

THE NAMUR TEST ROAD : BEHAVIOUR OF VARIOUS TYPES OF CONTRACTION JOINTS AFTER FIVE YEARS OF TRAFFIC

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This report deals with the observations and measurements made in order to study the behaviour of various types of contraction joints in the Namur test road, which was constructed in Belgium, in 1979, within the framework of the activities of P. I. A. R. C.'s Technical Committee on Concrete Roads. The concrete overlay, with a thickness of 20 to 23 cm, was intended to strengthen an asphaltic pavement, carrying about 17000 vehicles/day. Six types of joints were constructed, namely undowelled joints, joints with evenly spaced dowels and joints with variably spaced joints, each sealed and unsealed. Observation shows that on an average only one joint in three is active. Slab rocking movements, during the passage of a 13 ton axle, were until the end of 1981 only detectable in 40 cases out of 140 joints with an amplitude of the order of one hundredth of a millimeter. At the end of 1984, those measurements point out a different behaviour between dowelled and undowelled joints, yet without practical consequences, seeing the very low level of those movements in comparison to standard concrete roads. No apparent defects resulted from unsealed joints. The high quality asphaltic underlayers and the efficient drainage system for infiltrated water are surely important factors of the excellent behaviour of all the joint variants.

At a meeting in München of the P. I. A. R. C. Committee on Concrete Roads, it was decided to construct a test site which would combine all the different approaches to the construction of contraction joints in concrete pavements then in use, in a region offering all the seasonal effects of a suitably severe climate.

The test site was constructed in Belgium in 1979 south of Namur on the N 4 road, which links Brussels and Luxembourg (1).

The work involved the construction of a concrete overlay after widening the old bituminous pavement which was built between 1962 and 1964 with an over-

all thickness of 15 cm on a 65 cm layer of graded aggregate.

The experimental road is 4.5 km long, with two carriageways of two lanes each.

Traffic in 1980 amounted to 17000 vehicles a day, including 2500 trucks of more than 3.5 tons.

Annual rainfall is in the region of 0.85 m and temperatures usually lie between a minimum of -15°C and a maximum of 30°C.

Description of the experiment

The main object of the experiment was to compare the behaviour of various types of contraction joints over a period of time.

Six different sorts of joints were used :

- joints with evenly spaced dowels, both sealed and unsealed ;
- joints with variably spaced dowels, both sealed and unsealed ;
- undowelled joints, sealed and unsealed.

All transversal joints were of the contraction type, formed by sawing a crack inducer 4 mm wide, and between 75 and 80 mm deep.

Combining the variables led to the construction of twelve different test sections, each 750 meters long. The main characteristics of these sections are summarized in Table 1. We may add that for about half the sections, those marked "B", an extra half a meter was added to the width of the outer slabs. This extra width was kept free of traffic by suitable road markings.

The concrete was laid by an SGME MSP 150 slip-form paver equipped with a vibrating device for inserting the dowels into the fresh concrete (figure 1). The surface of the wet concrete was finished by deep transverse grooving. The concrete was manufactured using 400 kg of HK 40 blast furnace cement per cubic meter. The compressive strength of the concrete as determined on cylindrical drilled cores was on an average 62.3 N/mm² after 90 days, with a standard deviation of 3.6 N/mm².

In order to avoid water infiltrating under the

Table 1. Characteristics of the test sections

Section number	Slab width (in m)	Slab length (in m)	Slab thickness (in cm)	Type of joint	Joint sealing
I A	2 x 3.75	5	min 23	undowelled (a)	sealed
II A	2 x 3.75	5	min 23	undowelled	unsealed
III A	2 x 3.75	5	min 20	evenly spaced dowels (b)	sealed
IV A	2 x 3.75	5	min 20	evenly spaced dowels	unsealed
V A	2 x 3.75	5	min 20	variably spaced dowels	sealed
VI A	2 x 3.75	5	min 20	variably spaced dowels	unsealed
I B	3.75 + 4.25	5	min 20	evenly spaced dowels	sealed
II B	3.75 + 4.25	5	min 20	evenly spaced dowels	unsealed
III B	3.75 + 4.25	5	min 23	undowelled	sealed
IV B	3.75 + 4.25	5	min 23	undowelled	unsealed
V B	3.75 + 4.25	3 to 4 (c)	min 23	undowelled	unsealed
VI B	3.75 + 4.25	5.5-6 (d)	min 20	evenly spaced dowels	sealed

