Alleviating the Skid Resistance Problem - The Israeli Experience

Yaron R. and Nesichi S.
Aram Engineers – Haifa Israel, Public Works Department - Israel

Abstract

Since the year 2000, the Israeli PWD (Public Works Department) has been leading a comprehensive process aimed at the improvement of the skid resistance (SR) condition of Israel's interurban highway network.

The issue of skid resistance in Israel is influenced by the country's unique climatic conditions, which are characterized by a long (about 8 months) dry season with zero precipitation, followed by about 4 months of a rainy season. These conditions require a maintenance policy aimed at tackling two problems:

(1) "First Rain Skidding Accidents" (FRSA) – a problem manifested by many skidding accidents occurring during and just after the first rain following the dry season, due to the excessively contaminated pavement surface.

(2) "Normal" skidding problems related to inherent pavement surface mix deficiencies (polishing, loss of macrotexture, bleeding, etc.).

The improvement process that began in 2000 involved the following main stages:

1. A literature review that was mainly aimed at recommending preferred skid resistance monitoring devices and operation techniques. Following this review, skid resistance measurement services were procured using the ROAR system (by Norsemeter). The chosen mode of operation, based on considerations explained in the paper, was 86% fixed slip at an operating speed of 75 km/h.
2. A policy for two separate comprehensive network surveys was implemented: "end-of-summer" and "winter-spring" surveys. The end-of-summer surveys are aimed at identifying contaminated sections, which should be dealt with in order to mitigate the FRSA problem. The winter-spring surveys are aimed at tackling "normal" pavement surface mix related problems.
3. Parallel to the above surveys, work was done in order to establish threshold skid resistance values for the Israeli interurban roads. Further details on the considerations for choosing these values are detailed in the paper.
4. Based on the results of the skid resistance survey and the newly established threshold values, the Israeli PWD initiated large efforts to enhance the skid resistance condition of the road network. Fast improvement of the skid resistance of existing roads was performed by the use of three newly adopted techniques:
   - Water blasting.
   - Fine milling.
   - Rotating Discs.

Conclusions were made regarding the proper use and durability of these treatments and recommendations based on this experience are presented in the paper.

1. General

Since the 1970's, the Israeli PWD (Public Works Department) conducted regular skid resistance (SR) measurements with a Locked wheel, ASTM E274 device. The measurements were performed in most of the interurban road network (which the Israeli PWD is in charge of). Some measures were taken in order to improve the SR of substandard road sections. However, the awareness, and consequently the budgets that were allocated for this purpose, were quite small. In the municipal sector, most cities in Israel did (and still do) practically nothing in order to check and alleviate the SR problem. The Haifa region is one of the exceptions in that matter, due to the ongoing activities of Yefe Nof, which is the authority in charge of the development of new transportation facilities in the Haifa area.

In October 1999, during the first winter rain, a bus (driving on road no. 65, on the Galilee area, not far away from the city of Nazareth) slipped on the road, which was wet due to the first winter rain, and skidded off it. 17 people were killed. Even though it was obvious that the bus was not in a proper mechanical situation, questions regarding the SR of the road surface were raised. This tragic accident was one of the causes of a very deep change in the general attitude and awareness in Israel regarding the issue of SR.

The present work is intended to portray the major steps that were taken by the PWD since 2000, in order to confront the issue of SR in the Israeli interurban road network. The work that has been carried out, up to the present, consisted of the main following steps:

A. The adoption of a new SR measuring device and measuring procedures.

B. The process of embracing new threshold values of SR, relevant to the new testing equipment and testing procedures.

C. After several trials, the new measuring device was put into routine work, and a comprehensive survey of almost all the interurban roads in Israel was performed. Deficient sections were pointed out for repair.

D. New techniques for surficial treatment of existing road sections were tested and implemented in regular maintenance work. The main purpose of this activity was to enable the PWD to treat efficiently large amounts of road sections that have deficient SR.

2. SKID RESISTANCE – THE GENERAL ISSUE AND LOCAL EMPHASIS

For many years skid resistance has been recognized as one of the significant contributors to road safety. Some countries, like the United Kingdom, Netherlands, France, some states in the US and New Zealand, have put the SR issue on a high place in their priority list. These countries have allocated substantial resources for research of the issue, monitoring the road network, solving SR deficiencies and finding new construction and rehabilitation solutions to provide better performance for the long run.

During the 1970's Israel's PWD conducted an intensive eight-year research program on SR (ref.1). The main product of this program was the development of a Basalt gap graded asphalt mixture. Another product was the adoption of ASTM E-274 equipment for routine testing of the network. Unfortunately, this equipment became non-operational in the late 1990s. In addition, for many years the overall maintenance budgets of the Israeli PWD have been severely reduced. The SR issue was not given a high level of priority, amongst other maintenance and safety issues, due to the following main reasons:

- A basic unawareness of the severity of the problem, amongst many in the civil engineering community, both professionals and decision makers.

- The elusive nature of SR. Unlike other pavement deficiencies, like cracking, roughness etc., a slippery pavement does not "show itself". Drivers can use a slippery road, especially when it is dry, without noticing its condition. When accidents occur they are usually attributed to other causes. Slippery conditions are seldom recognized as the main cause of an accident. Due to the lack of public awareness, the public pressure focuses on promoting many other aspects of road safety, other than SR. The issue of providing high levels of SR has a low rank in the priority list of safety considerations.

The above is especially typical of hot and relatively dry countries, where the number of rainy days per year is low. Since skidding problems usually occur in wet conditions, the general tendency is to regard the SR issue as a somewhat minor one.

Another issue that should be mentioned about SR in Israel, is the influence of the long dry period. The Israeli sub-tropical semi-arid climate consists of a short wet winter of about four months, followed by a dry, hot and rainless season of about eight months. These conditions lead to a gradual accumulation of various types of contaminants on the road surface, including dust, oil, tire rubber particles, spilt materials from passing vehicles etc.

During the first rains, which come after the dry season, the mixture of water, dust and other materials creates a somewhat muddy and very slippery film. This situation is very risky and is the cause of quite a lot of accidents, termed as "First Rain Skidding Accidents" (FRSA). In that matter, the Israeli experience is different from that of many other countries, where precipitation is spread all around the year with only short rainless periods.

An example of the influence of the long dry season on SR can be seen in Figure 1. The picture depicts early trials to evaluate the extent of SR decrease due to the above-mentioned phenomenon. The measurements, conducted by a British Pendulum with a TRL type slider, were performed on the same spots before and after a cleaning process. The cleaning process included wetting the surface, scrubbing it with a hand brush (with plastic bristles) and rewashing it with water. As illustrated, the cleaning process revealed more than 20% reduction in SR due to the contamination of the asphalt surface.

Another example is demonstrated in Figure 2. Two series of SR measurements were taken at the same road, a heavily trafficked arterial in the Haifa bay, in the northern part of Israel. One series was conducted at the end of December 2003 and the second on May 2004, after about 2 months of no precipitation (the last rain was recorded on the 26 of February). Both measurements were made with the ROAR, using procedures as will be specified later. The difference in the results between the two series (after correcting for the change in ambient temperatures) is very significant and reflects a reduction of 15%-20% in SR.

Ref 2 and Ref. 3 are amongst the few professional articles that mention the issue of FRSA. Generally, the professional literature rarely deals with this problem. In the past no engineering means existed in Israel to deal with the problem. The only means used were posting special warning signs during the end of summer (in order to warn the drivers from the first rain skidding hazards), and trying to alert the public awareness through the media. These means are also used in other countries. It seems however that their effectiveness is questionable, to say the least. In this respect, the situation in Israel is no exception.

