.8 m/min were obtained, and as high as 130 m³/hour were spread, in pavement concrete. (Figure 12)

![Figure 12. Concrete spreading train](image)

To achieve greater homogeneity in the vibrated concrete, pre-spreading was carried out in front of the slip-form paving machine. For this purpose, the concrete load was tipped from the dumper truck in front of the paving machine and back hoes were used for the initial spreading, which contributed towards homogeneity and improved production.

The front split auger serves to spread the concrete to a predetermined width (Ø=406 mm). Vibration is provided to the throat area of the mold for consolidation of concrete. The vibrators, with an automatic on/off control, activated with machine movement, are hydraulically powered with variable speeds up to 10,500 vpm. The vibrator positioning is hydraulically controlled for ease in start-up and finish.

Secondly, an auto-float designed to seal the concrete was passed to fill or trim the defects. This mechanism is called a “dancer” and it was used to go over and trowel the finished surface. The concrete pavement spreading width was 7.80 metres for the lean concrete and 8.70 metres for the reinforced concrete.
4.3.5. Termination and Curing.

Once the concrete was spread over the roadway a series of operations were carried out without which the pavement could not be put into service, as its functional capability and durability would not be suitable for the purpose for which it was built.

First of all, after the passage of the paving machine, some final touches were given to the finished surface by hand with trowels, screeds, floats or darbies to remove possible specific isolated imperfections from the pavement.

After the auto-float rule (dancer), a texturing mat made up of three or four layers of sackcloth was then drawn over the slab. (Figure 13). Besides removing the little marks sometimes caused by the dancer, it provided the pavement with the necessary microtexture. This mat was suspended from the rear of the spreader. (Figure 14)

In this way, the pavement is given a more suitable surface texture so that vehicles may obtain a better surface grip. Later, it was given a longitudinal texture. The arguments in favour of this are its better rolling quality and lower noise level.

The macrotexture was executed with a plastic bristle brush which oscillated transversely and was adjustable for height (Figure 15). These groovers were made up of plastic teeth 2-4 mm in diameter and 2-4 cm apart, with an approximate length of some 10 cm. These groovers were mounted on a cam in order to produce a sine curve in the pavement with a wave length of some 150 cm and an amplitude of about 10 cm. The distribution of the groovers and their diameter was modified in the course of the work in order to achieve the desired result, i.e. an average depth in the sand circle of between 0.6 mm and 1.2 mm, with these values high anti-slip properties are obtained, along with a sufficiently low noise level.

The curing process was carried out with a curing product, a filmogen. This product was spread over the surface of the concrete creating upon drying a fine film that stopped the water from evaporating. It was applied first of all with sprayers but, as these became clogged, a manual system was adopted which offered better assurance of proper application. In time these liquids are eliminated due to the effect of the atmospheric agents and the actual traffic running on the pavement. (Figure 16)

The curing carriage was normally retarded some 50 m in relation to the spreading. At this distance it was observed that the concrete had a satisfactory surface consistency, neither very soft, which would cause the bristles to be inserted too deeply into the pavement, nor very hard, which would have the opposite effect.
The application of these resin-based products was such that it did not allow the water to evaporate, and for this purpose the manufacturer's instructions were followed, with standard dosages being in the region of 250 gr/m². Their distribution was monitored visually to make certain of uniform application. The liquid contained a white pigment, titanium dioxide, which, besides extending the joint cutting times in hot weather (2 - 3 hours more), enabled the curing to be checked for its state of curing. Care was also taken that the spreading surface covered even the vertical edges.

4.3.6. Construction details

The end-of-working-day joints represented a very important discontinuity in the CRCP on account of its reinforcement and the absence of bonding between one surface and the other. At every joint, therefore, rods were placed to duplicate and thereby strengthen the reinforcement.