(a) The undowelled joints are angled at 80° to the axis of the road

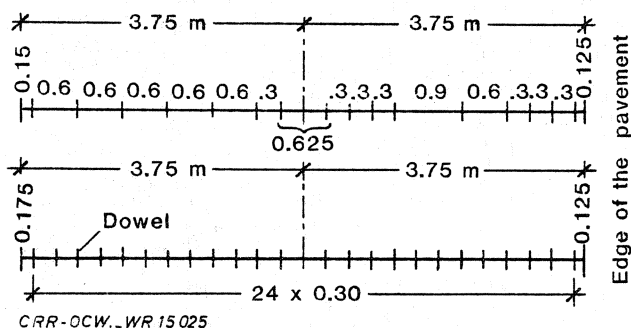
(b) The layout of the dowels is described in figure 2.

(c) Repeated sequences : 3 - 3.5 - 3.2 - 4 - 3.8 - 3 - 4 - 3.5 - 3.8 - 3.2 m

(d) Alternatively 5.5 and 6.0 m.

Figure 1. Vibrating device on the slip-form paver for inserting the dowels in the fresh concrete.

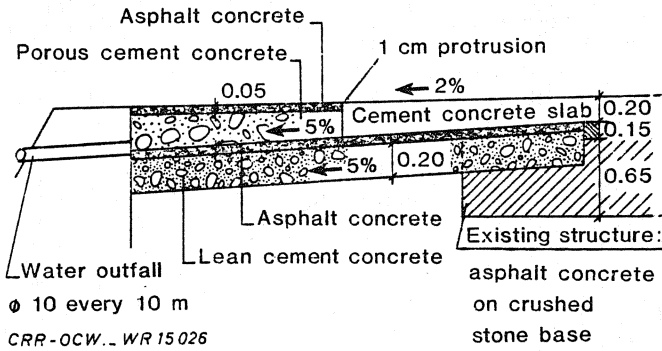
Figure 2. Lay-out of the dowels (ϕ 2.5 cm and L 60 cm) - either with variable spacing - or with constant spacing.



slabs or the hard shoulder, a thick course of porous lean concrete was laid under the hard shoulder (figure 3). This course, about 20 cm thick, is provided with outfalls every 10 meters. It is highly permeable to water (15 to 20 % voids) and was laid between two impermeable courses of asphalt concrete. The upper one is an asphalt concrete wearing course (about 5 cm), while the underlying

course is a 6 cm layer of dense mix, profiled at the level of the old pavement of the carriageway and thus also at the level of the base of the new concrete slabs. Rain water penetrating into transverse or longitudinal joints can thus be drained out by this route before it causes erosion or pumping, or has any other harmful side-effect at the interfaces.

Figure 3. Cross-section of the pavement



Observations and measurements

Five years after the road was put into service, certain effects can be noticed regarding the various aspects of the behaviour of the joints or the slabs.

Joint activity - opening and closing movements

Joint activity. It has turned out that many transverse joints are inactive and that the concrete does not even crack.

Observations made on joints under favourable conditions, such as on the hottest days of summer or, even better, during rapid temperature drops in winter, have made it possible to tabulate joint activity, as is shown in figure 4. This figure refers to 100 consecutive joints in section II B, where a long stroke indicates an active joint, a short stroke an inactive joint, and an intermediate stroke a doubtful or only slightly active joint.

The location of the active joints does not show a regular periodicity however they are never more than five slabs apart and there are practically no pairs of consecutive active joints. On the other hand, there is a satisfactory correspondance between the location of the active joints and that of joints which were observed to crack a few days after concreting. The cracking of the concrete under the sawn inducers did thus not progress in any pronounced fashion since then.

