STRUCTURAL DETERIORATION OF AC PAVEMENTS WITH AND WITHOUT STEEL REINFORCEMENT. IN FIELD EXPERIMENTAL COMPARISON.

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ABSTRACT

The paper focuses on the monitoring of an experimental stretch of road over a five year period in order to measure the effects of steel reinforcement on Asphalt Concrete (AC) pavement performance.

The experimental stretch of road was constructed in 2001 alternating sections with and without steel reinforcement. This paper presents the results regarding the effects of steel reinforcement that were obtained by monitoring the AC pavements with Non-Destructive Deflection Measurement Techniques (NDT) and comparing the performances of pavements with and without reinforcement.

Falling Weight Deflectometer (FWD) surveys were conducted on the experimental stretch immediately following its construction and after five years of service, in order to evaluate the modifications of structural capacity resulting from the presence of steel mesh. Using the FWD measurements deflection basin parameters, the AASHTO Structural Number and the Pavement Residual Life were evaluated.

In general, all the analyses confirm that the installation of road mesh produces a significant improvement in pavement performance. After five years of service an analysis of the pavement sections with steel reinforcement showed an extension of Residual Life by a factor of two when compared with the equivalent pavements without reinforcement.

Keywords: pavements, maintenance, rehabilitation, reinforcement, performance, monitoring

1. INTRODUCTION

The continual improvement in performance required from the road network and in particular from pavements has inspired research towards the study of new materials and technological solutions that can guarantee efficiency and durability.

To this end, macro-reinforcement techniques have been proposed as an effective solution to limit the cracking phenomenon on asphalt concrete layers and, consequently, to increase pavement service life.

Initial experience in the field of steel reinforcement of flexible pavements was gained in 1950, based on the general concept that reinforcement could provide the necessary resistance to tensile stress which characterized the hot-mix asphalt. However, this system was abandoned for a long time due to the installation difficulties encountered. Then, from 1980, above all in Europe, new interest was shown in this technique thanks to the considerable technological advances made in the production of meshes able to guarantee better working performance and installation procedures.

Most recent research confirms that the improvements in terms of pavement resistance brought about by the meshes are to be attributed more to the containment and interlocking capacity of the reinforced mesh-layer package than to any increase in structural capacity due to the membrane effect provided by the presence of the mesh (Busching, Elliott and Reyneveld 1970; Graf and Werner 1993).

Moreover, it has been concluded that the reinforcing steel starts to work when cracks begin to form in the HMA, but an evaluation of its effects on pavement performance is still uncertain at the present moment. As it is essential to quantify performance, in order to implement steel reinforcement mesh in new road construction and rehabilitation design, recent research has aimed at quantifying the contribution made by the steel reinforcement to the structural capacity and service life of the pavement.

Brown et al. (Brown, Thorn and Sanders 2001), based on semi-continuous laboratory fatigue-tests, reported that such grids could extend the fatigue life of an asphalt mixture by a factor of three. Moreover, based on strain measurements in pavement test sections with and without reinforcement, Said et al. (Said, Zarghampour, Johansson, Hakim and Carlsson 2002) indicated that steel netting might improve the pavement fatigue performance by a factor of two for the designs examined.

Experimental tests conducted at Virginia Smart Road on sections with and without reinforcement indicated that steel reinforcement would extend overlay service life against reflective cracking. This extension ranges from 50 to 120 % when a 50 to 150 mm overlay is applied to the cracked pavement structure (Elseifi, Al-Qadi and Leonard 2003). Furthermore, the experimental tests establish (Elseifi and Al-Qadi 2004) that the improvement provided by steel reinforcement is manifested primarily at intermediate and high temperatures, reporting a percentage improvement for a pavement with mesh contained in AC layers which ranges from between 10 % at 5° C to 260 % when a temperature of 40° C is applied.