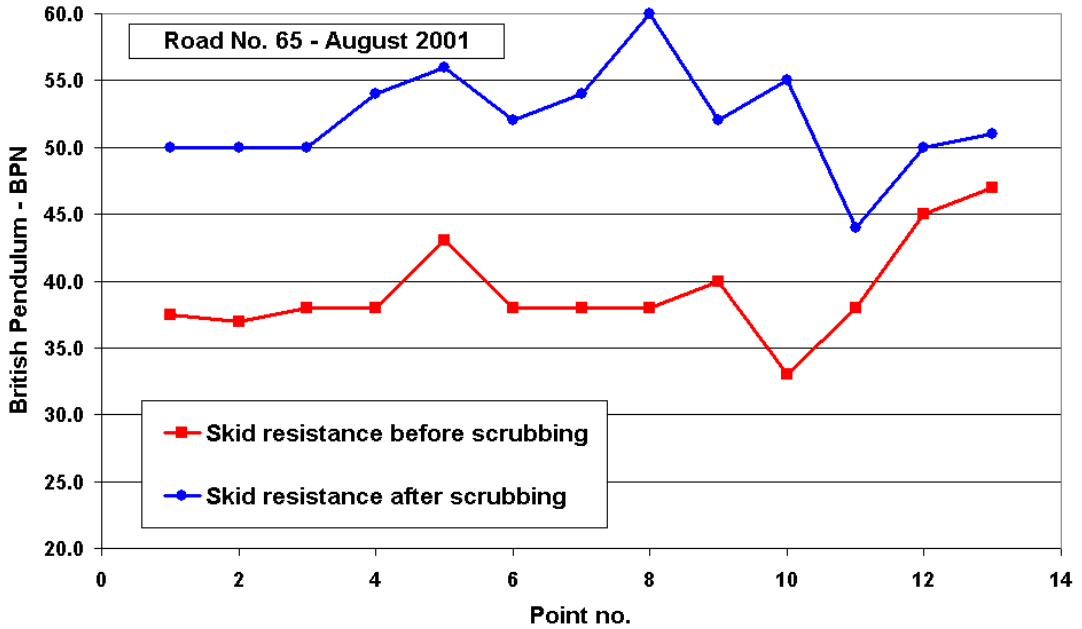

Figure 1: Skid resistance regain due to surface cleaning

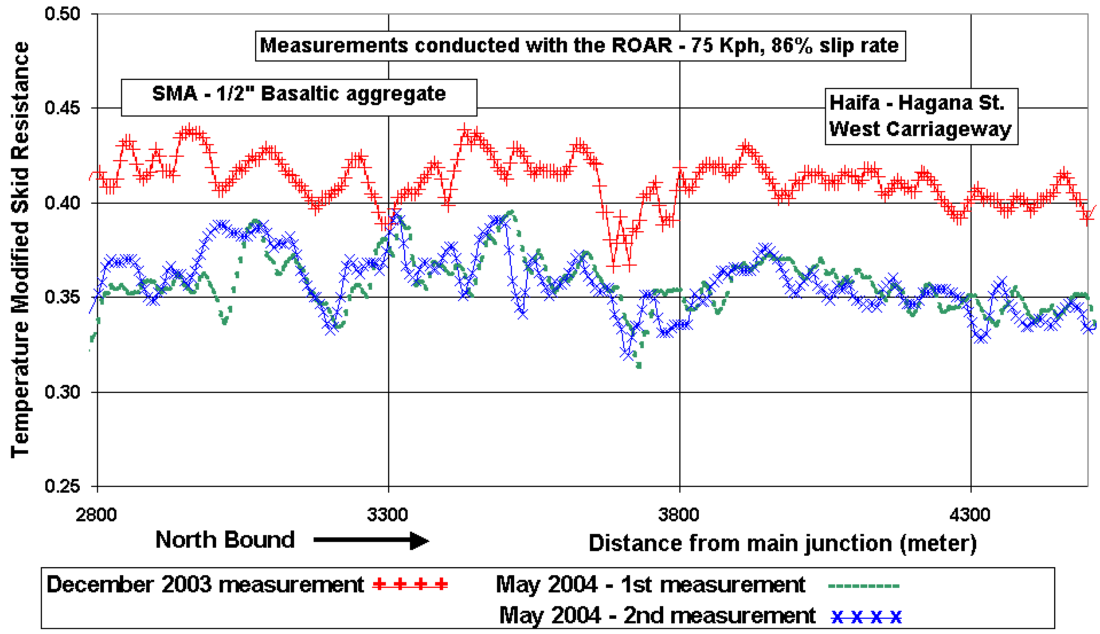

Figure 2: Example of skid resistance decrease after about 2 months without rain

A final issue worthwhile mentioning regarding skid resistance in Israel is the soundness of pavement structure. In the early 1990's, the Israeli PWD adopted a new pavement design method. The main characteristic of the new method (Ref. 4) was an increased thickness of the asphaltic layers relative to the older method. Since then, many of the newly constructed or rehabilitated interurban roads were paved with 15-25 cm of asphalt layers. The above change greatly reduced the deterioration rate of the pavement surface, mainly the development of fatigue cracks. On the other hand the polishing rate of the road surface increased continuously, due to higher traffic volumes and traffic loads. These led to a situation in which many roads got slippery while maintaining a sound condition in every other respect. The combination of the above phenomenon and the insufficient awareness of the skid resistance issue raised the severity of the problem.

3. ADOPTING A NEW MEASURING DEVICE AND NEW MEASURING PROCEDURES

SR monitoring was the first step in the process of reorganizing and restructuring SR management in Israel. As stated above, the former locked wheel-testing device was inoperative. Thus, it was decided to conduct a literature survey in order to determine the preferred type of device and testing procedures.

The recommendations of the literature survey (Ref. 5) were implemented in a tender for SR testing services for the PWD. The specifications included various requirements regarding the testing device, testing procedures, quality control procedures and more. The tender allowed two types of equipment, locked wheel ASTM E274 devices and the Norsemeter ROAR.

The results of the tender process ended choosing the ROAR as the new SR testing device. The main advantage of this type of equipment (among commercial devices in the market in the year of 2000) was the ability to perform continuous measurements at high skidding velocities.

The main reason for the high skidding velocity requirement was the need to get information about the SR generated during emergency braking of high-speed vehicles. It is believed that this critical moment should dictate the needed values of SR.

When measuring SR at low skidding velocities, it is necessary to assume macrotexture depth in order to estimate high speed SR (according to most models, like the PIARC model, Ref. 6). In Israel, many of the existing roads surface layers are still composed of low macrotexture densely graded asphalt mixtures (the use of SMA and other SHRP type asphalt mixtures began only about 8 years ago). Where the macrotexture depth is about 0.5-mm, the difference between the SR at low skidding velocities and high skidding velocities may be very significant. Measuring high velocity SR provides the critical SR values in a direct manner, without the need to measure macrotexture depth and make use of various model estimations.

Specifically, the vehicle towing the ROAR is operated at 75 km/h, while the ROAR is set at 86% fixed slip mode, which gives 64.5 km/h skidding velocity. It is worth noting that:

- The required skidding velocity is almost identical to that of the ASTM E274 locked wheel equipment (40 miles/h – 64.4 k/h).
- The slip rate of 86% is the same as that used in the Netherlands with the DWW (Ref. 7).

Other important operating specifications included:

1. Water film depth of 0.5-mm
2. Smooth test tire, conforming to ASTM E-1551.
3. SR data is obtained every about 5 m and averaged over sections of 125 meters (recently changed to a more convenient 100-m sections).
4. General SR surveys of the road network must be conducted during the first 3-4 months of the year. This was required in order to avoid the influence of contaminants on the SR values. The winter-spring surveys are designed to cover about 30% of the road network each year. In addition, special surveys are conducted at the end of summer. These surveys are conducted on road sections that might be suspicious of greater than usual

contamination (for example, vicinity of quarries, large volume of agricultural crop haulage and more). Road sections that have very low SR are treated before the rainy season, detailed as follows.

4. THE DECISION PROCESS ON THRESHOLD SKID RESISTANCE LEVELS

4.1. GENERAL

Since the Israeli PWD decided to adopt new testing device and testing procedures, it was necessary to decide upon allowed threshold values of SR. This step was obviously a crucial one in the process as a whole. It must also be noted that this step was conducted under hard restraints of time and budget.

One of the main obstacles in the process was the inability to use other types of testing devices that are used elsewhere, in order to compare, harmonize, and eventually help to derive the Israeli SR threshold values. The only exception to the above was the British Pendulum tester, which could be of limited help due to its inherent limitations.

The process consisted of the following steps:

- A survey of the various SR threshold values and related testing techniques in other countries. One of the reasons for this step was to get some idea about the range of values sought for, especially in comparison to other countries that use high skidding velocity testing.
- Use of other countries threshold values, in conjunction with the PIARC model, in order to try and "harmonize" SR threshold values from different countries.
- Conducting field-testing of the ROAR in the new testing mode, along with:
  - British Pendulum testing
  - ROAR measurements, conducted in "SCRIM mode" (34% fix slip at 50 km/h)
  - Sand Patch test for the evaluation of macrotexture depth.

  The use of the other tests was conducted in order to try and correlate the SR values through the PIARC model, and obtain PIARC parameters for the new mode of operation of the ROAR.

4.2. F60 VALUES THAT CORRESPOND TO THRESHOLD SKID RESISTANCE

Table 1 (from Ref. 7, 8 and more) depicts some details regarding known SR testing techniques and SR threshold values. All the devices in table 1 participated in the PIARC experiment and have associated parameters in order to derive IFI values (Ref. 6, 9).

The data in table 1, in conjunction with the PIARC IFI model, was used to calculate for each record in table 1, the theoretical F60 values that are required in order to have adequate SR values at each level of macro-texture depth.

Figure 3 summarizes the results of the above analysis. For example, a surface having SR value of 50 BPN (an average threshold value, slightly under the recommended value for major highways in UK and the value required in Switzerland for highways, Ref. 10) has a good F60 value if the macrotexture depth is 2-mm, but a very poor F60 value, if the macrotexture depth is about 0.4-mm. It should be noted that similar behavior characterizes all low velocity SR testing devices. The picture as a whole depicts, for each value of macrotexture depth, the range of minimum F60 that is needed in order to provide adequate skid resistance.