This was carried out as soon as it became known that the working day was coming to an end, in accordance with the process described below (Figure 17):

- Placement of reinforcing frame.
- Insertion of formwork planks under the longitudinal frame.
- Placement of formwork planks over the longitudinal frame.
- Placement of wooden and plastic sheets on the frame to collect the excess concrete.
- Spreading the concrete with the paving machine.
- Final finishing by hand.
- Removal of the excess concrete.

The execution of these joints affected production during the first days and the ancillary operations lasted even more than two hours. However, the practical experience gained by the operators and the refinement of the technique meant that in the end they were executed faster and more
satisfactorily. (Figure 18). Right from the outset the Project Manager ruled out the use of setting retardants through fearing the loss of strength of the concrete in those localized areas. This technique might have facilitated on-site placement.

Another significant detail in these pavements is the abutment of the continuous concrete slab, representing a discontinuity in the pavement.

The anchorage beams are sized in accordance with the subgrade and its nature, while their number ranges from 3-6, the latter being the more usual number.

The anchoring beams consisted of six strongly reinforced transverse beams embedded in the underlying layer at a dept of 1 metre, executed prior to the pavement and after spreading the lean concrete. (Figure 19). They were attached to the pavement with steel dowels. These anchorages restrict the end movements of the pavements at points coming close to drainage works. (Figure 20)

5. RESULTS OBTAINED

Amongst the numerous parameters that are needed to define the surface characteristics of a pavement, tyre-road grip is the most important from the standpoint of safety, as it enables vehicles to maintain the desired path at all times and permits braking, when necessary, to take place in a relatively short distance. To this end, the slip characteristics of the pavement were evaluated in order to offer users a proper level of safety. To evaluate the surface texture, three types are defined in accordance with the dimensions of the irregularities present in a surface:

<table>
<thead>
<tr>
<th>Type</th>
<th>Irregularity dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horizontal</td>
</tr>
<tr>
<td>Microtexture</td>
<td>0-0.5 mm</td>
</tr>
<tr>
<td>Macrotexture</td>
<td>0.5-50 mm</td>
</tr>
<tr>
<td>Megatexture</td>
<td>5-50 cm</td>
</tr>
</tbody>
</table>

Of these three types, microtexture is linked essentially to the slip resistance of a pavement, and macrotexture to the possibility of the aquaplaning phenomenon and to rolling noise. Megatexture has a lesser degree of influence on the grip and aquaplaning phenomena. Internationally, other factors admitted include the value of the coefficient of transverse friction (CTF) as a joint indirect measure of microtexture and macrotexture. The sand circle test is also used. On the other hand, the International Regularity Index (IRI) is adopted as a measure of regularity (irregularities with wave lengths of more than 0.5 m).
5.1. Surface Regularity

To measure the IRI, a Greenwood profilometer was used. This instrument is capable of measuring two longitudinal profiles in order to obtain the regularity.

<table>
<thead>
<tr>
<th>Lane</th>
<th>Wheel Track</th>
<th>Arithmetic Mean</th>
<th>Standard Deviation</th>
<th>Percentage</th>
<th>&lt;2.0 (50%)</th>
<th>&lt;2.5 (80%)</th>
<th>&lt;3.0 (100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer</td>
<td>Left</td>
<td>1.66</td>
<td>0.42</td>
<td></td>
<td>82.11</td>
<td>95.79</td>
<td>98.95</td>
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<td></td>
<td>Right</td>
<td>1.76</td>
<td>0.40</td>
<td></td>
<td>74.74</td>
<td>94.74</td>
<td>100</td>
</tr>
<tr>
<td>Mean IRI</td>
<td>Outer Lane</td>
<td>1.71</td>
<td>0.39</td>
<td></td>
<td>78.42</td>
<td>95.27</td>
<td>99.47</td>
</tr>
<tr>
<td>Inner</td>
<td>Left</td>
<td>1.74</td>
<td>0.38</td>
<td></td>
<td>78.95</td>
<td>95.79</td>
<td>98.75</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>1.67</td>
<td>0.48</td>
<td></td>
<td>78.95</td>
<td>93.68</td>
<td>98.95</td>
</tr>
<tr>
<td>Mean IRI</td>
<td>Inner Lane</td>
<td>1.70</td>
<td>0.41</td>
<td></td>
<td>78.95</td>
<td>94.74</td>
<td>98.85</td>
</tr>
<tr>
<td>Mean Road IRI</td>
<td></td>
<td>1.71</td>
<td>0.40</td>
<td></td>
<td>78.69</td>
<td>95.01</td>
<td>99.15</td>
</tr>
</tbody>
</table>

