IMPROVEMENT IN IRI VALUES OF CONCRETE PAVEMENTS CONSTRUCTED IN ARGENTINA WITH SLIP-FORM PAVERS

Marcelo Dalimier
Portland Cement Institute of Argentina, San Martín 1137, 1004 Buenos Aires

Dr. Roberto Torrent
Holcim Group Support Ltd., CH-5113 Holderbank, Switzerland

ABSTRACT

Measurements of the International Roughness Index (IRI) were conducted on eight pavement sections, corresponding to two highways and one airport runway, constructed in the period 1995-1999 in Argentina.

All three pavements were built using slip-form pavers. Different sections of the pavements were built by different contractors, using different logistics and machinery.

The IRI was measured using an Inertial Profilometer T6500 K.J. Law, corresponding to Class 1 according to ASTM E 950-98.

The results obtained in the different sections vary widely according to the technology applied in each of them. The average IRI of the sections ranged from values near 4 m/km to values below 2 m/km.

Linking the IRI values registered in each section with the technology applied in them, showed that the best results were obtained where appropriate logistics (e.g. higher concrete production rates) and the use of heavy pavers (CMI, GOMACO and Wirtgen) were employed.

Another important conclusion is that the IRI values obtained decreased chronologically, reflecting the importance of experience and know-how transfer from one job to the next.

The main conclusion of this study is that, with modern and powerful pavers, appropriate logistics of concrete production and delivery, and personnel, trained and experienced at all levels, is possible nowadays to build in Argentina concrete roads of evenness comparable to that of high-quality asphalt roads.

INTRODUCTION

Excessive roughness has traditionally been a serious drawback of concrete pavements vis-a-vis their eternal competitor, the asphalt pavement. Surface unevenness and improper joint construction has led to the perception of concrete pavements as “bumpy” riding surfaces.

In recent years, significant improvements have been achieved in concrete pavement construction, which open good prospects of removing that stigma.

In particular, the use of the last generation of high-performance, slip-form concrete pavers, supported by appropriate logistics for high rates of concrete production and delivery, permits to build concrete roads with highly satisfactory roughness levels, equivalent to those of good asphalt pavements. Needless to mention is the much

longer preservation of those satisfactory levels with time, for concrete pavements are more durable than those made of bituminous materials.

In Argentina, the use of these High-Performance Technologies (HPT) is relatively recent; actually the first application started just some 6 years ago. Actually, there are three emblematic constructions with these technologies, which showed the potential to produce high-quality riding surfaces with HPT.

To ascertain the achieved level of quality, in terms of evenness, the International Roughness Index (IRI) was measured on all three constructions.

The object of this paper is to present and analyze the results of those measurements:

- to judge the level of quality achieved
- to link the values obtained to the particular conditions for each section of pavement
- to study the chronological evolution of the IRI values and
- to draw conclusions about the influence the way of producing and delivering concrete has on the evenness of the pavement surface.

CHARACTERISTICS OF THE CONCRETE ROADS STUDIED

The three constructions under analysis are:

- Route No. RN127, in the province of Entre Ríos, a 120 km long federal state road, which carries an important amount of traffic and constitutes an important link for the commerce with Brazil. Construction was started in Sept.'95 and finished in Sept. '97.
- Route No. RP39, in the Province of Santa Fe, a 37 km long provincial road. Construction was started in May '97 and finished in Sept. '98.
- Runway of the airport of El Calafate, a 115,000 m2 concrete pavement, exposed to the rough climate of Patagonia. The airport is already receiving an intensive air traffic of tourists eager to visit the wonderful glaciers located nearby. Construction started on 21 Jan. '99 and finished on 12 March of the same year.

For the analysis, the three constructions were subdivided into pavement sections, which were built under nominally the same conditions: same contractor and same machinery (paver and concrete production and delivery system). This subdivision resulted in the definition of eight pavement sections, the characteristics of which are summarized in Table I.

It can be seen that the first four sections were built with light pavers and that the concrete was produced in a batching plant and mixed and transported to the placement site in ready-mixed trucks. Central mixing and delivery by dumpers was used for the last four sections. Notice also that sections 4b-RN127, 6-Airport and 5b-RP39 were built using heavy pavers and that, in the latter, the paver was equipped with automatic dowel-bars insertion (DBI).

IRI – THE INTERNATIONAL ROUGHNESS INDEX

The International Roughness Index (IRI) is the standard scale on which road roughness information is reported in many countries of the world [1,2]; it has been developed under the sponsorship of the World Bank [3].

The measurement of the IRI of a given road consists essentially of four steps [4, 5]:

1. The physical measurement of a single longitudinal profile
2. That profile is then filtered with a moving average on a 250 mm base length. This filtering simulates the "smoothing" effect of the deformation of the tire
3. The resulting profile is further filtered with a quarter-car simulation [6]. This simulation records the physical response of an "ideal" car (the Golden Car) traversing the profile at a speed of 80 km/h
4. The IRI (m/km) is calculated as the accumulated movement (m) of the suspension of the Golden Car, divided by the profile length (km)

The IRI scale starts at zero for a road with no roughness and covers positive numbers that increase proportionally to the roughness of the profile.