Regarding the use of NDT techniques to analyze the contribution made by the reinforcement in terms of structural resistance, a previous study by the authors (Cafiso and Di Graziano 2003) highlighted how the experimental variability of data that usually characterizes FWD test results and the slight increase in structural stiffness due to steel mesh installation in the period immediately following construction does not allow statistically significant considerations to be drawn regarding an effective increase in pavement structural capacity. For this reason a FWD monitoring of steel reinforcement effects was carried out over a significant period of time to compare performances of pavements with and without reinforcement.

2. THE EXPERIMENTAL ROAD SECTION

In 2001, in order to verify the performance of reinforced pavement as compared to similar pavement without reinforcement, an experimental road section was constructed, alternating sections with and without steel reinforcement.

The experiment was carried out on a rural road (SS 121) in Sicily (Italy). The road has a single carriage-way with two 3.75 m wide lanes, and a 0.50 m wide shoulder, in each direction. The experimental stretch of road was constructed on an embankment, in the right-hand lane, covering a distance of 250 meters between kilometres 9+410 ÷ 9+160.

The experimental site was constructed as part of maintenance work which consisted in a partial milling and reconstruction of the existing pavement. The experimental section was subdivided, so as to have more than one comparison, using two kinds of mesh positioned at two different depths (8 and 15 cm), with a final scheme of the area under investigation as shown in Figure 1.

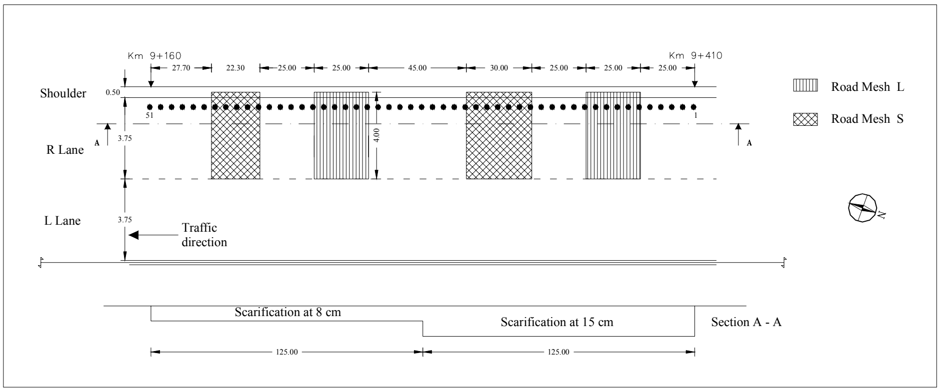

Figure 1: Plan of the Experimental Stretch of Road

Road Mesh® reinforcement was used, consisting of a double-twist, hexagonal double zinc-coated steel mesh which is transversally reinforced with steel wires. The characteristics of the two types of road mesh used in the experimental sections are shown in Figure 2.

Road Mesh Kind	Mesh opening [mm]	Distance between bars [mm]	Mesh diameter [mm]	Transverse steel diameter	k longitudinal [MN/m]	K trasversal [MN/m]
Strong	83.5	165	2.7	3.4	2.,7	11.5
Light	83.5	165	2.4	4.4	22.7	19.34

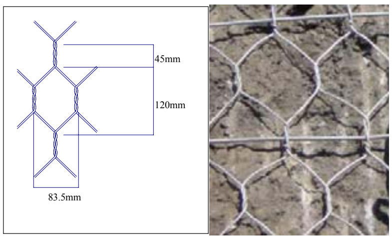

Figure 2: Geometrical and Technical Characteristics of the Used Road Mesh

3. PRE AND POST-CONSTRUCTION EVALUATION

In 2001, two Falling Weight Deflectometer (FWD) surveys (ASTM D 4694 1996) were conducted on the experimental section before (FWD_B01) and after (FWD_A01) pavement milling and reconstruction with the installation of the steel mesh, in order to evaluate the consequent variations in structural capacity produced by the installation of the reinforcement.

A Ground Penetrating Radar survey was also carried out in order to identify the total depths of the asphalt concrete (AC) layers (new and old) and of the granular foundations (Figure 3). At the same time the suitability of this technology as a means of discovering the presence of reinforcement and its displacement was tested, obtaining good results and adequate precision (Cafiso and Di Graziano 2003).