It should be mentioned that in general the sections comply with the specific standards in the case of vibrated lean concrete for the rolling layer, while the IRI measurement obtained is also satisfactory. Yet they do not comply with the specific standards in the case of vibrated concrete, while the IRI measurement obtained for the rolling layer is unsatisfactory.

<table>
<thead>
<tr>
<th>Lane</th>
<th>Wheel Track</th>
<th>Arithmetic Mean</th>
<th>Standard Deviation</th>
<th>Percentage</th>
<th>&lt;1.5 (50%)</th>
<th>&lt;1.8 (80%)</th>
<th>&lt;2.0 (100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer</td>
<td>Left</td>
<td>1.88</td>
<td>0.52</td>
<td></td>
<td>22.11</td>
<td>50.53</td>
<td>68.42</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>1.84</td>
<td>0.52</td>
<td></td>
<td>25.26</td>
<td>57.89</td>
<td>68.42</td>
</tr>
<tr>
<td>Mean IRI</td>
<td>Outer Lane</td>
<td>1.86</td>
<td>0.5</td>
<td></td>
<td>23.69</td>
<td>54.21</td>
<td>68.42</td>
</tr>
<tr>
<td>Inner</td>
<td>Left</td>
<td>1.87</td>
<td>0.49</td>
<td></td>
<td>18.95</td>
<td>46.32</td>
<td>67.37</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>1.89</td>
<td>0.43</td>
<td></td>
<td>16.84</td>
<td>45.26</td>
<td>66.32</td>
</tr>
<tr>
<td>Mean IRI</td>
<td>Outer Lane</td>
<td>1.88</td>
<td>0.44</td>
<td></td>
<td>17.9</td>
<td>45.79</td>
<td>66.85</td>
</tr>
<tr>
<td>Mean Road IRI</td>
<td></td>
<td>1.87</td>
<td>0.47</td>
<td></td>
<td>20.8</td>
<td>50</td>
<td>67.64</td>
</tr>
</tbody>
</table>

5.2. Surface Texture

As already mentioned, grip is closely linked to microtexture, i.e. to the materials making up the pavement (aggregates and bonding material or binding mortar). An indirect evaluation of the microtexture is what is done using the SCRIM.

Macrotexture is evaluated with the Laser texture meter, which is mounted on the Greenwood profilometer.

As regards macrotexture, the usual and merely representative method when it comes to the study of the aquaplaning phenomenon is the sand circle test.

The sand circle method is suitable for field tests to determine the average thickness of the pavement surface macrotexture. Knowing the thickness of the macrotexture is useful as a tool in the characterization of pavement surface textures.

Macrotexture measuring equipment has been developed taking into account the new technologies. This equipment is mounted on the SCRIM so as to be able to proceed at the same time to the measurement of the CTF and the macrotexture.

Macrotexture is evaluated at a maximum speed of 80 km/h, in 1 longitudinal profile, with measurement of the Mean Profile Depth (MPD), which is correlated to the ETD (Estimated Texture...
Depth), which is the equivalent to the MTD (Mean Texture Depth), obtained with the sand circle test. The results are expressed as means every 100 m.

For Concrete Pavements, according to Spanish Normative, the MTD values have to lie between 0.6 and 0.9; in our case they gave the result shown in the table below.