Fig. 1, taken from [4], associates typical IRI values with verbal descriptors from a World Bank Technical Paper [7], for roads with bituminous pavements.

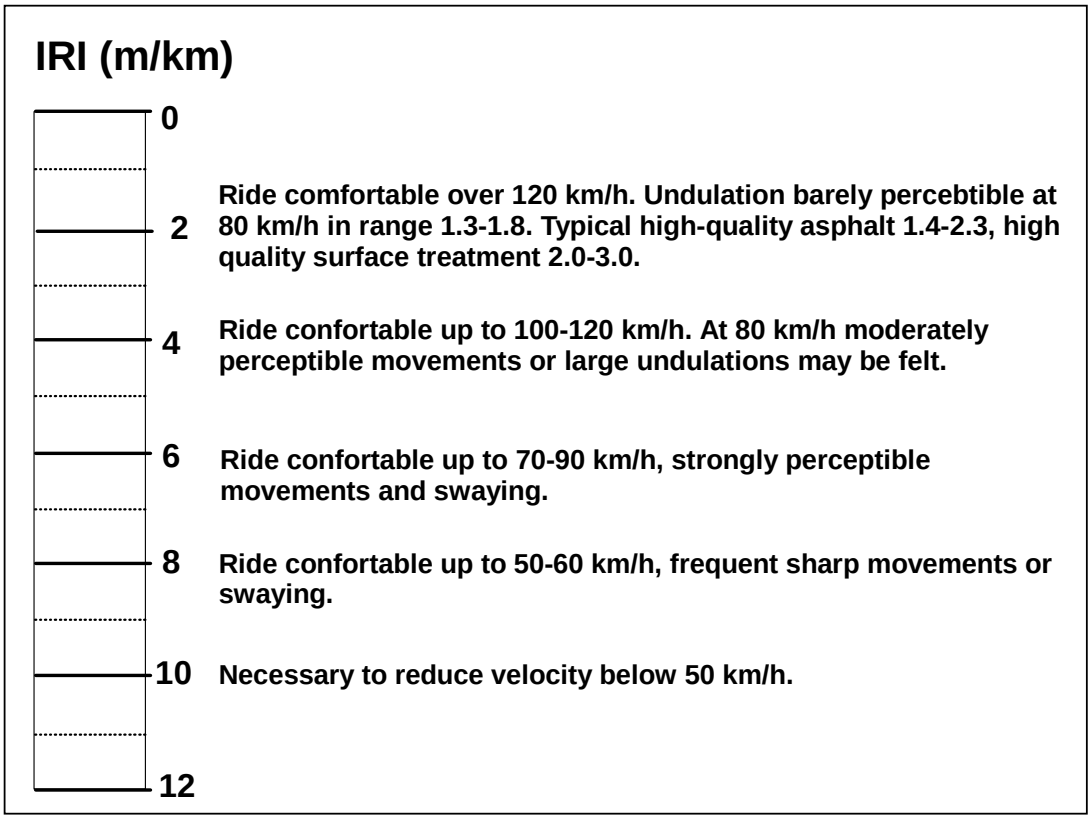

Fig. 1 – IRI estimation scale for roads with asphaltic concrete or surface treatment [4].

MEASUREMENT OF THE IRI

The measurement of the IRI was contracted with a specialized company, which is a concessionaire for operating and maintaining the network of roads of Córdoba City and, thus, a totally independent organization.

The longitudinal profile of all eight pavement sections was measured using a single piece of equipment: an Inertial Profilometer T6500 K.J. Law, corresponding to Class 1 according to ASTM E 950-98 [8]. The unit, while travelling at 80 km/h, measures the elevation of the profile each 25 mm with an accuracy better than 0.1 mm; the measured elevations are smoothed by computing the moving average each 150 mm. The unit records and processes electronically the data so as to provide a value of IRI each 10 m of profile length, in the form of a spreadsheet. The unit performs these calculations for both the left and right hand track of the vehicle; in this paper only the right hand track values are considered.

DATA PROCESSING

For the analysis of the data it was necessary, first, to discard spurious values, indicated in the report by notes such as: bridge, overtake, speed reducers, railway line, etc. These spurious data represented only 0.5% out of the total 19,567 data recorded for the eight pavement sections. The maximum incidence in a single section corresponded to section 2, where the discarded data reached 2% of the whole set of data.

The reported data of IRI values measured at 10 m intervals, were statistically processed as follows:

1. The 10 m IRI values of each and all sections were taken individually to calculate the following statistical parameters:

   The mean, the median, the standard deviation (S_{10}), the maximum and the minimum values (see Table II).