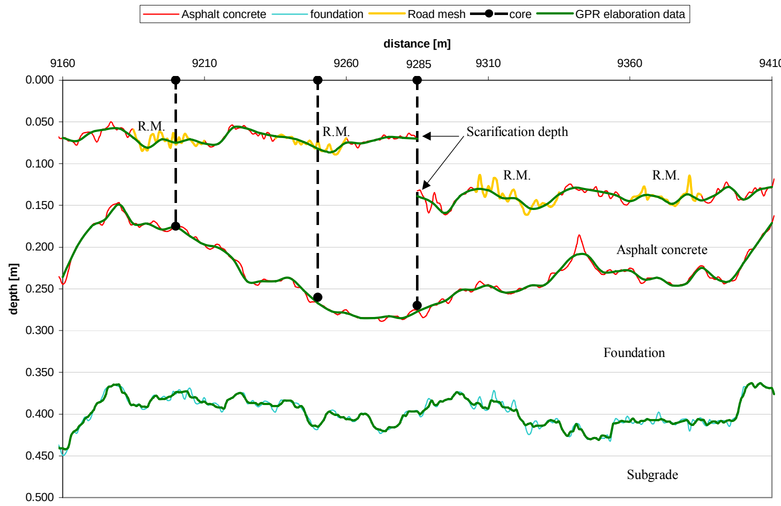

Figure 3: Layer Thickness of the Experimental Stretch of Road

Due to the variability of the layer stratigraphy in the experimental stretch, it was necessary to identify groups of sections that were homogenous, in terms of structural capacity, within which to carry out the appropriate analyses (Cafiso and Di Graziano 2003). Starting from 51 drop points and measurements of deflection basins, the choice of groups was made according to the Structural Number (SN) calculated by means of the AASHTO direct structural capacity prediction procedure (AASHTO Guide 1993). With reference to the "before" situation (FWD_B01 data) it was possible to identify four homogenous groups within which there was a SN variation, of less than 3% compared to the average, a value that was considered acceptable for data aggregation (Figure 4). However, Group 4 was excluded from further processing as it included points which corresponded to a part of the mesh characterized by positioning defects.

Each of the remaining three homogeneous groups was further divided into two subgroups with drop points falling in the tracts where reinforcement was placed (subgroups type GR) and where it was not placed (subgroups type G). Within the homogeneous groups the comparison between SNs, "pre" and "post"-installation of road mesh, did not highlight a statistically significant variation of structural capacity in those sections where reinforcement had been installed. In general, all analyses in 2001 confirmed that the installation of road mesh produces a slight increase in the load distribution of the pavement structure capacity (Cafiso and Di Graziano 2003). This increase in capacity was difficult to quantify by means of the FWD tests, due to random data variation. It could be concluded that the effective benefit of the mesh is difficult to evaluate in the period immediately following construction.