Country	Device	Tire type	Skidding Velocity	Threshold Value
USA - various states	Locked Wheel	Ribbed	64 km/h	0.35
USA - various states	Locked Wheel	Smooth	64 km/h	0.2
UK	SCRIM	Smooth	20.5 km/h	0.45
UK	British Pendulum	Smooth	10 km/h	50
The Netherlands	DWW - 86%	Smooth	43 km/h	0.37
Germany	Stuttgarter Reibungsmesser	Ribbed	60 km/h	0.35

Table 1: SR testing devices and SR threshold values in various countries (Ref. 6, 9)

One should keep in mind that the above analysis has many limitations. Historically, threshold values were usually not decided upon by any mathematical analysis and seldom by any direct reference to macrotexture depth. Therefore, the present analysis does not reflect any desired situation, but a rough picture of the present state of affairs.

The general idea regarding the above analysis was to decide upon the Israeli SR thresholds in such a way that the theoretical F60 values would fit in the range of accepted values for the full extent of possible values of macrotexture depth.

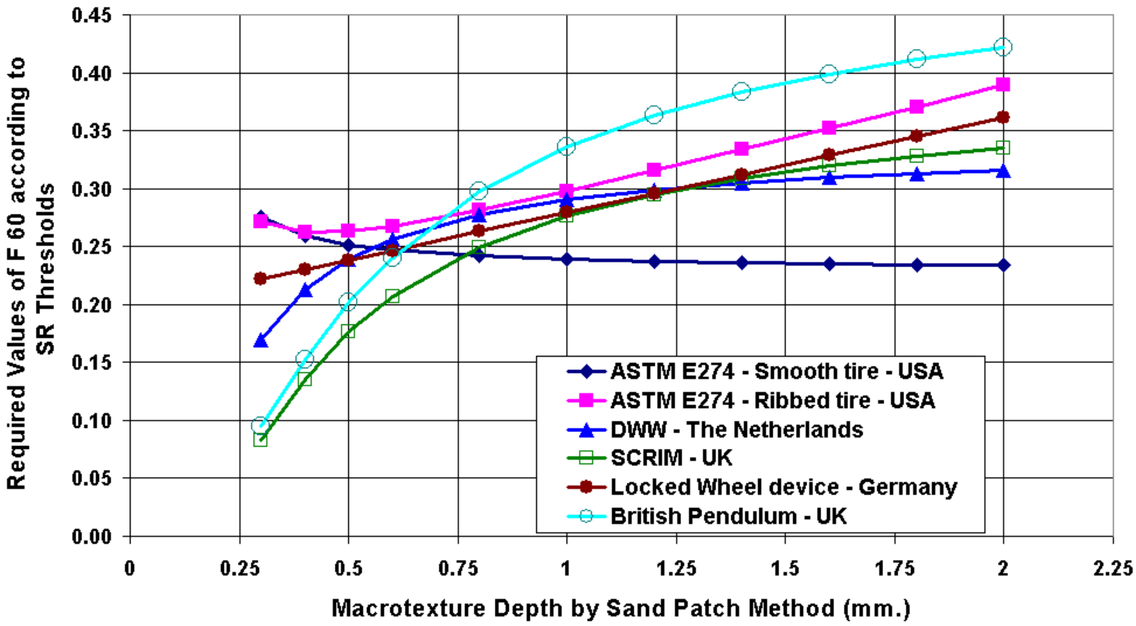

Figure 3: Required values of F60 according SR thresholds vs. Macrotexture Depth

4.3. DETERMINING THE PIARC MODEL PARAMETERS FOR THE ISRAELI ROAR

Budgetary and time problems did not allow a full calibration process according to Ref. 9 and others. Therefore, two calibration process were conducted by using existing equipment

1**. The British Pendulum**

The calibration process was performed in 6 different test sections, relatively a smaller amount than desired. Another point to be noted is that most test sections had relatively high macrotexture depth, leaving low textured road sections with a representation that is too small.

Figure 4 depicts the results of one of the test sections. The values represent the average of 4 consecutive runs with the ROAR and 30 British pendulum test points along the 1500 meter section. Additional 30 tests of texture depth were conducted by the Sand Patch method.

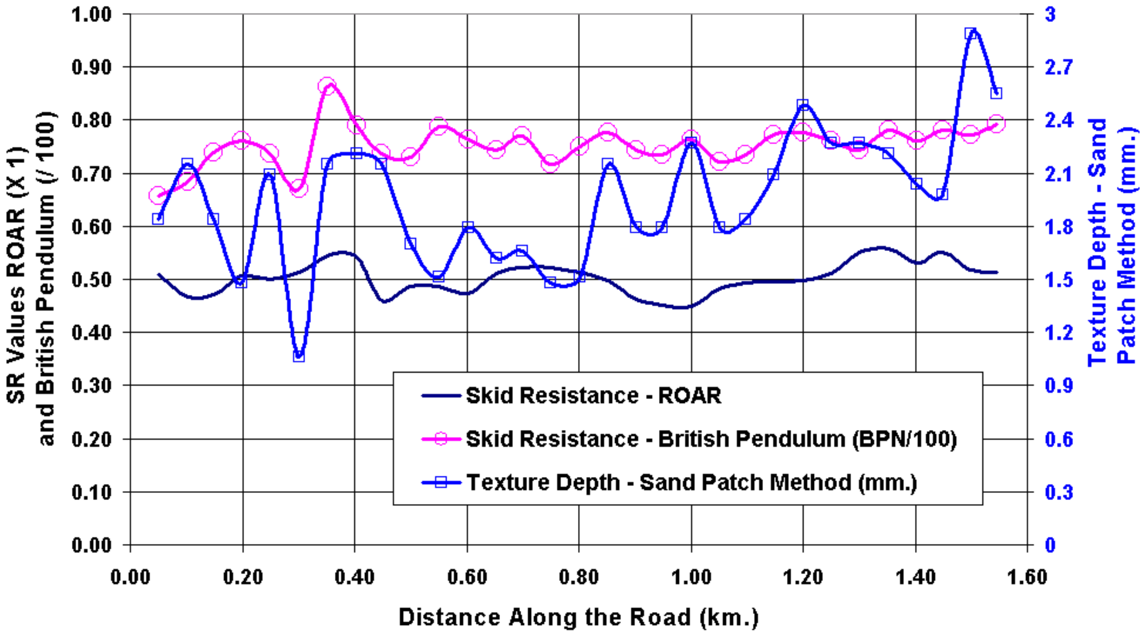

Figure 4: Results of SR measurements at a test section – Road no. 806

A regression process was then performed in order to find the A, B and C constants of the ROAR (working according the new Israeli method). The British Pendulum constants (derived at the PIARC experiment) were used to perform the regression, along with the total measurements made in the 6 test sections.

Specifically, at each point the F60 according to the British Pendulum was calculated and equated to the F60 obtained through the ROAR measurements. The regression process used least square methods to finds the A, B and C constants of the ROAR. Accordingly, the computed values of the ROAR were:

$$F60 = 0.11 + 0.81 \text{ X } FRS_{ROAR} \text{ X } EXP[(64.5-60)/S_p]$$

Where:

- PIARC Model Constants: **A=0.11, B=0.8, C=0** (the constant C was set to 0 as all smooth tire devices, Ref. 6)
- FRS_{ROAR} – The SR measured by the ROAR
- S – skidding velocity of the ROAR = 64.5 km/h

Figure 5 shows the distribution of the results and the difference between the F60 according to the British Pendulum vs. the F60 predicted by the "Israeli" ROAR (with the new PIARC constants). The R^2 of the results is 0.64.