Table 2 shows the proportion of active (or doubtful) joints in 100 consecutive joints for the sections of the carriageway running to Brussels. It appears that the proportion of active joints is between 29 and 48 % depending on the section under consideration, without it being possible to establish any certain relationship between the number of active joints and the type of joint.

The gross average value for all the sections is 35 % of active joints, or more or less one active joint in three.

Amplitude of opening movements. Exact measurements of joint width variations were also carried out. To this end, twenty consecutive joints in each of the twelve sections were provided with steel studs, which were set into the concrete on each side of the joints, and flush with the surface of the slabs.

Figure 4. N 4 Assesse - Assesment of the joints activity by visual inspection - February 1981 - 100 consecutive joints of section II B.

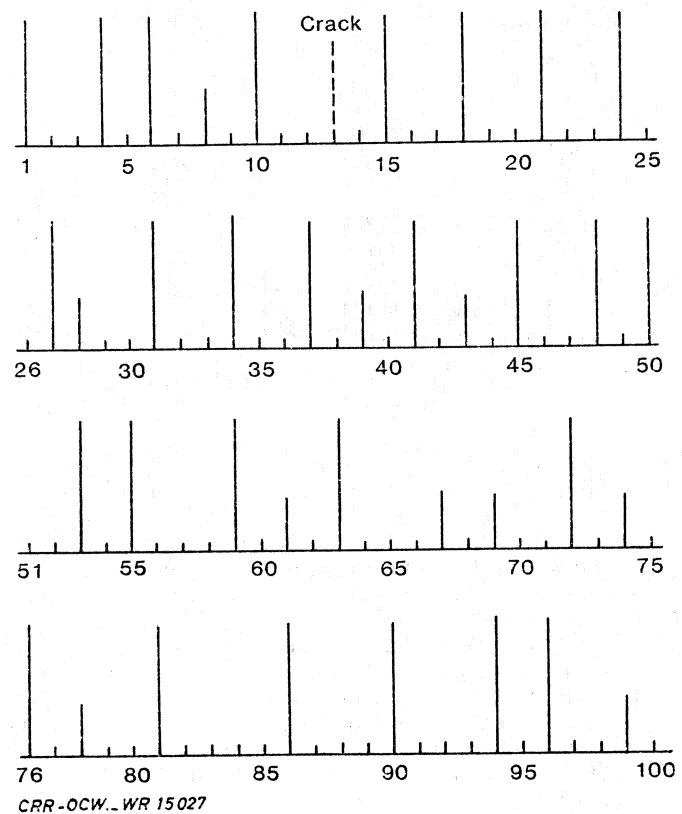


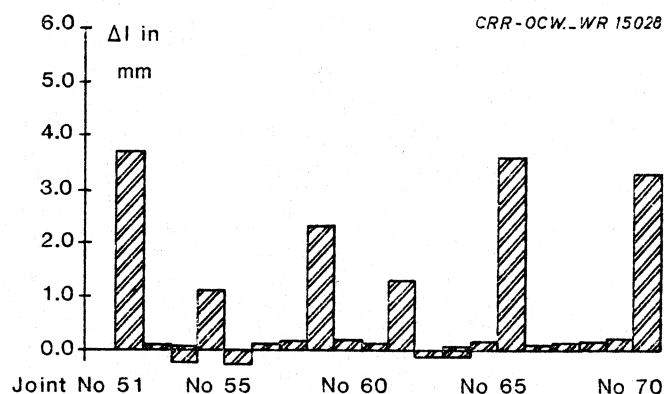
Table 2. Analysis of active joints by visual inspection (February 1981).

Section		Active joints in 100 consecutive joints		
I B	Dowels	29	or	1 in 3.5
II B	Dowels	38	or	1 in 2.6
III B	Undowelled	38	or	1 in 2.6
IV B	Undowelled	43	or	1 in 2.3
V B	Undowelled short slabs	29	or	1 in 3.5
VI B	Dowels	37	or	1 in 2.7
Overall mean :		35.6		1 in 2.8

The measurements were carried out using dial gauges, graduated in hundredths of a millimeter and fitted with spikes which the operator inserted in the markings set in the concrete; an Invar bar provided with two similar markings 200 mm apart allows the constant calibration of the apparatus.