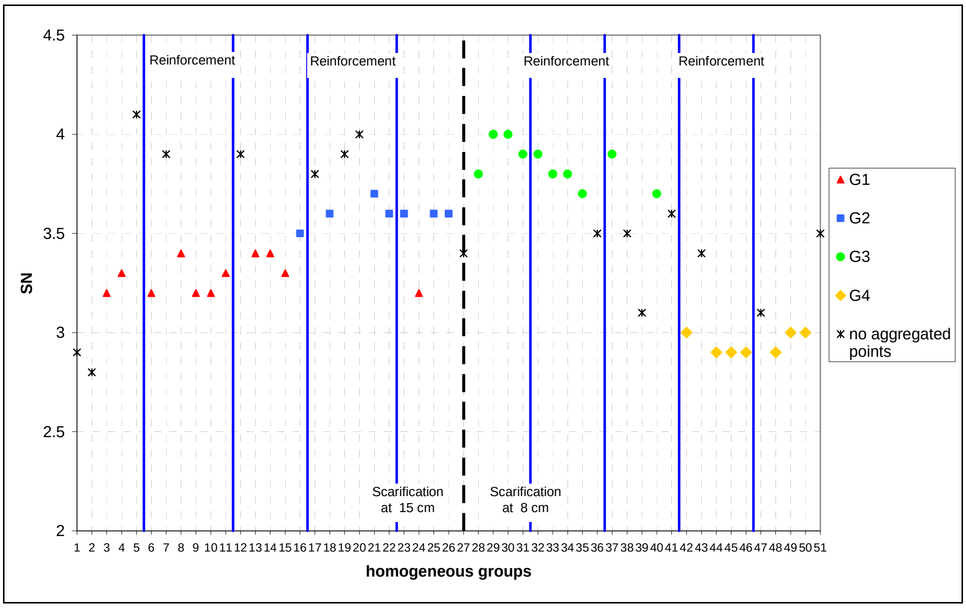

Figure 4: Homogenous SN groups starting from the pre-construction FWD survey

4. IN-SERVICE TESTING AND EVALUATION

Over the last five years the experimental stretch has been monitored to valued its traffic and environmental conditions. Relating more specifically to the traffic, by means of daily manual surveys, it was possible to estimate an average annual number of ESALs equal to 6.5E+05. As regards the environmental conditions, it was possible to use the database of two climatic stations located close to the experimental stretch which registered a range of average air temperatures between 3°C÷21°C during the winter and 11°C÷34°C during the summer. However, no problem of frost was registered.

In 2006, the survey (FWD_A06) was carried out at the same 51 points positioned every 5 meters identified and marked in the post-construction phase (2001). The aim of analyzing the FWD data after five years of service was to analyze reductions in pavement structural capacity with respect to the values immediately following construction comparing the sections with and without reinforcement.

Based on previous experience (Cafiso and Di Graziano 2003) the use of parameters obtained directly by the deflection basins proved to be more effective than analysis carried out by means of elastic modules, for the evaluation of which it is necessary to introduce further uncertainty factors connected to the backcalculation.

In this context, first of all, data were compared using the deflection basin parameters. Specifically the characterization was carried out using the AREA and F1 Shape Factor parameters (Hossain and Zaniewski 1991; May and Von Quintus 1994), which are functions of deflection values at more than one sensor :

1) AREA: area of deflection basin

$$\mathrm{AREA} = \frac{\mathrm{Dist}_2}{2} + \left[\sum_{i=2}^{n-1} \delta_i \times \frac{(\mathrm{Dist}_i + \mathrm{Dist}_{i+1})}{2\,\delta_1} \right] + \frac{\mathrm{Dist}_n \times \delta_n}{2\,\delta_1} \qquad \text{(Eq. 1)}$$

where

n : number of sensors used to measure basin (n = 9);

δ_i : deflection measured with the sensor i;

Dist_i : distance between sensor i and i-1;

2) F_1 : Shape factor

$$F_1 = (\delta 1 - \delta 5) / \delta 3 \qquad \text{(Eq. 2)}$$

In order to meaningfully analyze and compare results coming from the two different surveys in 2001 (FWD_A01) and 2006 (FWD_A06) taking into account the effects of temperature, the deflections were adjusted to a common reference temperature of 20 °C by the way of adjustment factors (Lukanen, Stubstad and Briggs 2000).

With reference to the survey points within the three homogenous groups selected in 2001, the adjusted values of the deflection basin parameters were compared between the subgroups with mesh (type GR) and those without mesh (type G). For both parameters, a comparison between the post-construction situation (2001) and that of the present day (2006) shows an expected difference between the G subgroups and the GR subgroups,

the latter performing better. In particular, the shape factor F_1 results (Table 1) highlight an average increase equal to about 25% of the parameter values in the subgroups without mesh as compared to an average increase of only 12% registered at points with mesh. Lower F_1 values underline a higher residual contribution of the compound layers where the mesh is placed. Similar considerations can be made comparing the AREA parameter (Table 2) characterized by a percentage decrease between those subgroups with and those without mesh, that is again correlated by a factor of two (8% for the G and 4% for the GR subgroups).
Moreover the t-Student test with one tail (test t) was carried out in order to verify if F_1 and AREA parameters of subgroups with and without mesh could be held to belong to populations with different averages with a level of significance higher than 90% (test t <10%). The results reported in tables 1 and 2 confirm the statistical significance of the differences between the G and GR groups.