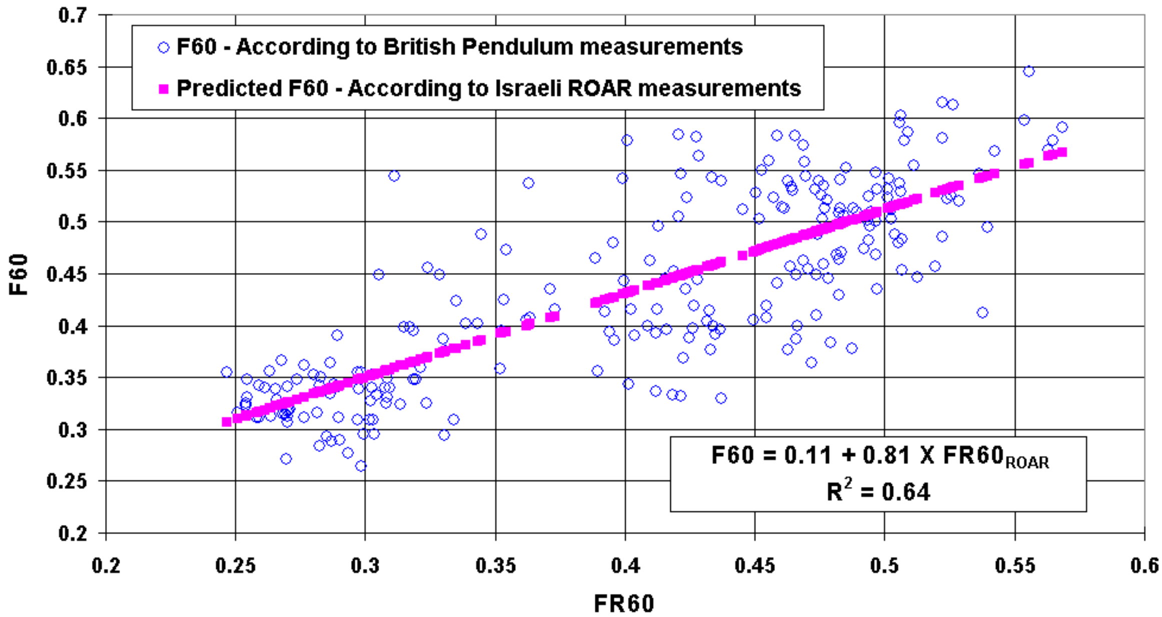

Figure 5: Distribution of results – IFI constants of the ROAR through regression process with the British Pendulum

2. The ROAR operated in "SCRIM mode".

The ability to operate the ROAR in various modes allowed a comparison of results with tests that were conducted elsewhere in other modes of operation. In the specific case, Ref. 11 and 13 suggest the following connection to convert ROAR SR values (driving at 50 km/h, at 34% slip ratio and with 0.5-mm water film depth) to equivalent SCRIM values. The equation is:

$$ESC = 0.12 + 0.55 \times \mu$$

Where:

ESC - Predicted SR by the SCRIM

μ - SR value measured by the ROAR at the above mode of operation

Accordingly, the following steps were undertaken:

A. During the measuring phase of the test sections, parallel measurements were made by the ROAR at 50 km/h, 34% fixed slip and 0.5-mm water depth. Figure 6 depicts the results obtained at one of the test sections.

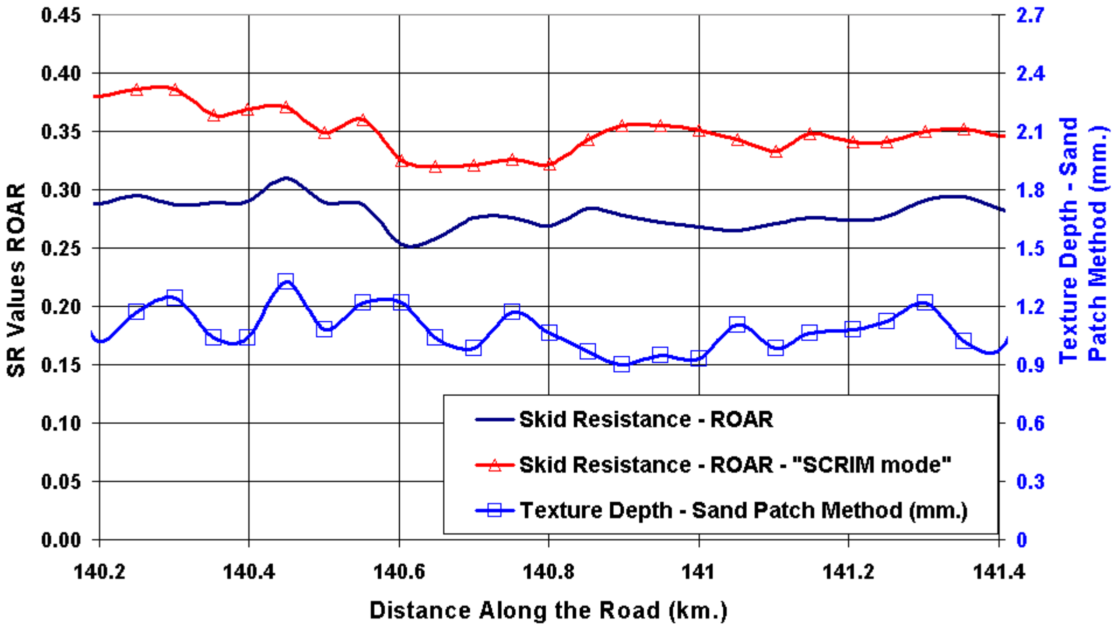

Figure 6: Results of SR measurements at a test section – Road no. 4

B. The results were converted to SCRIM values by use of the above equation.

C. During this stage the results were treated as if they were the results of a SCRIM device. The same procedure that was enacted in the case of the British Pendulum was repeated in this case. The only problem was to find the PIARC constants of the New Zealand SCRIM. In that matter Ref. 12 was of help. The values were extracted by regression from table 1 of the above reference (which includes SR investigatory levels in IFI terms). The PIARC constants of the SCRIM were: A = 0.013, B = 1.17, C = 0.

Once again a regression process was performed and the resulting equation was:

$F60 = -0.016 + 0.96 \times FRS_{ROAR} \times EXP[(64.5-60)/S_p]$

Where the values of the PIARC Model Constants are: **A=- 0.016, B=0.96, C=0**

Figure 7 shows the distribution of the results. The R^2 of the results is 0.88, better than the result obtained with the British Pendulum.

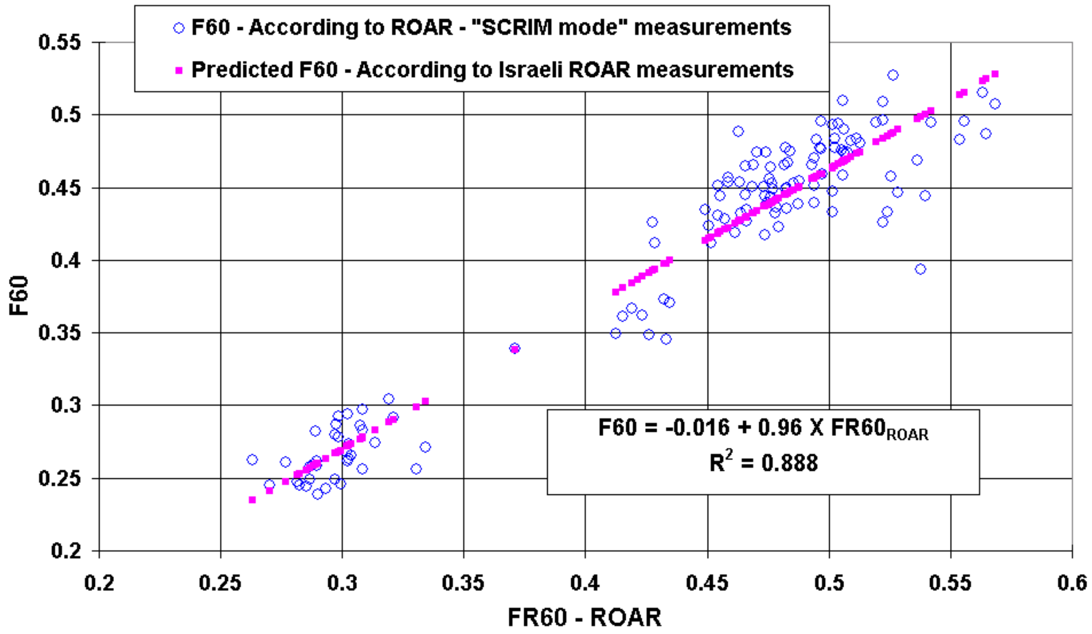

Figure 7: Distribution of results – IFI constants of the ROAR through indirect regression process with the SCRIM

4.4. COMPARING THE ISRAELI ROAR WITH OTHER SR TESTING TECHNIQUES

The results of section 4.3 were used to facilitate the decision process of the Israeli SR threshold values. Figure 8 depicts the “envelope” of threshold values obtained earlier in section 4.2. The “envelope” shows the range of minimum “required” F60 values for each value of texture depth.

On the same figure, the F60 values obtained by the Israeli ROAR new IFI equations are shown, both for a tentative SR threshold value of 0.25. Each point on these curves shows the minimum value of F60 that will supply (at a given texture depth) SR values conforming to the threshold value.

As can be seen, the F60 values obtained through the B. Pendulum regression are higher than the values obtained by the “SCRIM” regression. The equation obtained by the “SCRIM” regression yields values that are very close to the lower border of the “SR threshold envelope”.

Choosing a lower value of SR threshold could bring the F60 values according to the “SCRIM” regression to values that are lower than the lower boundary of the “envelope” of threshold values. On the other hand, choosing a higher value of SR threshold yields F60 values that are much higher than those required in most other places (especially according the B. Pendulum regression). Consequently, it seems that the 0.25 SR threshold value could provide an adequate initial value for the Israeli road network.