2. The 10 m IRI values were taken in groups of 30 (not overlapping), and averaged, thus getting the 300 m IRI values. Three hundred meters was chosen because it is a usual length over which the compliance of roughness specifications is often evaluated.

   With these 300 m IRI values, the following statistical parameters were calculated: the median, the standard deviation (S_{300}), the maximum and minimum values and the percentage of IRI results below 2.3 m/km (see Table III). The latter deserves some explanation. As can be seen in Fig. 1, a value of IRI= 2.3 m/km is regarded as the maximum expected from a high-quality asphalt pavement. Thus, this percentage serves to establish which proportion of the concrete pavement sections can be considered as having a quality comparable to a high-quality asphalt road, in terms of roughness.

   The mean values are the same as those in Table II, so they are not shown in Table III. Instead, the values of $S_{10}/30^{1/2}$ are presented. This is the standard deviation that would be expected for the averages of 30 results of 10 m IRI values, if these were independent normal random variables. Under this assumption, the variance of the means of *n* values is the variance divided by *n;* hence $S_{300} = S_{10}/30^{1/2}$.

Furthermore, two sections were further evaluated using the CuSum technique, a powerful tool to detect trends in a series of data. Appendix A gives a brief description of the technique.

ANALYSIS OF THE RESULTS

From Table II, it can be seen that the median is always larger than the mean, which gives an indication that the frequency distribution of 10 m IRI values presents a positive kurtosis, i.e. it has an asymmetric longer right hand tail. This can be seen in Fig. 2, which presents the frequency distribution of 10 m IRI values for the sections with the lowest mean (5a - RP39) and the highest mean (1 – RN127). Table III shows that this effect is reduced for the 300 m IRI values (the medians get closer to the means); the averaging process removed the isolated very high values.

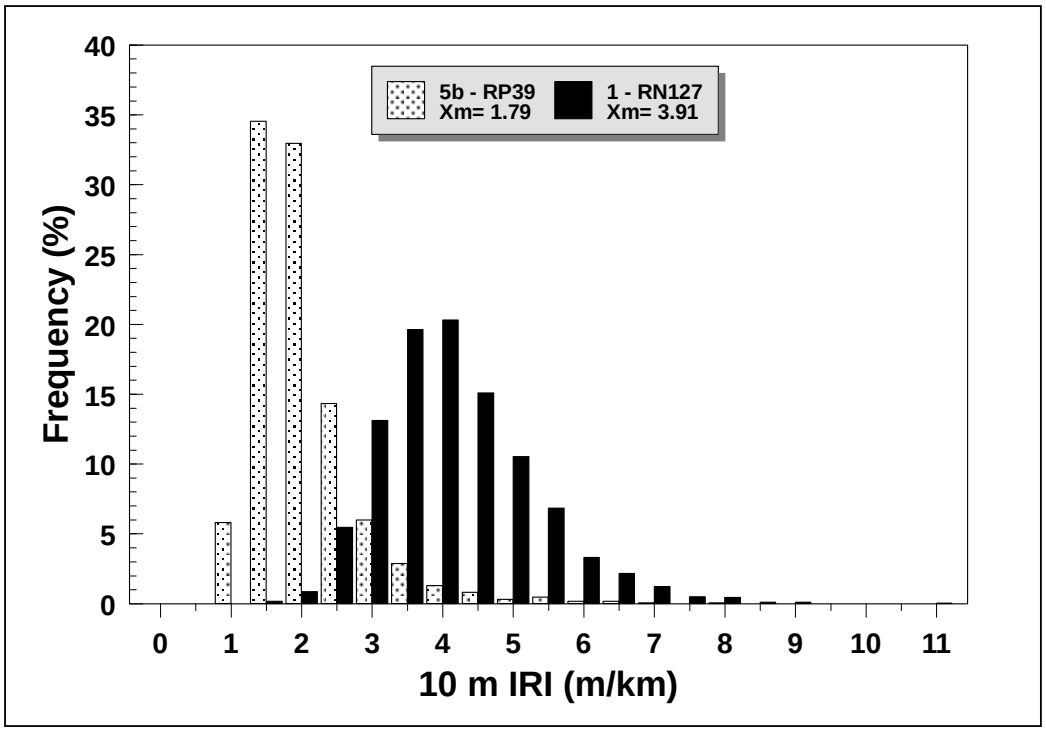

Fig. 2 – Frequency distribution of 10 m IRI for sections with lowest and highest mean.

Fig. 3 shows the mean IRI values for the 8 different pavement sections. It can be seen that for the first four sections, where light pavers were used and mixing and delivery of concrete was made through ready-mixed concrete trucks, the mean IRI ranged between 3 and 4 m/km. The better results achieved in section 4a-R127, just 5 km long, is attributed to the short distance from plant to placement spot. The figure also shows the sustained improvement in IRI achieved chronologically in the successive sections, reflecting the gain in “know-how” from previous experiences. The latest two sections, where the most appropriate technology and experienced personnel were involved, present mean IRI values below 2 m/km, which can be regarded as very good.