A thermometric station, consisting of thermocouples inserted at construction at the bottom and half way in the concrete slab, was provided for each group of 20 joints.

Figure 5. N 4 Assesse - Difference in joint widths between February and August 1980 ($\Delta t^\circ = 14.3^\circ\text{C}$) - Twenty consecutive joints of section I B.



The comparison of two series of measurements carried out at different temperatures of the concrete gives the results shown in figure 5. The variation in width Δl of the joint between the two dates is displayed for each joint. The first glance confirms the conclusion of the visual inspections : only a fraction of the joints shows measurable activity.

In figure 5, we find 14 inactive joints and 6 more or less active joints with joint-closing movements ranging from 1 to 3.6 mm. This state of affairs which is similar to that for other sections, leads to the conclusion that, for such structures, calculations aimed at forecasting the opening and closing of a joint are illusory. If, however, the entire section under examination is considered, that is a section of 20 slabs and 100 meters long, the correct order of magnitude for the coefficient of expansion of the concrete is observed. For example, from figure 5, the sum of the width reductions of the six active joints is 15.18 mm, the corresponding temperature range is 14.3 K. This gives a coefficient of expansion of the concrete of $1.06 \times 10^{-5} \text{K}^{-1}$.

In some cases the horizontal movements of the edges of transverse joints were measured by means of an apparatus which allows continuous measurement during a periode ranging from a few hours to a few days. From this it is possible to establish the relationship between joint movements and slab temperature (for example, at the mid-slab level). Conditions have to be favourable for this relationship to appear to be simple and rectilinear : figure 6 shows results from measurements made on a fine winter day, with calm winds and open skies, at three joints close to one another (section II B - dowelled). The mid-slab temperature of the concrete rose from -1°C to 4.8°C in smoothly uniform fashion. In this range of temperatures, rectilinear relationships were obtained with slopes of :

0.057 mm per degree C for joint n° 78

0.109 mm per degree C for joint n° 72

0.155 mm per degree C for joint n° 76

Still referring to the same joints, figure 7 shows closing movements in relation to temperature re-recorded on two sunny days in June with temperatures rising from 13°C to 29°C at mid-slab level. The first part of the traces, up to about 19°C , corresponds to the slopes determined in winter for temperatures between 0 and 5°C . However, once beyond 20°C the progressive blocking of the joints becomes apparent.

Figure 6. N 4 Assesse - section II B - Horizontal movements of joints 72 - 76 - 78 in relation to temperature measured at mid-slab (1982, Febr. 2, 3).