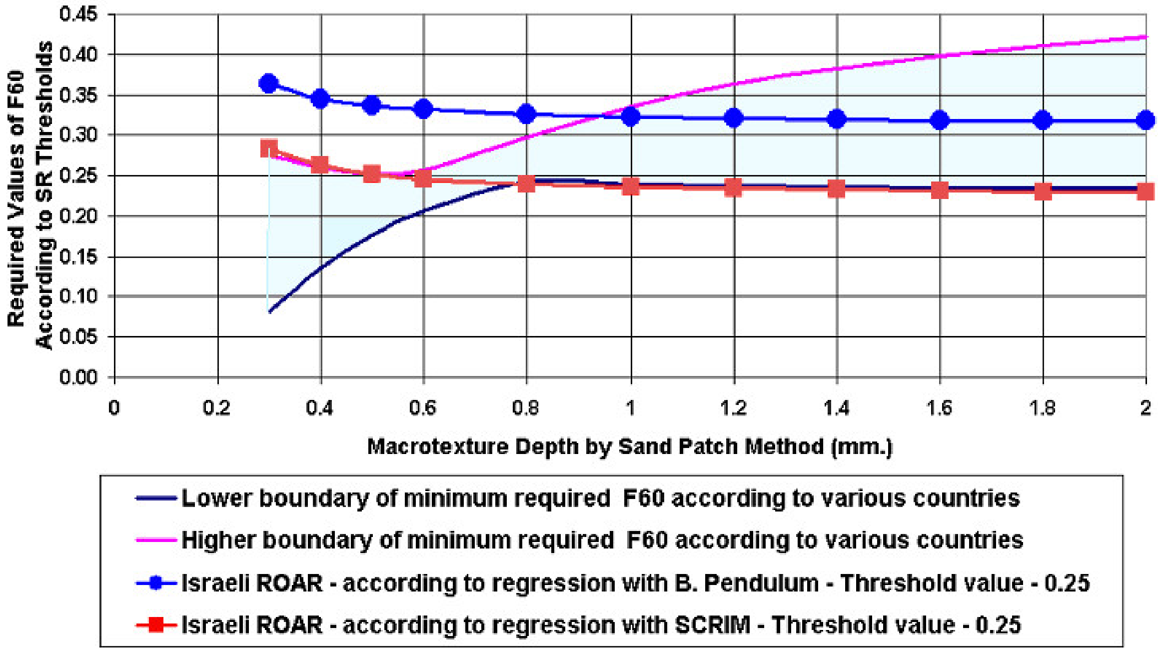

Figure 8: The "SR Threshold Envelope" and the required F60 values according to 2 ROAR IFI equations and a threshold value of 0.25

4.5. THE CHOSEN INITIAL SR THRESHOLD VALUE AND SOME RESERVATIONS

It has been shown in numerous cases (ref. 13, 14 and more) that better SR provides more safety to the drivers. Obviously, SR threshold values are therefore determined in order to provide the drivers with a relatively high resistance to skidding at all times. On the other hand it is obvious that SR threshold values do not provide the driver with a skid free environment. Usually the process of choosing the appropriate SR threshold attempts to take into consideration many other aspects, such as budgetary and technological limitations, noise of vehicles, deterioration of tires, and more.

The initial Israeli SR threshold value was chosen to be 0.25, according to SR obtained by the ROAR (operated according to the Israeli mode of operation). Apart from the above analysis (which certainly has its limitations), the following reasons led to the decision:

A. The SR values of new road sections in Israel (even with basalt aggregates) are frequently in the vicinity of 0.4 (about 6 month after construction). Choosing a threshold value that is too close to 0.4 will put the system in an unbearable situation.

B. As will be detailed ahead, the general 2003 survey revealed that about 16% of the Israeli road network was substandard, according to the 0.25 threshold value. In such a situation a lot of work has to be carried out in order to promote the network.

Some additional reassurance was that the chosen SR threshold value is very close to the values required in the US for locked wheel devices that test with a smooth tire and with the same skidding velocity (0.20 - 0.25).

It should be stressed that the chosen value is regarded at this point as an initial threshold value. Further steps planned to be held in order to "fine tune" the threshold values include:

– Adopting adjustments to the basic threshold thereby requiring higher SR values on special road sections, such as roads with high traffic volumes, sloped and tightly curved road sections etc. An initial work has already been finished and its recommendations are studied by the PWD.

– Further research on skid resistance vs. wet weather accidents is planned in the near future. Part of the expected outcomes of the research will be the reconsideration of adjustments of the SR thresholds.

5. THE FIRST SURVEYS CONDUCTED WITH THE NEW EQUIPMENT

5.1. WINTER-SPRING SURVEYS

The first comprehensive survey of the Israeli interurban road network was conducted during the first months of 2003. The survey included more than 4500-km of roads, about 85% of the road network. Every road was measured at least in one direction. Dual carriageways were measured in both directions, usually on the right lane. The measuring wheel was positioned on the right wheel path, about 80-cm from the right edge of the lane.

Figure 9 depicts the general results obtained in the survey. The results show that about 12% of the road network has substandard skid resistance and has to be treated. About 29% have medium values of skid resistance, in the range of 0.25 to 0.35. In the cumulative representation of the results it can be seen that if the threshold was set on 0.30, about 28% of the road network would be labeled as substandard.

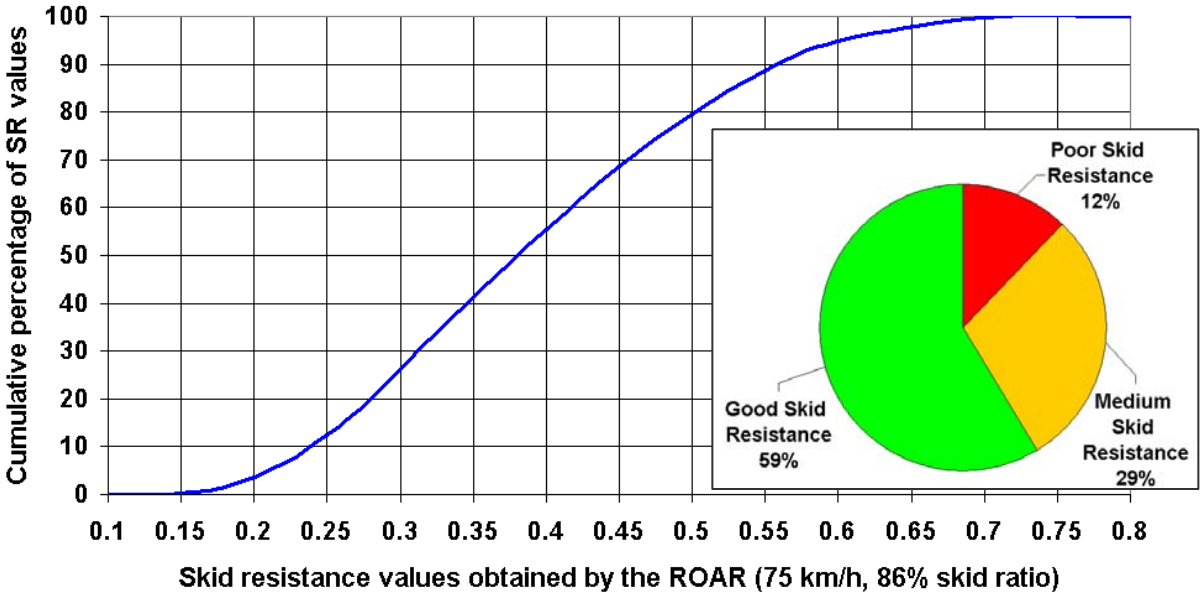

Figure 9: Summary results of the general 2003 winter-spring survey

One of the most interesting results of the survey was the large number of major roads that had deficient skid resistance. The Israeli road network is divided into four levels of roads. The most important high volume roads are generally labeled by a one-digit number (like road no. 1 from Tel Aviv to Jerusalem). Two digit roads are generally large volume roads, while the three and four digit roads are roads of lesser importance and lesser traffic. Figure 10 depicts the survey results on each of the road levels. The worst results were obtained on the one-digit roads, with 19% substandard skid resistance. 14% of the two digit roads had substandard skid resistance. The lesser important roads, which are usually maintained at a lower standard, showed a much better performance with only 8% with substandard SR.