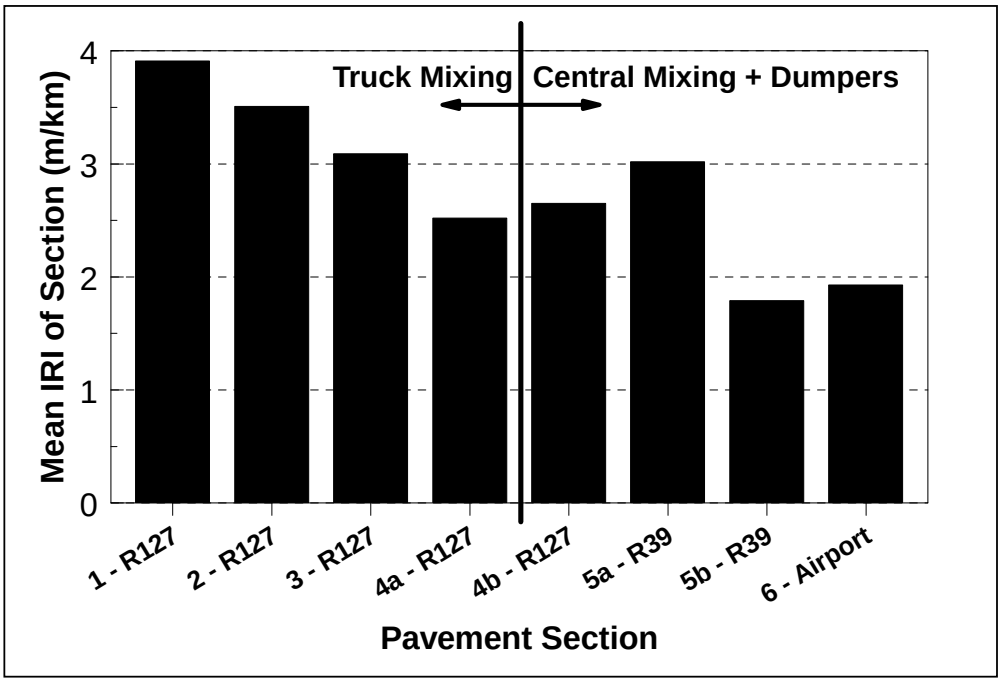

Fig. 3 – Mean values of IRI for the eight pavement sections studied

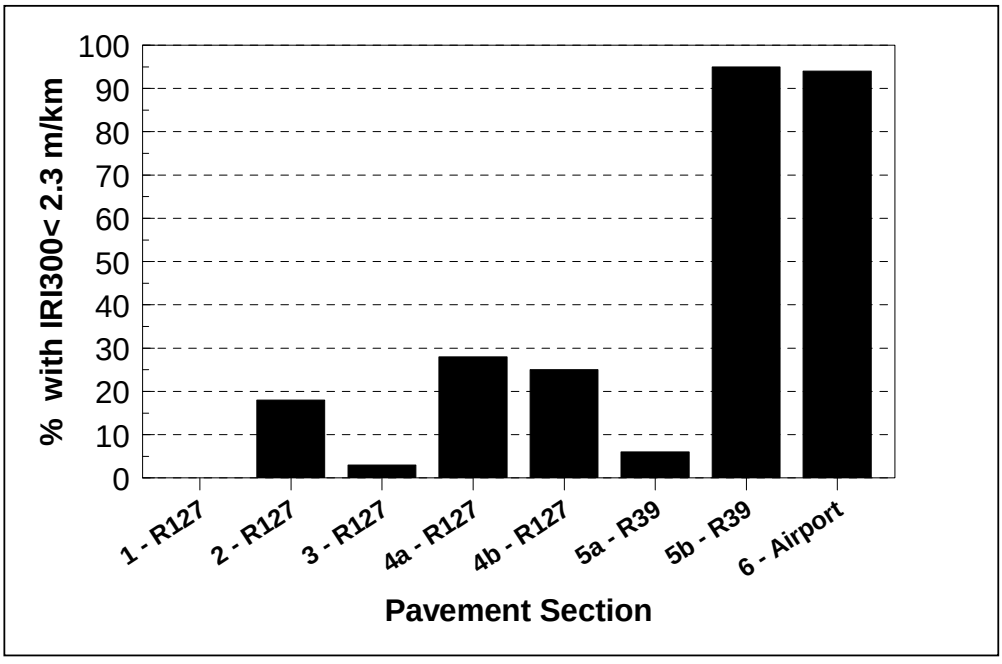

Fig. 4 – Percentage of 300 m IRI values below 2.3 m/km for the 8 sections studied

Fig. 4 shows the percentage of 300 m IRI values, within each pavement section, with an IRI below the limit of 2.3 m/km, i.e. comparable to that of a high-quality asphalt road. It is interesting to notice that nearly 95% of the latest two concrete pavement sections have IRI values below 2.3 m/km. This shows that, with appropriate equipment and experienced personnel, it is possible to build concrete roads with high standards of serviceability, comparable to that of high-quality asphalt roads.