Table 1: "Mesh and No Mesh" Basins F1 Shape Factor and Results of T Test

Subgroups G1					Subgroups G2					Subgroups G3				
Sections	F1_A01	F1_A06	Δ F1 [%]	test t	Sections	F1_A01	F1_A06	Δ F1 [%]	test t	Sections	F1_A01	F1_A06	Δ F1 [%]	test t
3	1.26	1.40	11.2%		16	0.96	1.26	30.5%		28	0.99	1.39	40.6%	
4	1.18	1.32	11.7%		23	0.88	1.10	24.7%		29	1.18	1.42	20.3%	
13	1.02	1.42	39.4%		25	1.00	1.28	27.5%		30	1.01	1.18	16.2%	
14	1.06	1.43	34.2%		26	1.04	1.33	27.8%		31	1.02	1.13	11.3%	
15	0.95	1.21	27.0%											
mean	**1.10**	**1.36**	**24.7%**		**mean**	**0.97**	**1.24**	**27.6%**		**mean**	**1.05**	**1.28**	**22.1%**	
Subgroups GR1				8%	**Subgroups GR2**				0%	**Subgroups GR3**				10%
Sections	F1_A01	F1_A06	Δ F1 [%]		Sections	F1_A01	F1_A06	Δ F1 [%]		Sections	F1_A01	F1_A06	Δ F1 [%]	
6R	1.06	1.21	13.9%		18R	0.91	1.03	13.2%		28	1.14	1.30	13.2%	
8R	1.07	1.12	4.1%		21R	0.90	0.98	8.9%		29	1.16	1.38	18.4%	
9R	1.00	1.08	7.7%		22R	0.89	0.97	9.0%		30	1.05	1.16	10.6%	
10R	0.97	1.18	21.1%							31	1.11	1.17	5.0%	
11R	0.99	1.22	23.5%											
mean	**1.02**	**1.16**	**14.1%**		**mean**	**0.90**	**0.99**	**10.4%**		**mean**	**1.12**	**1.25**	**11.8%**	

Table 2: "Mesh and No Mesh" Basins AREA Shape Factor and Results of T Test

Subgroups G1					Subgroups G2					Subgroups G3				
Sections	F1_A01	F1_A06	Δ F1 [%]	test t	Sections	F1_A01	F1_A06	Δ F1 [%]	test t	Sections	F1_A01	F1_A06	Δ F1 [%]	test t
3	1.26	1.40	11.2%		16	0.96	1.26	30.5%		28	0.99	1.39	40.6%	
4	1.18	1.32	11.7%		23	0.88	1.10	24.7%		29	1.18	1.42	20.3%	
13	1.02	1.42	39.4%		25	1.00	1.28	27.5%		30	1.01	1.18	16.2%	
14	1.06	1.43	34.2%		26	1.04	1.33	27.8%		31	1.02	1.13	11.3%	
15	0.95	1.21	27.0%											
mean	**1.10**	**1.36**	**24.7%**		**mean**	**0.97**	**1.24**	**27.6%**		**mean**	**1.05**	**1.28**	**22.1%**	
Subgroups GR1				8%	**Subgroups GR2**				0%	**Subgroups GR3**				10%
Sections	F1_A01	F1_A06	Δ F1 [%]		Sections	F1_A01	F1_A06	Δ F1 [%]		Sections	F1_A01	F1_A06	Δ F1 [%]	
6R	1.06	1.21	13.9%		18R	0.91	1.03	13.2%		28	1.14	1.30	13.2%	
8R	1.07	1.12	4.1%		21R	0.90	0.98	8.9%		29	1.16	1.38	18.4%	
9R	1.00	1.08	7.7%		22R	0.89	0.97	9.0%		30	1.05	1.16	10.6%	
10R	0.97	1.18	21.1%							31	1.11	1.17	5.0%	
11R	0.99	1.22	23.5%											
mean	**1.02**	**1.16**	**14.1%**		**mean**	**0.90**	**0.99**	**10.4%**		**mean**	**1.12**	**1.25**	**11.8%**	

The comparative analysis of the deflection basins shows that the reinforced pavement performed better but it did not make it possible to quantify the effective contribution made by the reinforcement.