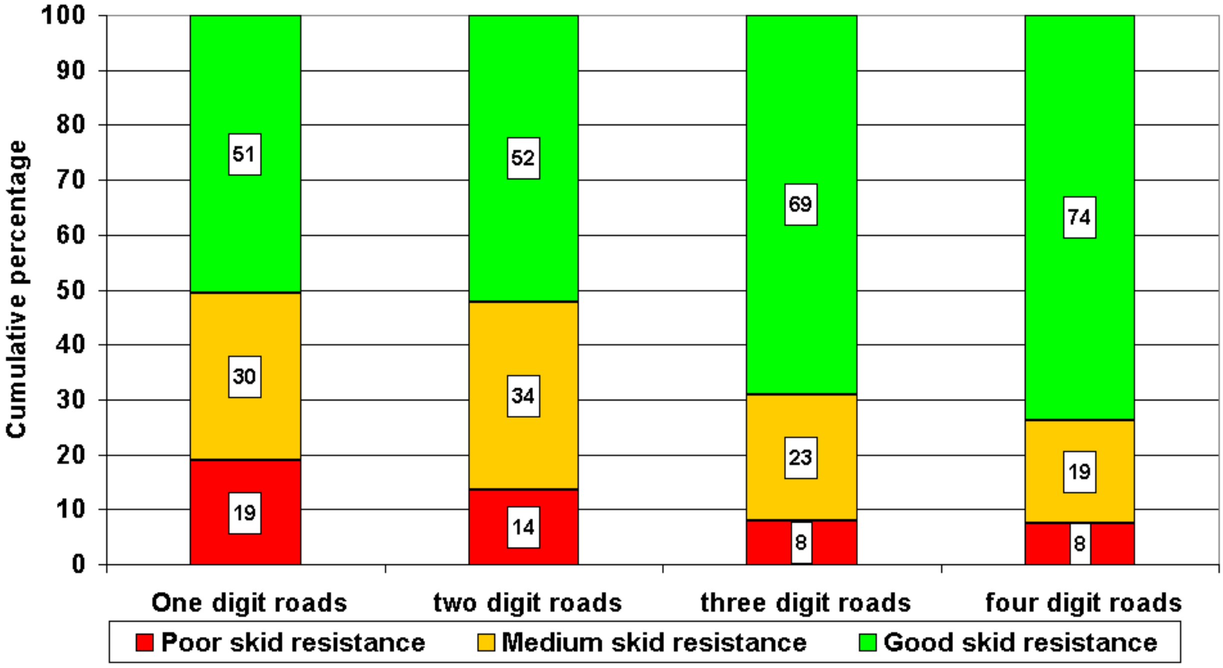

Figure 10: The results of the general survey sorted according to road class

The above phenomenon exhibits the destructive polishing effect of the traffic on the pavement surface. The higher-class roads are usually better maintained and the asphalt wearing course usually contains basalt aggregates. In spite of that, the average skidding resistance of these roads is substantially worse than the rest of the network.

The results of the comprehensive survey initiated an intensive effort of the PWD to improve skid resistance of the problematic road sections. At this stage, the PWD was already ready with three new methods to improve SR of existing road sections (as will be detailed ahead).

During the first months of 2004, a second winter-spring survey was conducted. The survey encompassed about 40% of the road network. Presently, the Israeli PWD plans to cover the whole network during every three years cycle.

5.2. END OF SUMMER SURVEYS

Two end-of-summer surveys were conducted up to the present, in 2003 and in 2004. Each survey included about 600 to 800 km. of road sections that were estimated as being contaminated to a dangerous degree. The main reasons that are used to decide upon the road sections to be tested during these surveys are:

1. Road sections that have SR values close to the threshold value, i.e. less than 0.3. Any change in the SR due to contamination may result in a substandard SR.

2. Road sections located in the vicinity of contaminating sources. Examples are quarries, trails of vehicles carrying agricultural crops, and more.

The results of the end-of-summer surveys were used in order to take action before the occurrence of the first rains. The main practical step used was the water blasting method, activated in a cleaning mode, which enables very fast and effective results. Details about the method are given below. Before beginning a cleaning process at a certain road section, verification has to be made, to assure that the contaminants are the cause of the low SR. On other road sections that cannot be treated until the first rains, the PWD still uses large warning signs that alert the passing drivers of the slippery wet road section.

6. NEW TECHNIQUES ADOPTED FOR IMMEDIATE TREATMENT OF DEFICIENT ROAD SECTIONS

6.1. GENERAL

Even at the beginning of the present process, a long time before the statewide SR survey, it was evident that the results of the survey would reveal a substantial number of road sections that have insufficient SR.

For economical, budgetary and other reasons the option of resurfacing every slippery road section was obviously ruled out. Posting warning signs along the roads can provide a very limited and even questionable solution. It became obvious that new techniques, which were never used in Israel at that time, need to be employed, in order to:

- Allow the treatment of a large number of road sections in a short time and at relatively low costs.
- Provide a solution for roads that are slippery, but sound in every other aspect.

Beginning in 2001, three new techniques for the surficial treatment of asphalt road sections were implemented in Israel. All methods improve the SR of the asphalt surface, by one or more of the following:

A. Deepening the surface macrotexture, thereby improving the drainage of water from the tire-pavement interface and increasing high-speed SR.

B. Revealing new and fresh surfaces of the coarse aggregates of the asphaltic mixture, thus improving the microtexture SR of the surface.

C. Removing the surface layer including excess bituminous material, various contaminants etc.

The following sections summarize the general working principles and the accumulated experience with the newly adopted techniques.

6.2. WATER BLASTING

6.2.1. General description

Water blasting techniques are used in various civil engineering fields, usually for the controlled removal of materials having different resistance to the power of water jets. In road maintenance, some variant of water blasting has been used for many years, for the purpose of rehabilitating the acoustic and drainage properties of porous asphalt. Another example is the removal of rubber from airfield landing and take-off strips.

The use of water blasting for SR restoration of pavements has already been performed in some countries for several years. The usual use is improving the macrotexture of asphalt surfaces by removing excess amounts of binder material (ref. 15, 16).

The general principles of the equipment that is used in Israel (other types of equipment are usually based on the same principles) are:

- Revolving water sprinklers spray high-pressure water of up to about 1000-atm on the asphalt surface. The sprinklers spin constantly at a high speed, a few centimeters above the pavement and the water jets are directed toward the surface at a specific angle.
- The sprinkler system is placed under a special hood. The hood allows the proper performance of a high capacity vacuum system, which sucks the water and the material removed from the pavement, back into a large container. The hood is also used for safety reasons, in order to prevent the highly dynamic water and particles to be sprayed or flinged on people or passing vehicles.

Figure 11 depicts pictures of one of the water blasting trucks that presently work in Israel. The truck has large containers for fresh water and for “used” water that was vacuumed from the road surface during the working process.

Figure 11: General view of a water blasting truck that works in Israel

First experimental use of the water blasting equipment commenced at the end of 2001. Presently three different water-blasting machines operate in Israel. The water blasting trucks are used for two main purposes, as detailed below.

6.2.2. Macrotexture improvement or water retexturing

In that mode the truck is operated at very high water pressures, up to 1000-atm. The high-pressure water jets remove the less durable upper bitumen film, sand and fine aggregates at the upper part of the wearing course, along with various contaminants. The use of this method was experienced in several types of asphalt mixtures that are used in Israel.

After about three years of experience, the main conclusions regarding this type of treatment are:

A. The method can be successfully used for the improvement of asphalt mixtures that are based on a strong “skeleton” of coarse aggregates. In such mixtures, like the

SMA, or SHRP based mixtures. The process is very efficient in removing excess quantities of bitumen (a common problem with SMA mixtures) and restoring the original texture depth. Figure 12 shows an example of a road section treated by water retexturing on December 2002 due to inadequate levels of SR. The wearing course is ¾" SHRP type basaltic asphalt mixture. As can be seen, the SR values remain high more than a year after the treatment and according to the rate of SR degradation, another treatment is not necessary for at least another year.

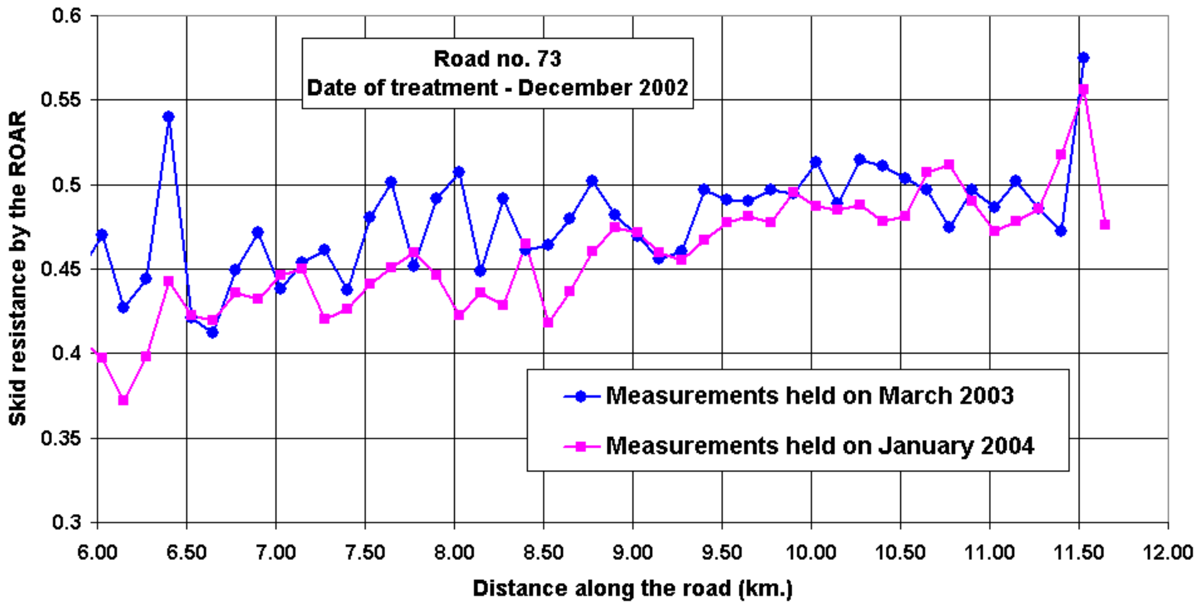

Figure 12: Skid resistance results on a road section treated with water retexturing

B. The water retexturing method is much less adequate in the case of densely graded asphalt mixtures. Due to the structure of the mixture, which lacks the "stone to stone" contacts (of the coarse aggregates in the mixture), the effects of the treatment can hardly be controlled. A little less energy (lower water pressures or higher speed) can provide only minor improvement of texture depth, while a little more energy can easily result in substantial damages to the surface. Furthermore, the durability of the treatment on these asphalt mixtures is usually short, in most cases no more than several months.