Fig. 5 presents the values of standard deviation of IRI for the eight pavement sections, corresponding to the following parameters:

- S_{10} : standard deviation of the individual values recorded at 10 m intervals
- S_{300} : standard deviation of the averages of 30 consecutive individual values, not overlapping; it thus represents the standard deviation of the IRI of segments 300 m long
- $S_{10}/30^{1/2}$: this is the value of S_{300} expected from the S_{10} values if these were independent, normal distributed and random, according to the theory of statistics

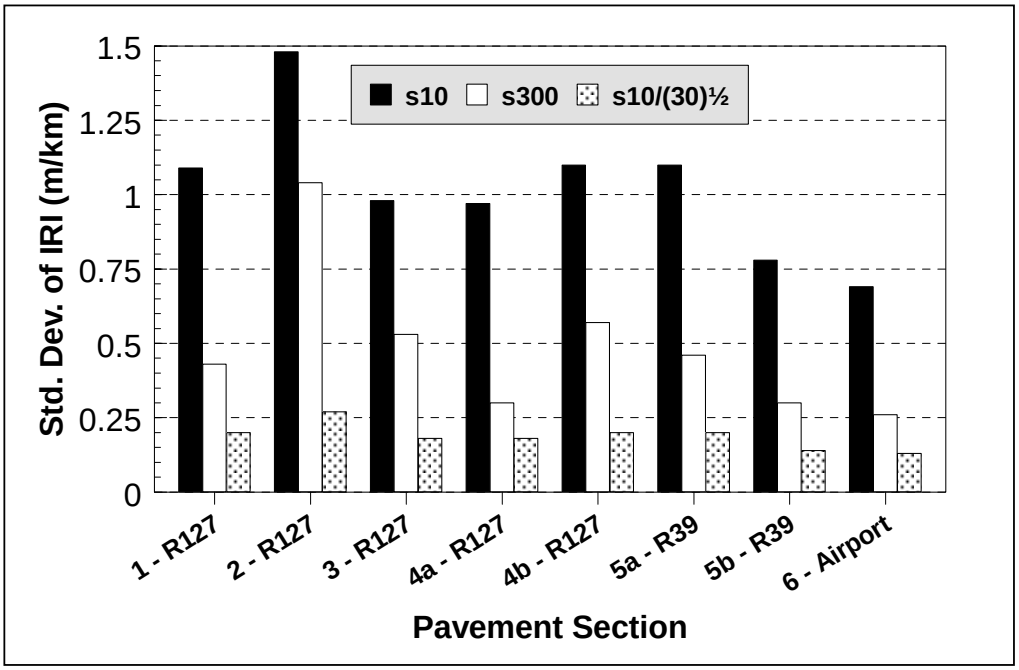

Fig. 5 – Standard deviations of IRI for the eight pavement sections studied

From Fig. 5 it is observed that the individual values present standard deviations S_{10} of IRI, typically around 1 m/km, with a higher value near 1.5 m/km for Section 2-R127. On the other hand, the improvement in uniformity of IRI achieved in the latest two sections is clearly appreciated in the graph, with S_{10} values about 30% lower.

As expected, the S_{300} values are lower than the S_{10} values, as a consequence of the averaging process. However, as can be seen in Fig. 5, they are as an average 2.5 times higher than the $S_{10}/30^{1/2}$ values predicted by the theory of statistics. As the latter assumes that the results are independent, normal distributed and random, the difference should be attributed to a deviation from that assumption. It is suspected that, within each pavement section, the IRI values are not independent nor

distributed at random, but that there are some trends, e.g. segments of consistently higher and lower IRI than the overall mean.

That this is the case is shown in Fig. 6 which presents the CuSum chart of the individual IRI values for section 5b-RP39 (the one with the lowest mean). The CuSum statistical technique (described in Appendix A) is particularly appropriate to detect trends in a series of data. The slope of the graph indicates, in the scale shown, the mean value of a given group of the data.