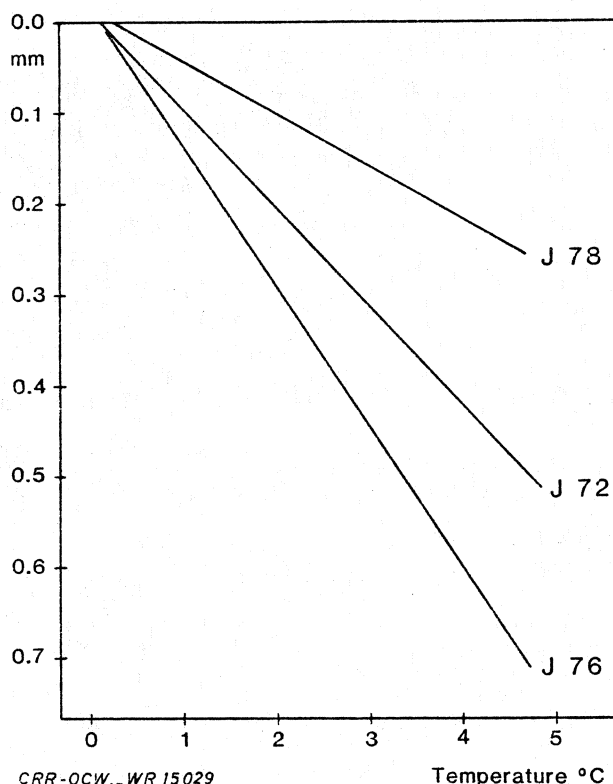
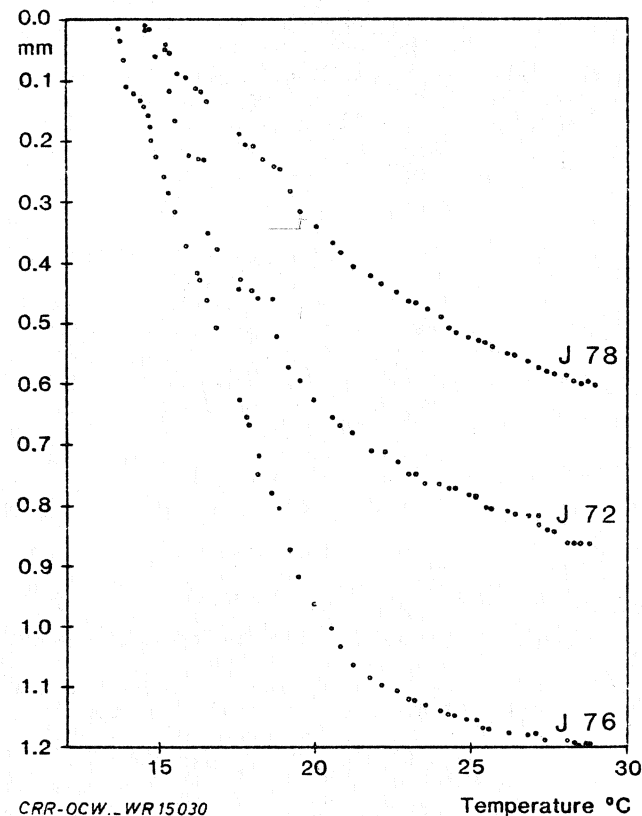


Figure 7. N 4 Assesse - section II B - Horizontal movements of joints 72 - 76 - 78 in relation to temperature measured at mid-slab (1982, June 22, 23).



Such observations indicate that these pavements, contrary to the assumptions of the project, are not divided into slabs 5 meters long. The stresses resulting from thermal or mechanical actions will thus often differ from those provided for when setting up a project. The movements resulting from the same temperature change in the concrete can, depending on the joint, be of very different amplitude and speed but can also often be nil.

Nevertheless we can observe that for practical purposes this has not resulted so far in any harm to the general behaviour of these pavements.

These observations lead us to suppose that concrete slabs slide fairly easily on a bituminous concrete sub-base. The marked opening of certain joints makes us fear that the interlocking of the edges of the crack is reduced and that consequently there is a less effective transfer of the shearing force due to the passage of loads (for undowelled joints).

Slab rocking at the joints

Determining the amplitude of the vertical displacements of the slab ends when subjected to the passage of a heavily loaded axle makes it possible to assess load transfer efficiency at the joint and to draw conclusions about the present condition and the foreseeable evolution of the pavement and the underlying courses when trafficked. This is the crux of an experimental technique which should make it possible to distinguish differing construction methods for concrete pavements without having to wait for the appearance of such clear signs as the development of stepping, pumping at the joints, cracking or breaking of slabs.

The technique employed on the N 4 road consisted in placing an apparatus, comprising a vertical displacement transducer across the joint to be examined and allowing an axle loaded to the legal limit (in Belgium) of 130 kN to pass slowly over the joint (figure 8). The electrical signal from the displacement transducer is, after appropriate processing, recorded on tape for later use.

The displacement determined by these means is thus the displacement of the end of one slab in relation to the end of the adjacent slab. Figure 9 displays a typical record obtained on an undowelled contraction joint: amplitude of the relative vertical displacement of the slab ends is shown in function of time (or load displacement). The slab rocking amplitude is, by convention, the sum of the displacement amplitudes Ar^+ and Ar^- measured at the passage of the 130 kN axle.