Water retexturing can be a useful method when used in the right places. Caution should be exercised when the surface is characterized with segregation or open cracks. The method requires tight inspection in order to achieve the best possible results under a given situation. Up to the end of 2004, about 400,000 m2 were retextured by this method in Israel.

6.2.3. Water blasting for contaminant removal

The same water blasting equipment is used for the removal of contaminants from the road surface, especially before the beginning of the rainy season. This technique is the main short-term solution to the problem of FRSA. In addition, the Israeli PWD uses this technique to treat road sections that were contaminated by accidental or unintended events, such as oil or other liquid spillage from vehicles. Another use that was recently introduced for environmental reasons is cleaning road sections that are close to water reservoirs. This action is also taken before the rainy season, in order to prevent various harmful materials to penetrate the water system.

The water blasting equipment is operated at much lower water pressure (usually up to 500-atm) and the truck is moving at a relatively high speed. The daily production can mount up to 10,000 m^2 and more.

Quality control of the process is essentially based on measuring the SR after the cleaning process. At each point, two sets of measurements are performed with a British pendulum. In between the two sets of measurement, the measured points are scrubbed by hand with water and a brush with plastic bristles. If the results of the two measurements differ by more than 2-3 BPN, there is an indication that the cleaning process was not performed properly and should be repeated.

The durability of the contaminant removal process is relatively short and depends on the intensity of recontamination of the surface. Up to the end of 2004, more than 1,500,000 m2 of road surface were treated using this method.

6.3. FINE MILLING

Fine milling is performed by the same milling machines that are used in pavement rehabilitation for the controlled removal of asphalt layers. In fine milling, the main drum is replaced by a finer one, which can produce relatively smooth surfaces. The milling process removes the upper layer of the asphalt pavement, thereby exposing “fresh” and unpolished aggregates, and creating a new surface texture. The macrotexture depth attained is close to 2-mm, according to the sand patch method. This value is much higher than the one attained by the other methods used in Israel.

Figure 13 shows examples of treated asphalt pavements. Usually the depth of milling can be limited to about 1-cm. However, when the existing pavement is uneven (due for instance to minor ruts), milling has to be deepened in order to prevent the appearance of untreated spots. The above is due to structure of the milling drums, which perform the milling in straight lines.

Figure 13: Examples of the results of a fine milling retexturing process

As a result of the large texture depth, the durability of the fine milling method is the largest of all other methods tested in Israel. The process of texture re-flattening by the combined effect of hot weather and vehicle load takes longer in pavements treated by fine milling. Figure 14 shows an example of SR values of a road section (3/4” basaltic densely graded asphalt mixture), treated by fine milling. Even after more than a year and a half, SR values remain high.

On the other hand, the texture attained by fine milling is rougher than the other retexturing methods tested in Israel. Traveling at high speeds (more than 70-80 km/h) on these pavements is noisier and less convenient. In addition, in many road sections it was very hard to get a fully treated surface, due to unevenness of the old pavement. In such cases the daily production was lower (than the average of about 4,000 m^2) and the depth of milling was much higher than the typical average depth (thereby damaging the pavement structural strength).

Accordingly, it was decided to restrict the use of this method to particular road sections, especially high sloped roads or roads that have tight radii. These places usually have low driving speed limits, so the decrease in driver's comfort is insignificant.

The inspection of fine milling process should ensure that the whole area is treated and on the other hand, that the milling will be as shallow as possible (in order to minimize damage to the pavement).

Up to the present, the fine milling method was used in Israel to a relatively small extent, about 250,000 m^2 in total.

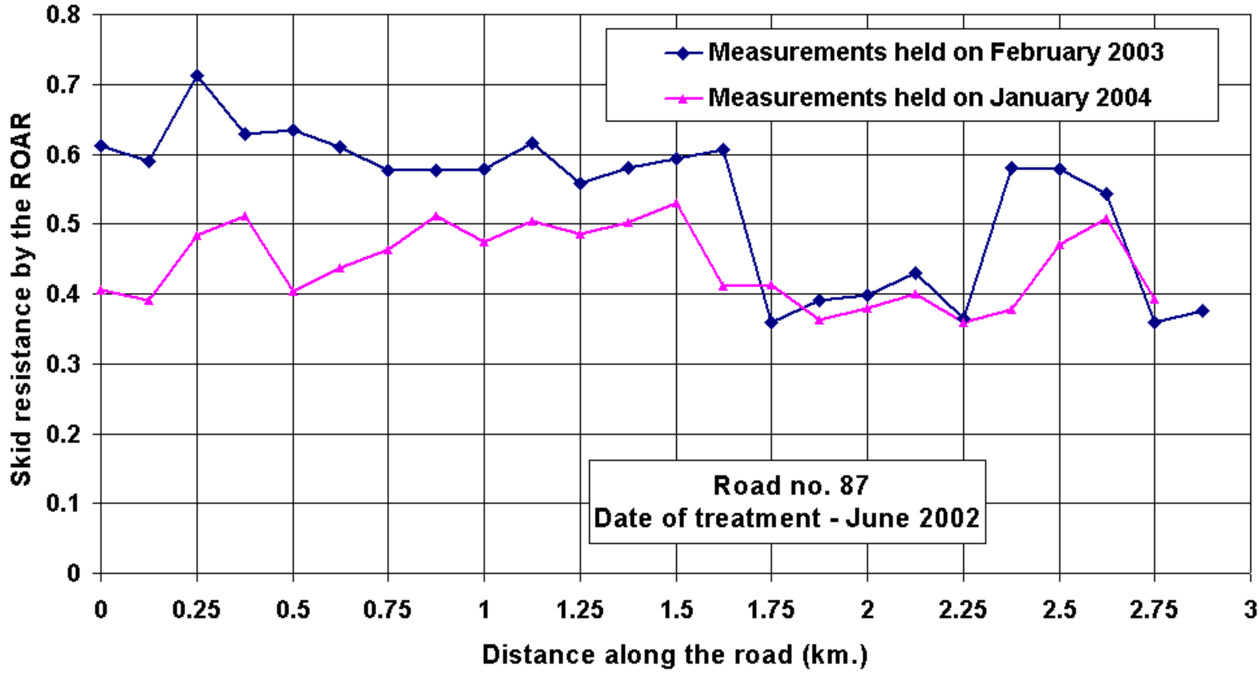

Figure 14: Skid resistance results on a road section treated with fine milling

6.4. ROTATING DISCS

Rotating discs, or disc hammering, was the last retexturing method that was implemented in Israel. The first trials commenced in the autumn of 2002. Quite soon this method became the most widely used of all the above-mentioned methods.

The main principles of the method are depicted in figure 15. Metallic discs revolve freely around each of six secondary axes, which in turn revolve around the main axis. Each disc is loosely mounted on the axis, so it is capable of dynamically "bouncing" on the road surface and perform the retexturing action.