Therefore, further analyses were carried out on structural capacity and Residual Life. To define the residual structural capacity of the pavement expressed in terms of Structural Number (SN), the AASHTO direct structural capacity prediction procedure was applied (AASHTO Guide 1993) using data from the same measurement points on the homogenous groups. In Figure 5 the value of SN taken from the FWD_A01 deflections measured in 2001 (SN_A01) and the FWD_A06 deflections of the 2006 survey (SN_A06) are reported.

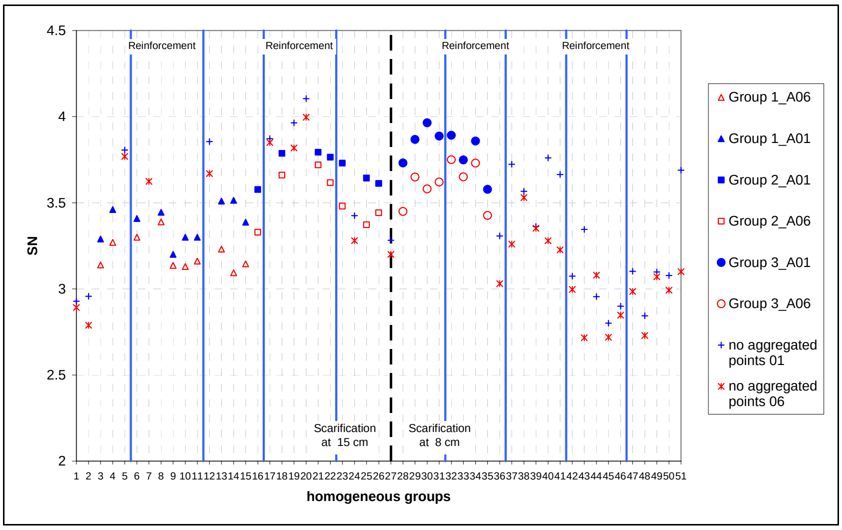

Figure 5: SNs immediately post-construction and after five years of service

Figure 6 shows a general reduction in SN with the highest decrease being observed in the G1, G2 and G3 sub-groups without mesh (0.26 inch drop equal to a 7% reduction of the initial value) as compared to the GR1, GR2 and GR3 subgroups with mesh (0.12 inch drop equal to a 3% reduction of the initial value). Once again, the t test (table 3) confirmed that the SN reduction is statistically different between the subgroups G and GR with a level of confidence of 90%.

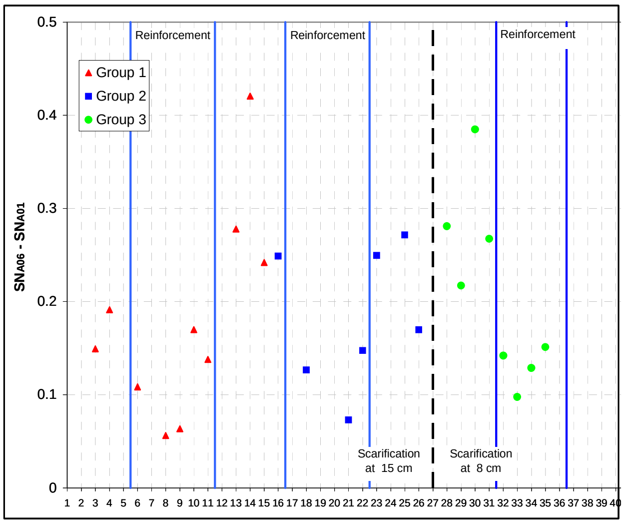

Figure 6: Difference between SNs after construction and after five years of service

Table 3: Difference between SNs after construction and after five years of service