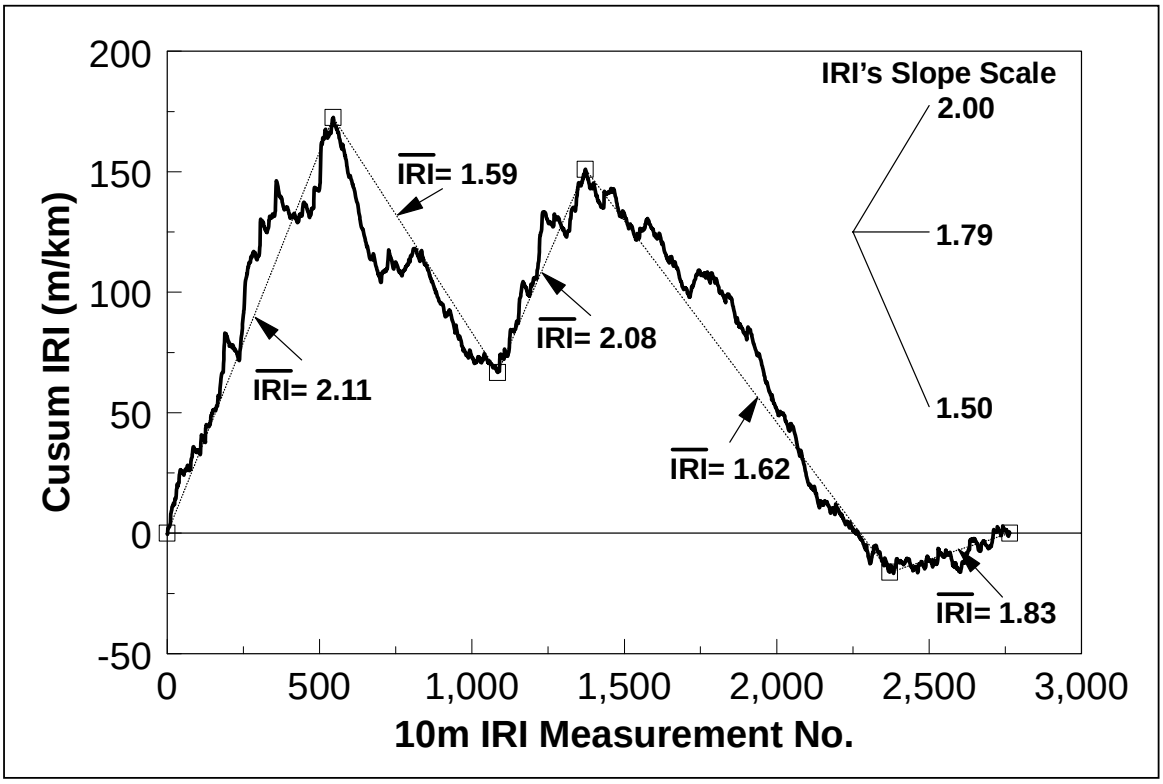

Fig. 6 – CuSum chart of the 10 m IRI results of section 5b-RP39.

If the values were randomly distributed the plotted points should fluctuate randomly around a horizontal line (corresponding to the mean IRI value of the section: 1.79 m/km). Instead, it is clearly seen that there are segments with consistently higher IRI (about 2.1 m/km) and others with consistently lower IRI (around 1.6 m/km) than the overall average. This explains the S_{300} values higher than what might be expected from the theory of statistics.

Fig. 7 shows the CuSum chart for section 2-RN127, quite an interesting case. Here, we can differentiate three segments, two of them with mean IRI around 4.2-4.3 m/km and the third one with mean IRI of 2.4 m/km (the overall mean IRI was 3.51 m/km). In the graph, the location of the concrete plant, referred to the measurements is shown.