<table>
<thead>
<tr>
<th>Table V. MTD Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>0.77</td>
</tr>
</tbody>
</table>

The results in general lie between the 0.60 mm and 0.90 mm stipulated by PG-3 for concrete pavements, although there are areas where this maximum value has been exceeded. These values do not affect the required mean considerably. It may be seen that the results lie within the range of values between 0.60 and 1.0, which is usually a regular trend, and that the percentage of values that have exceeded 0.9 is very small. This indicates that practically the whole of the measurement offers values in the range specified by the standards.

Furthermore, in the specific case of our project, in order to achieve suitable vehicle driving properties, we estimated that values comprised between 0.6 mm and 1.2 mm in the sand circle test would be sufficient. In this way, high non-slip properties would be attained, along with a sufficiently low noise level. In the tests conducted according to NLT-335/00 for measuring surface macrotextere by the volumetric technique, it was found that the depth and distribution of the brush groovers gave values of around 0.6 mm in this test. (Figure 21)

As regards the evaluation of this Coefficient of Transverse Friction, it was performed, as already mentioned, with the SCRIM/Texture Meter equipment. During measurement, the tanker truck wetted the road with a 1 mm film of water. The data were collected every 2.5 m and a measurement of the mean CTF was obtained every 20 m as an average of the 8 measurements taken over those 20 m. They were divided into 1000 m subsections, with 50 measurements being taken in each of them. The normal auscultation speed was 50 km/h.

![Figure 21. End result](image)

In conclusion, it may be said that the mean results of the Coefficient of Transverse Friction (CTF) in the investigational sections are (expressed in percentages):

<table>
<thead>
<tr>
<th>Table VI. CTF values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
</tr>
<tr>
<td>A-7</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

CTF values that exceed the minimum value set by Spanish Normative, where the following requirements should be met: CTF ≥ 60 in the case of draining binder, and CTF ≥ 65 in the others.
CONCLUSIONS

It could be said that the CRCPs present a series of disadvantages stemming mainly from their on-site placement, besides their high cost. The presence of reinforcements raises the cost of this roadbed, although it may reduce its thickness. In addition to its cost, it entails a difficulty of the on-site placement of the concrete, so that its placement rates are lower and in most cases it is necessary to resort to lateral feed, as was shown during the execution of this project.

These pavements need careful execution and more stringent placement controls than other concrete pavements, both on account of the installation of the reinforcement frame and the compaction of the concrete. It could be estimated that these cost 20-30% more than an alternative solution than mass concrete pavement with joints. Even so, having a stricter control of the roadbed, the fact of its being placed in a single layer conditions its surface regularity and texture to a single execution, so that any minor deviation in this process has a significant impact on the end finish and the on-site placement proves crucial.

The IRI results obtained show us better values for lean concrete versus the CRCP, rolling layer. They makes us think that the current standards over-penalize pavements of this type executed in a single pass compared with the multi-layer type.

The final conclusion of the Project Management in face of the numerous doubts existing at the outset was that of satisfaction due to the good results obtained. Even though the regularity tests appear to indicate the opposite, driving on this pavement is comfortable and not very noisy. It is a solution that is highly rated in areas of potential subsidence, as the "flexibility" of the pavement enables it to adapt to ground movements through being divided into "slabs" of a short length. If we add the environmental and maintenance costs to those of construction, in many cases they prove cheaper than alternative solutions.

These pavements are a solution widely used in a considerable part of Europe and the USA, although their use has been fairly limited in Spain, probably because of the higher specialization and investment effort required by their construction. This is the case in spite of the fact that the pavements built in the 70s and 80s have shown an excellent, demonstrating considerable savings in maintenance needs.

We may expect that in Spain that the methodologies of pavement life cycle cost analysis (LCCA) may be gradually introduced as decision tools in the selection of pavements, including environmental considerations in our infrastructure projects.

REFERENCES


JOHAN SILFWERBRAND. Design of Heavily Loaded Continuously Reinforced Concrete Pavements. 8th International Conference on Concrete Pavements Colorado Springs, Colorado, USA • August 14-18, 2005.