Subgroups	Points	SN_A01	SN_A01	SN_A06	SN_A06	Δ SN	Δ SN	Δ SN [%]	t test
G1	3	3.29	3.43	3.1	3.18	0.15	0.26	7.5%	1%
	4	3.46		3.27		0.19			
	13	3.51		3.23		0.28			
	14	3.51		3.09		0.42			
	15	3.39		3.15		0.24			
GR1	6R	3.41	3.33	3.30	3.22	0.11	0.11	3.2%	
	8R	3.45		3.39		0.06			
	9R	3.20		3.14		0.06			
	10R	3.30		3.13		0.17			
	11R	3.30		3.16		0.14			
G2	16	3.58	3.64	3.33	3.41	0.25	0.23	6.5%	1%
	23	3.73		3.48		0.25			
	25	3.64		3.37		0.27			
	26	3.61		3.44		0.17			
GR2	18R	3.79	3.78	3.66	3.67	0.13	0.12	3.1%	
	21R	3.79		3.72		0.07			
	22R	3.76		3.62		0.15			
G3	28	3.73	3.86	3.45	3.58	0.28	0.29	7.4%	0%
	29	3.87		3.65		0.22			
	30	3.96		3.58		0.38			
	31	3.89		3.62		0.27			
GR3	32R	3.89	3.77	3.75	3.64	0.14	0.13	3.4%	
	33R	3.75		3.65		0.10			
	34R	3.86		3.73		0.13			
	35R	3.58		3.43		0.15			

With the aim of defining how the change in SN is related to pavement performance, starting from the ratio SN_A06 and SN_A01 (condition factor CF) the Residual Life in 2006 (RL_A06) was calculated using the graph (figure 7) reported in the AASHTO guide (AASHTO Guide 1993).

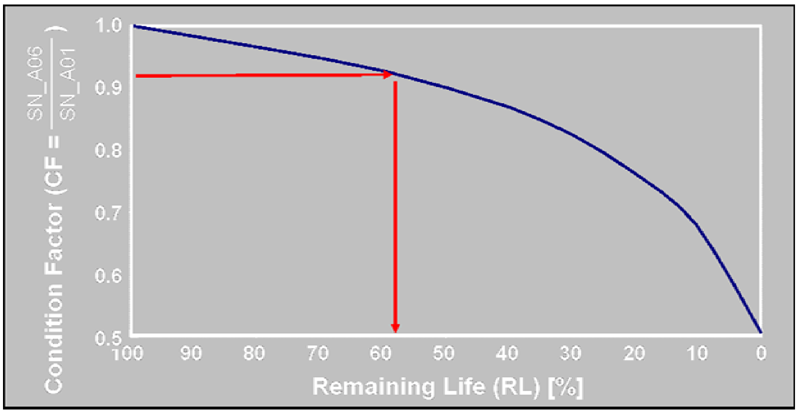

Figure 7: Calculation of the Residual Life (RL)

Starting from RL_A06 the total structural life of the pavement dissipated from construction ΔRL(01_06) was computed as:

$$\Delta RL(01\_06) = 100 - RL\ [\%] \qquad \text{(Eq. 3)}$$

The comparison between ΔRL values obtained for groups with and without mesh is shown in Table 4. Although the data set is a little limited to be able to draw absolute considerations, the results of the experiment made it possible to establish that after five years of service the same traffic load had dissipated 33% (ΔRL(01_06)) of the design life in the pavements with no reinforcement against 15% in the pavements reinforced with road mesh. Differences between light and heavy steel reinforcement netting and between reinforcement placed at different depths (15 or 8 cm) did not produce significant differences using the NDT evaluation. Once again, the t test confirmed that the residual life is statistically different between the subgroups G and GR with 90% level of confidence.