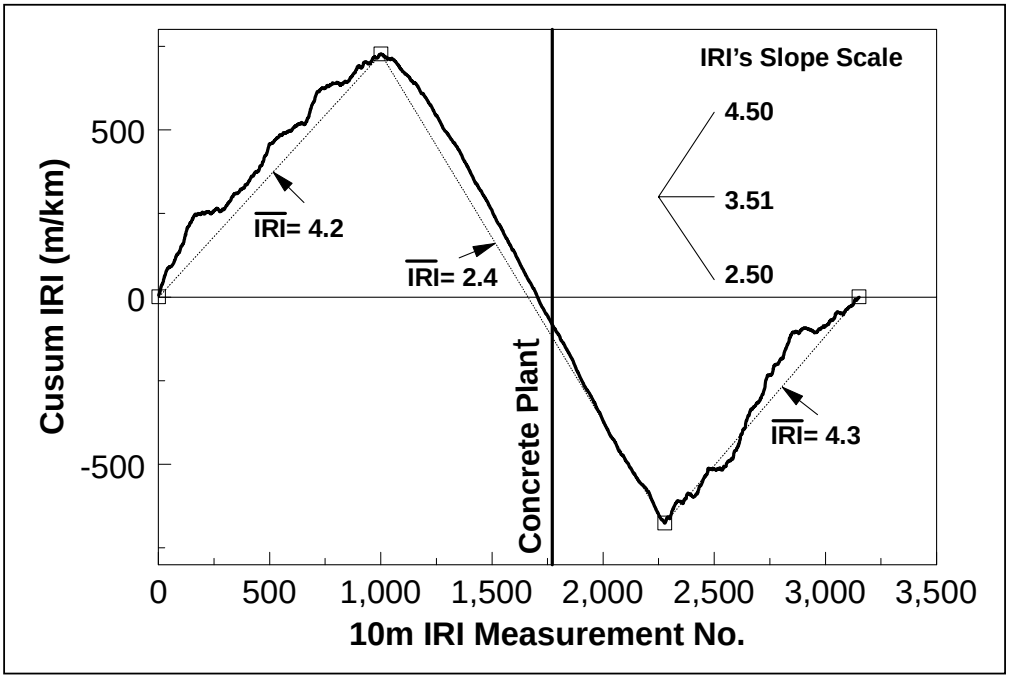

Fig. 7 – CuSum chart of the 10 m IRI results of section 2-RN127

The IRI values of the pavement segment closer to the plant are lower, whilst those farther away from the plant present higher IRI values, compared with the overall mean. This effect can be seen even more directly in Fig. 8.

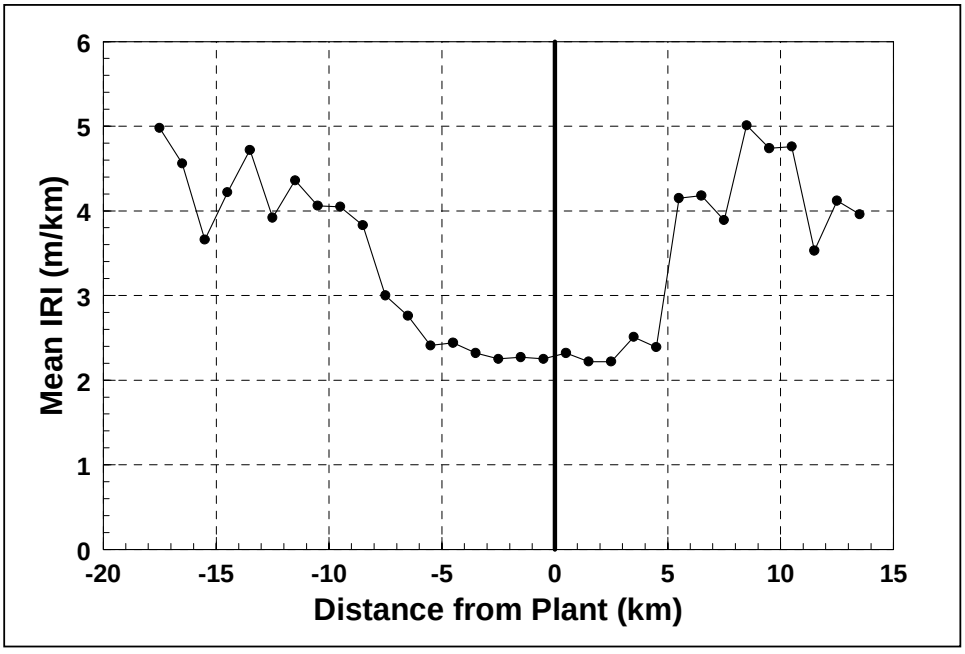

Fig. 8 – Effect of distance from concrete plant on IRI for section 2-RN127

The values in Fig. 8 are the mean of 100 values of 10 m IRI (i.e. of 1 km segments) plotted against the distance to the concrete batching plant (distance taken from the middle-point of each segment). The graph indicates that, for the particular conditions of this Section, where concrete was mixed and transported in 8 ready-mixed concrete trucks, carrying 5 m^3 each, the maximum distance over which a reasonable value of IRI was achieved is around 5 km. For longer distances, the rate of concrete supply did not allow a smooth and continuous operation of the paver, which resulted in a significantly higher roughness of the pavement.

CONCLUSIONS

The investigation of the roughness of the eight concrete pavement sections yields the following conclusions:

1. The IRI results, obtained in the different sections, vary widely according to the technology applied in each of them. The average IRI of the sections ranged from values near 4 m/km to values below 2 m/km.
2. The IRI values are not randomly distributed over the whole section; within each section it is possible to differentiate segments with consistently higher and lower mean IRI, relative to the overall average of the section.
3. Linking the IRI values registered in each section with the technology applied in them, showed that the best results were obtained where appropriate logistics (i.e. higher continuous concrete production rates, mixing plant and dumpers) were employed to feed the demand of heavy slip-form pavers (CMI, GOMACO and Wirtgen with DBI).
4. In a particular section, where concrete was batched at a plant and mixed and transported in ready-mixed concrete trucks, it was possible to identify the negative effect of the distance between placement point and concrete plant location on the roughness of the road.
5. The IRI values obtained decreased chronologically, reflecting the improvement in equipment, logistics and transfer of experience and know-how from one job to the next.
6. In the latest two sections, where the best technology and know-how was applied, about 95 % of the pavement presented 300 m IRI values below 2.3 m/km, a value indicated in ASTM E1926-98 as the top limit for high-quality asphalt pavements.