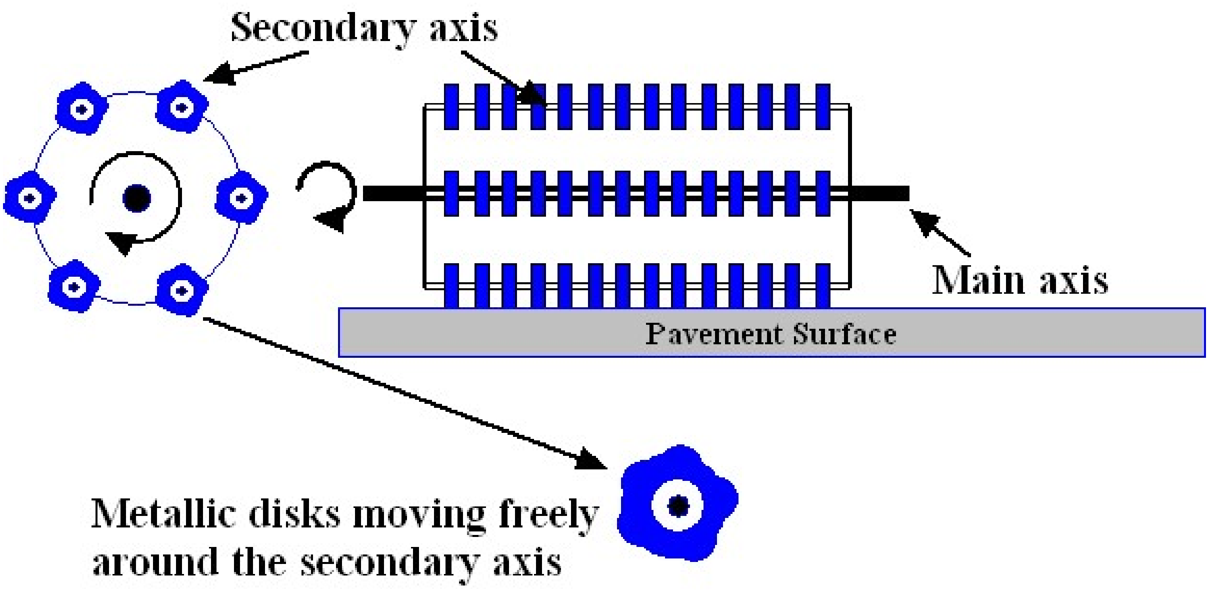

Figure 15: Schematic description of the Rotating Discs mechanism

The width of each element that is shown in figure 15 is about 30-35 cm and its height above the surface can be controlled. About six of these elements put in a row make a total effective width of almost 2 meters. In general, the machine is relatively much lighter than the fine milling equipment.

Due to the ability to adjust the height of adjacent elements (each, about 30 cm in width) and the free movement of the individual discs, the method can usually treat most surfaces, including uneven pavements.

As with the fine milling, a mechanical broom should follow the retexturing machines, in order to clean the pavement. However, the amounts of material that are removed from the surface are much smaller, usually no more than 2-3 mm. Figure 16 shows an example the working process and the attained surface of the road.

Figure 16: The Rotating Discs process at work and the attained surface

The Rotating Discs method provides a new pavement texture of about 1-1.2 mm. When retexturing densely graded asphalt surfaces that tend to flatten in time, the durability of the process is much higher than water retexturing and shorter than fine milling. Figure 17 depicts an example of SR results of a treated road section, having a densely graded 1" Dolomitic wearing course.

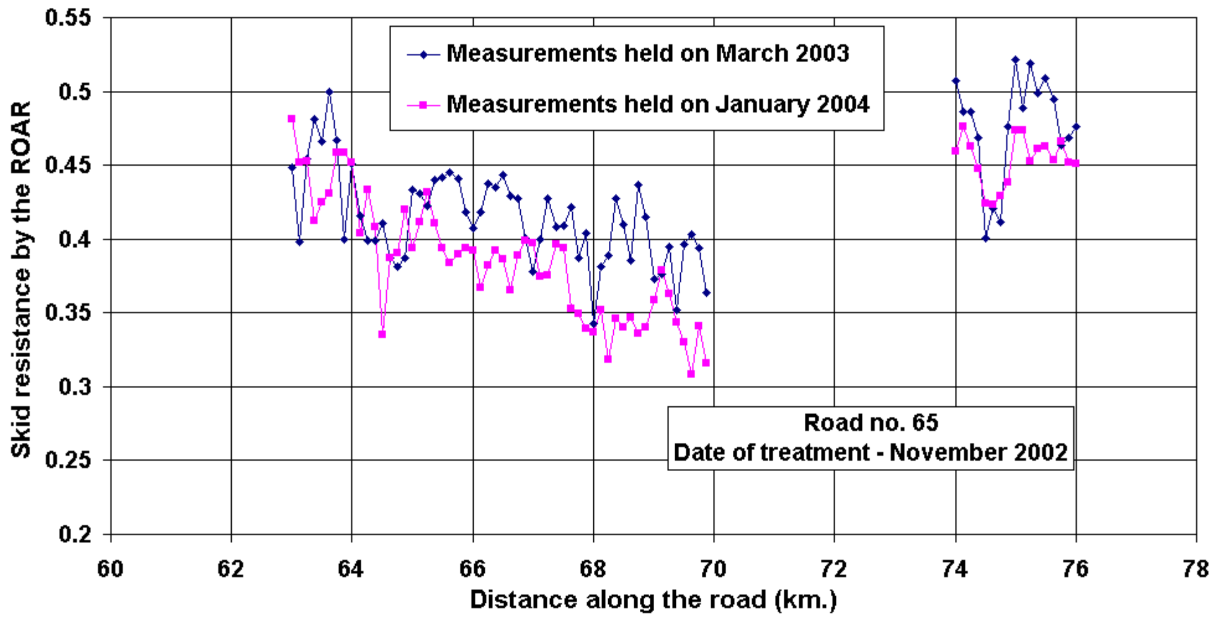

Figure 17: Skid resistance results on a road section treated with the Rotating Discs method

The Rotating Discs process proved to be the most successful one in Israel. Up to the present more than 2,500,000 m^2 of surfaces have been treated by this method.

6.5. CONCLUSIONS REGARDING THE VARIOUS TREATMENT METHODS

Usually, the best way to treat a road section that has a deficient skid resistance is to have it resurfaced. Resurfacing can be obtained by many techniques, including chip seal, microsurfacing, various thin open graded mixtures and of course conventional overlaying by various possible asphalt mixtures. Most resurfacing techniques will improve SR as well as other deficiencies of the pavement and will enhance the appearance of the pavement and the driving comfort.

In some occasions there is a need to improve the skid resistance of road sections that are totally sound in every other aspect except SR. In these cases (like for instance SMA with bleeding problems) retexturing techniques may prove to be the most appropriate and less expensive solutions.

During the last years effort, the PWD had to prepare several methods at hand, in order to cope with large amounts of road sections that had to be treated. In such a situation, resurfacing of all problematic road sections was not an option, due to budgetary limitations. In this case, the retexturing techniques provided a very important means, at least as temporary measures.

Three retexturing technologies have been implemented in Israel since 2001 and used in a large number of road sections in Israel. The main conclusions regarding the use of these techniques are:

A. Water retexturing can be used successfully in order to improve the texture depth of asphalt mixtures that have “bleeding” problems. The above is not relevant to densely graded mixtures, where the process can cause damages to the surface and has very temporary results. Water retexturing of coarse graded mixtures, gap graded mixtures and SMA mixtures, can be very useful and long lasting.

B. Retexturing of densely graded asphalt mixtures is only a short-term solution, mainly due to the hot Israeli weather. Heat and traffic loads tend to re-flatten the texture attained during the retexturing process. Of all processes, the fine milling seems to be the most durable one and the second best is the Rotating Discs method. The durability of the process improves with coarse and gap graded mixtures, due to the “stone to stone” contacts among the coarse aggregates.

C. The fine milling method produces the deepest texture and has the longest durability. The method cannot properly treat surfaces that have ruts or other smoothness problems. In addition, the attained texture is relatively harsh and is less suitable for high-speed road sections. The best areas to use this method are mountainous roads, which have speed restrictions. In these places the high traction provided by the deep texture is essential and less disturbing.

D. The Rotating Discs method can be used for the successful retexturing of most asphalt mixtures. The texture attained provides adequate SR and at the same time, the discomfort to drivers in terms of vibrations and noise is very small.

E. Contaminant removal by water blasting proved efficient in cleaning the road surface and hence alleviating skidding hazards during the first rains.

7. SUMMARY AND PLANS FOR THE NEAR FUTURE

About four years ago the Israeli PWD launched a large operation meant for the improvement and upgrading of the skid resistance of the Israeli road network. The operation included a series of major steps that deal with the monitoring of SR, analysis and evaluation of the results, and eventually, practical steps intended for the fast treatment of a large amount of deficient road sections.

The above operation provided the PWD with the tools to tackle the SR problem, increased the awareness of decision makers and established a standard mode of operation of continuous actions that keeps the problem under control.

In the future, the Israeli PWD intends to search for better solutions regarding the characteristics of wearing course asphalt mixtures. Special attention will be given to ensure the PSV of the coarse aggregates in the SMA and SHRP type mixtures that are extensively used in Israel for the last eight years. Additional effort is planned to be given to improved thin surfacing solutions, such as micro-surfacing, OGFC and more. This, in order to provide better durability of skid resistance, which will enable to cope with the extended durability of the pavement structure and the ever-growing traffic loads.

In addition, a statistical research has already been commenced in the aim of finding local relationships between skid resistance values and the rate of wet-weather accidents. This data is believed to enable the Israeli authorities to “fine tune” the selected SR thresholds according to more quantified safety targets.

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