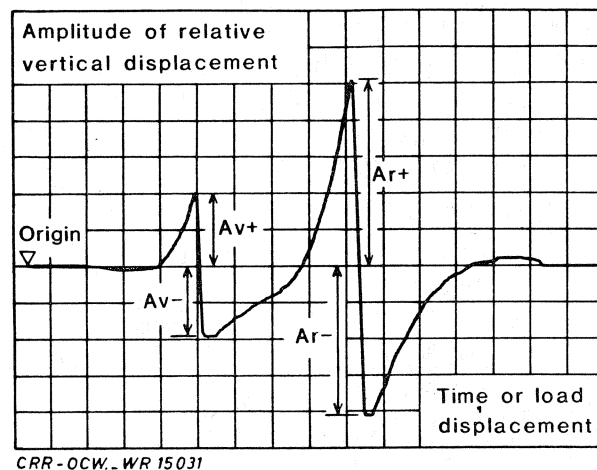
It should be noted that the aspect of the graph showing the relative vertical displacements of two adjacent slabs will not always be the standard aspect illustrated by the example in figure 9; such will notably be the case when part of the load is transferred by the interlocking and friction of the aggregates exposed in the crack or joint.

The absolute amplitude of the deflection of the slabs cannot be determined by the technique used. The acquisition of this information would require measurements from a fixed reference level (e.g. Benkelman beam resting on a point outside the carriageway) or by means of inertia accelerometers.

Furthermore, the amplitude of the slab rocking thus obtained at a given moment does not represent an invariable characteristic of the pavement but is subject to a series of more or less significant fac-

Figure 8. Measurement of the slab-rocking under passage of a 13 t axle (130 kN).

Figure 9. Slab rocking determination: typical graph recorded at the passage of the loading vehicle over a joint (two axles).



tors, such as :

- the extent to which the crack in the joint is open, which is related to the mean temperature of the concrete,
- the presence of any curvature in the slabs, related to the existence of a vertical temperature gradient in the slab,
- the distance of the load from the edge of the slab,...

The first two factors can be accommodated by taking measurements only under favourable conditions, that is to say at atmospheric temperatures lower than 10°C and varying little, with overcast skies, so that joints do not become blocked and that any temperature gradient in the slabs is limited.

The measurements carried out during the first two years the pavements were in service showed :

- that slab rocking was very limited compared to amplitudes frequently observed on recent pavements ;
- that this order of magnitude implied excellent load transfer and the absence of any deficiency of the joints whatsoever ;

- that this uniform order of magnitude of slab rocking makes it as yet impossible to determine any significant differences in behaviour between the various construction methods which are the object of the experiment.

Practical experience indicates that slab-rocking amplitude of :

- 0.1 mm or less correspond to pavements giving no reason to harbour any fears with regard to their immediate future ; these cases are in fact only rarely encountered ;
- between 0.1 and 0.25 mm are observed on pavements in good general condition ; a typical result for recent structures ;
- the order of 0.5 mm and more correspond to defective pavements requiring maintenance work.

Now the results of the measurements carried out on the experimental sections of the N 4 road indicate slab rocking amplitudes in the region of one hundredth of a millimeter, that is to say much less than the first threshold usually considered.

Table 3 shows, by way of example, the results obtained from a serie of measurements carried out in March 1980, on 20 consecutive joints on each of the 12 test sections.

The main conclusion to be drawn from such measurements is the very low value of the amplitudes, much less than the values observed on normal pavements in good condition ; moreover, during the course of the first two years it has not been possible to establish a relationship between the results and the characteristics of the various test sections.

From 1982 on, the order of magnitude of slab rocking values has not increased much but it has become possible to determine a significant difference between the slabs with dowelled joints and the slab with undowelled joints. The number of joints subject to slab rocking now appears to be very different for the two series of pavement and the difference in amplitude grows significantly.

The measurements made in November 1984 confirm this tendency (Table 4). At this moment, the number of joints with zero amplitude of rocking has clearly decreased and the arithmetical mean of the rocking amplitudes (different from zero) are now 0.039 mm for the undowelled joints and 0.020 mm for the dowelled joints.

Figure 10 displays typical results obtained in November 1984. The differences of behaviour are significant ; the various sections are spread over the test site in such a way to exclude the possibility of any systematic effect of temperature or hour of the day on the measurements. These results constitute the first indication in the experiment of the positive effect of dowelling on concrete pavements.