Table 4: "Mesh and No Mesh" Residual Life (RL) and dissipated life (ΔRL)

Subgroups	Points	SN_A01	SN_A06	CF	RL _A06 [%]	Δ RL (01-06)	Av. Δ RL [%]	st. dev.	t test
G1	3	3.29	3.1	0.95	78.5	21.5%	34.2%	11.8%	0.7%
	4	3.46	3.27	0.94	73.8	26.2%			
	13	3.51	3.23	0.92	62.4	37.6%			
	14	3.51	3.09	0.88	48.0	52.0%			
	15	3.39	3.15	0.93	66.1	33.9%			
GR1	6R	3.41	3.30	0.97	84.9	15.1%	15.3%	7.0%	
	8R	3.45	3.39	0.98	92.3	7.7%			
	9R	3.20	3.14	0.98	90.6	9.4%			
	10R	3.30	3.13	0.95	75.6	24.4%			
	11R	3.30	3.16	0.96	80.2	19.8%			
G2	16	3.58	3.33	0.93	67.0	33.0%	30.6%	5.8%	0.6%
	23	3.73	3.48	0.93	68.2	31.8%			
	25	3.64	3.37	0.93	64.6	35.4%			
	26	3.61	3.44	0.95	77.7	22.3%			
GR2	18R	3.79	3.66	0.97	84.2	15.8%	14.5%	4.9%	
	21R	3.79	3.72	0.98	90.9	9.1%			
	22R	3.76	3.62	0.96	81.4	18.6%			
G3	28	3.73	3.45	0.92	64.3	35.7%	35.3%	8.1%	0.2%
	29	3.87	3.65	0.94	73.3	26.7%			
	30	3.96	3.58	0.90	53.9	46.1%			
	31	3.89	3.62	0.93	67.3	32.7%			
GR3	32R	3.89	3.75	0.96	82.7	17.3%	16.4%	3.2%	
	33R	3.75	3.65	0.97	87.7	12.3%			
	34R	3.86	3.73	0.97	84.2	15.8%			
	35R	3.58	3.43	0.96	80.0	20.0%			

5. CONCLUSION

In 2001 an experimental stretch of road was constructed, alternating sections with and without steel reinforcement. The aim of the research was to investigate the performance of mesh-reinforced pavements in terms of structural capacity through NDT monitoring by the way of FWD.

However, a previous study by the authors, based on FWD surveys carried out before and immediately after the installation of the steel mesh, highlighted how the experimental variability of data that usually characterizes FWD test results and the slight increase in structural stiffness due to steel mesh installation does not allow statistically significant considerations to be drawn regarding the effective increase in structural pavement capacity.

For this reason in 2006 another FWD test was carried out to compare reductions in pavement structural capacity in sections with and without reinforcement, with respect to the situation immediately following construction.

After five years of service, AREA and F1 Shape Factor basin parameters registered an average modification that showed a statistically significant difference in the subgroups without mesh (an F1 increase of about 25%, an AREA decrease of about 8%) as compared to those with mesh (an F1 increase of about 12%, an AREA decrease of about 4%). An analysis of both basin parameters highlighted that the compound layers maintain a higher strength in the subgroups with mesh. Further analyses were carried out regarding the AASHTO Structural Number. Comparing SNs calculated from the deflections measured in the 2001 and in 2006 surveys, a general reduction in SN was registered with higher values being obtained for the subgroups without mesh (a 7% reduction with respect to the initial value) as compared to the subgroups with mesh (a 3% reduction with respect to the initial value). With the aim of relating this variation in SN to pavement performance, the AASHTO residual life was calculated. The results made it possible to establish that after five years of service the same traffic load had dissipated 33% of the design life of the pavement with no reinforcement as against 15% in the pavement reinforced with road mesh.

Although the data set is a little limited in order to draw absolute considerations, the experimental analyses confirm that the installation of road mesh produces a significant improvement in pavement performance. After five years of service the analyzed pavement sections with steel reinforcement showed an extension of Residual Life by a factor of two when compared with the equivalent pavements without reinforcement.

These conclusions are coherent with literature but, being based on experimental results, cannot be drawn with respect to the future service life of the pavement. If a hypothesis can be expressed we can expect a future increase in the gap between pavements with and without reinforcement due to an increase in the containment and interlocking capacity of the reinforced mesh-layer package.

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