The main conclusion of this study is that, with modern and powerful pavers, appropriate logistics of concrete production and delivery and personnel, trained and experienced at all levels, is possible nowadays in Argentina to build concrete roads with roughness comparable to that of high-quality asphalt roads.

APPENDIX A

The CuSum Statistical Chart

Conventional charting techniques, such as the Shewhart control chart, have the drawback that individual points are plotted independently, i.e., the location of the points bears no "history" of the previous points and, hence, they are not extremely good at determining trends in a given set of data.

One technique, developed in the late 1950s specifically to overcome that drawback, consists in accumulating the differences between each individual data point x_i and a reference value *k*. The term CuSum comes then from "Cumulative Summation".

Thus, if a series of points x_1, x_2, …. x_n is produced, then their CuSum is developed as follows:

$S_1 = (x_1 - k)$

$S_2 = (x_1 - k) + (x_2 - k) = S_1 + (x_2 - k)$

.
.
.

$S_n = S_{n-1} + (x_n - k)$

or, in general form $\boxed{S_r = \sum_{i=1}^{r} (x_i - k)}$

The CuSum chart is produced by plotting the CuSums S_r, as they occur. The Reference Value *k* can be any value, but it is usually set at the real or expected mean value of the data points. The graphs shown in Figs. 6 and 7 were built taking *k* as the mean IRI of the corresponding pavement section.

If, for a particular group of consecutive data, their mean is higher than the reference value *k*, then the CuSum plot will climb with a positive slope. Similarly, should the mean decrease, the graph begins to slope downwards.

In fact, a change of mean in the data points will be reflected in a change of slope in the CuSum chart. The position of a single point in the chart is immaterial, what matters are the changes in slope of the graph. For this reason, the chart should always carry a slope scale, to identify the magnitude of the eventual changes that might occur. The small deviations of the slope, a consequence of random fluctuations should be ignored; the average slope of a number of points should be looked at instead, to see if there are trends indicating changes in the mean values.

Practical information on CuSum charts can be found in [9] and, for a more in-depth knowledge of the technique, the reader is referred to [10].

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Table I – Main Characteristics of the Eight Pavement Sections Investigated

Pavement Section	Contractor	Length (km)	Width (m)	Thickness (m)	Paving Machine	Concreting Rate (m^3/h)	Concrete Delivery	Concrete Plant Type
1 – RN127	A	24.3	7.3	0.23	Power-Cuber	40	Truck Mixers	Batching
2 – RN127	B	32.0	7.3	0.22	GOMACO Comander III	60	Truck Mixers	Batching
3 – RN127	C	31.7	7.3	0.22	GOMACO Comander III	60	Truck Mixers	Batching
4a – RN127	C	5.0	7.3	0.22	GOMACO Comander III	60	Truck Mixers	Batching
4b – RN127	C	27.3	7.3	0.22	CMI SF450B	120	Dumpers	Mixing
5a – RP39	D	9.0	7.0	0.20	GOMACO Comander III	45	Dumpers	Mixing
5b – RP39	D	28.0	7.0	0.20	Wirtgen SP500 with DBI	45	Dumpers	Mixing
6 – Airport	E	2.55	45.0	0.32	GOMACO 2600, ASO 5000 mold	180	Dumpers	Mixing

Table II – Statistical parameters of the 10 m IRI values of the eight sections

Section	Mean (m/km)	Median (m/km)	S_{10} (m/km)	Maximum (m/km)	Minimum (m/km)
1- RN127	3.91	3.77	1.09	10.61	1.37
2- RN127	3.51	3.21	1.48	11.99	1.06
3- RN127	3.09	2.95	0.97	8.57	1.00
4a- RN127	2.52	2.31	0.97	8.47	0.99
4b- RN127	2.65	2.41	1.10	13.15	0.72
5a- RP39	3.02	2.83	1.10	9.05	1.09
5b- RP39	1.79	1.63	0.78	11.41	0.60
6- Airport	1.93	1.80	0.69	6.81	0.63

Table III – Statistical parameters of the 300 m IRI values of the eight sections

Section	Median (m/km)	S_{300} (m/km)	$S_{10}/30^{1/2}$ (m/km)	Maximum (m/km)	Minimum (m/km)	IRI < 2.3m/km (%)
1- RN127	3.92	0.43	0.20	5.11	2.86	0
2- RN127	3.65	1.04	0.27	5.77	2.01	18
3- RN127	3.04	0.53	0.18	4.88	1.99	3
4a- RN127	2.44	0.30	0.18	3.10	2.08	28
4b- RN127	2.58	0.57	0.20	4.30	1.61	25
5a- RP39	3.14	0.46	0.20	3.77	1.95	6
5b- RP39	1.73	0.30	0.14	3.00	1.23	95
6- Airport	1.93	0.26	0.13	2.58	1.26	94