However, this is no more than an indication of the (logically to be expected) distinct rates of evolution of the two sorts of pavement, as at the present time the very low order of magnitude of observed slab rocking means that its practical consequences still remain imperceptible.

Slab cracking

After two winters we could observe that 28 slabs out of a total of about 3600 had cracked.

This limited number has not increased since then.

There is only one slab with a transverse crack affecting the entire width of the carriageway ; the majority of cracks (18 out of 28) affect the slabs with

extra width and dowelled joints (sections I B, II B and VI B). These cracks affect an outer corner of the slab, they are active while the corresponding part of the transverse joint is not.

The origin of these cracks appears to be the inadequate depth of the crack inducer sawn into the green concrete. The sawcut was to a constant depth of 7.5 cm, whereas the thickness of the concrete increases towards the edges of the extra-wide slabs. The presence of dowels also appears to play some role.

in 1984 these cracks in no way disturb the evenness of the carriageway.

Joint sealing

Doubts have been cast on whether there is a real need to seal joints and the planners of the experiment provided for half of the transverse joints not to be sealed, the other half being sealed after the creation of suitable sealing grooves.

Until mid-1984 the various inspections and measurements have not made it possible to conclude whether any effect results from the absence of sealant. It should nevertheless be remembered that adequate drainage of infiltrated water has been provided for by constructing a course of lean cement concrete with a high void content and a high permeability under the shoulder. Premature generalization of this important conclusion should therefore be avoided (2).

Sealants

On the same N 4 test road, an other road experiment was set up to evaluate the field behaviour of different joint sealants (3).

Six hot poured products and six cold applied elastomeric products were used to seal 900 transverse contraction joints of the P. I. A. R. C. test road. These products covered the range of the sealants then (1979) marketed in Belgium. Sealing was conducted in respect of the rules of good practice (4), after grinding of adequate sealing grooves, partly in early summer and partly in late fall conditions.

This field test has led to useful conclusions after a few years only.

Conclusions

After five years, the influence of various types of contraction joints on performance is still imperceptible and the variants of the pavement offer a uniformly satisfactory performance.

Measurements show that the vertical movements of the slab ends under a heavy axle remain at a very low level (< 0.05 mm) in comparison to standard concrete roads. These measurements also point out, after three years, a different behaviour between dowelled and undowelled joints, yet without practical consequences.

Only one joint in three appears to be active and exact measurements of opening-closing movements under temperature changes in the concrete reveal considerable widening for part of the joints. This could be prejudicial to the correct transmission of shearing forces due to loads, the interlocking of the

Table 3. N 4 Road - amplitude of slab rocking measured in March 1980 (axle load 130 kN)

	Number	%
Slab rocking undetected	124	52
Detectable slab rocking ≤ 0.01 mm	75	31
Slab rocking less than 0.02 mm	17	17
Slab rocking less than 0.03 mm	13	
Slab rocking less than 0.04 mm	4	
Slab rocking less than 0.05 mm	3	
Slab rocking less than 0.06 mm	1	
Slab rocking less than 0.07 mm	1	
Slab rocking of 0.24 mm	1	
Total number of joints examined	239	100

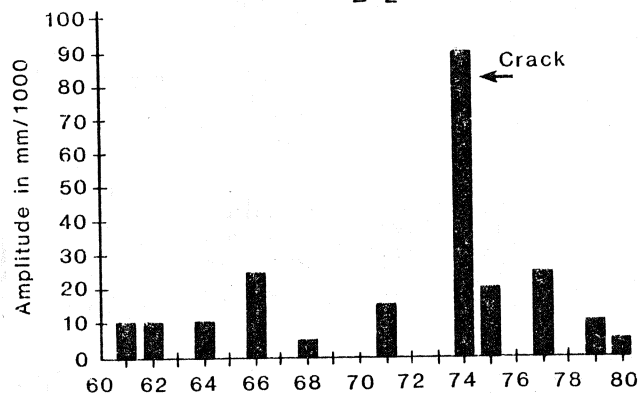
Table 4. N 4 Road - Slab rocking amplitude : evolution from 1982 to 1984

	Number of joints	
	Nov. 82	Nov. 84
on 100 <u>undowelled</u> joints :		
rocking amplitude nihil or ≤ 0.01 mm	64	15
0.01 to 0.02 mm	27	22
0.02 to 0.10 mm	9	58
> 0.10 mm	0	4
on 100 <u>dowelled</u> joints :		
rocking amplitude nihil or ≤ 0.01 mm	90	49
0.01 to 0.02 mm	9	20
0.02 to 0.10 mm	1	31
> 0.10 mm	0	0

Figure 10. N 4 road - Typical results of slab-rocking amplitude measurements in november 1984, after five years of traffic, on sections of twenty consecutive joints with and without dowels.

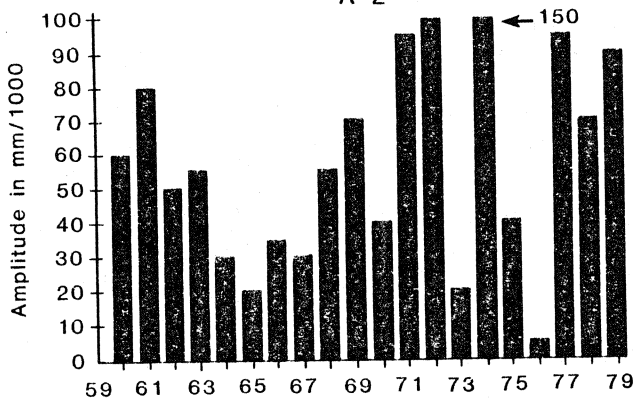
DOWELLED JOINTS

B 2

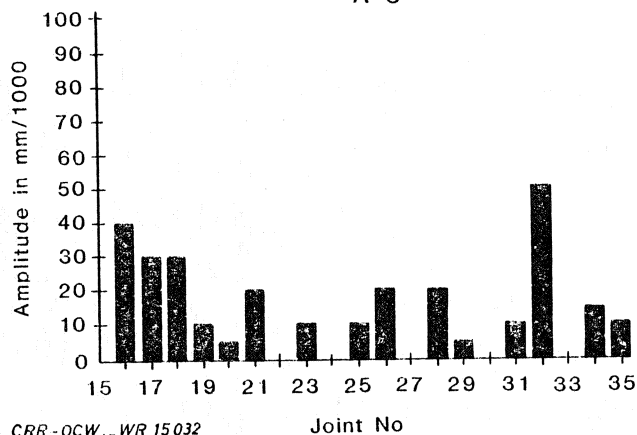


UNDOWELLED JOINTS

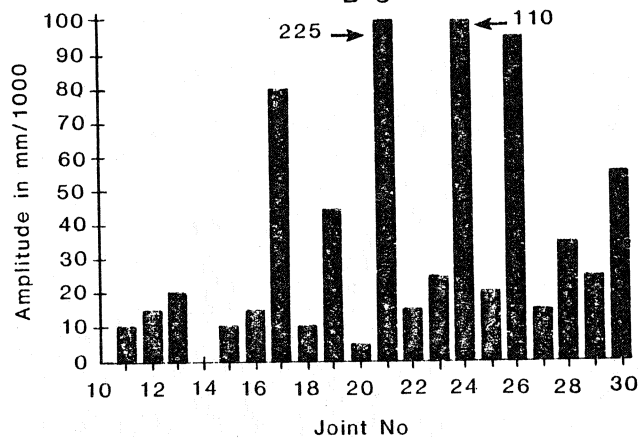
A 2



A 3



B 3



sidewalls of the crack being lost. The seals of these joints are also subject to excessive extension in cold weather.

The omission of sealant in some joints has not yet had any perceptible effect up to now ; it should be noted, however, that this omission is compensated by a drainage system for infiltrated water, in this case a thick porous lean concrete course with high permeability under the hard shoulder.

The uniform behaviour, the slow evolution and some rather unusual properties of the pavements are probably linked to the design of this concrete overlay on a still sound bituminous pavement and to the provision of efficient drainage of infiltrated water.

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