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Monitoring and Performance of AC Pavements Reinforced with Steel Mesh

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Abstract: The work 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 nondestructive test (NDT) and visual inspection techniques and comparing the performances of pavements with and without reinforcement. In general, all the analyses confirm that the installation of the steel reinforcement 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.

Key words: *Asphalt concrete; Nondestructive test; Performance; Reinforcement.*

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 (HMA). 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 [1, 2].

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. [3], 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. [4] 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 [5]. Furthermore, the experimental tests establish [6] 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 asphalt concrete (AC) layers which ranges from between 10% at 5°C to 260% when a temperature of 40°C is applied.

Regarding the use of nondestructive techniques (NDT) to analyze the contribution made by the reinforcement in terms of structural resistance, a previous study by the authors [7] highlighted how the experimental variability of data that usually characterizes Falling Weight Deflectometer (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 monitoring of steel reinforcement effects was carried out over a significant period of time to compare performances of pavements with and without reinforcement. The performance monitoring was conducted using both NDT and visual inspection techniques.

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

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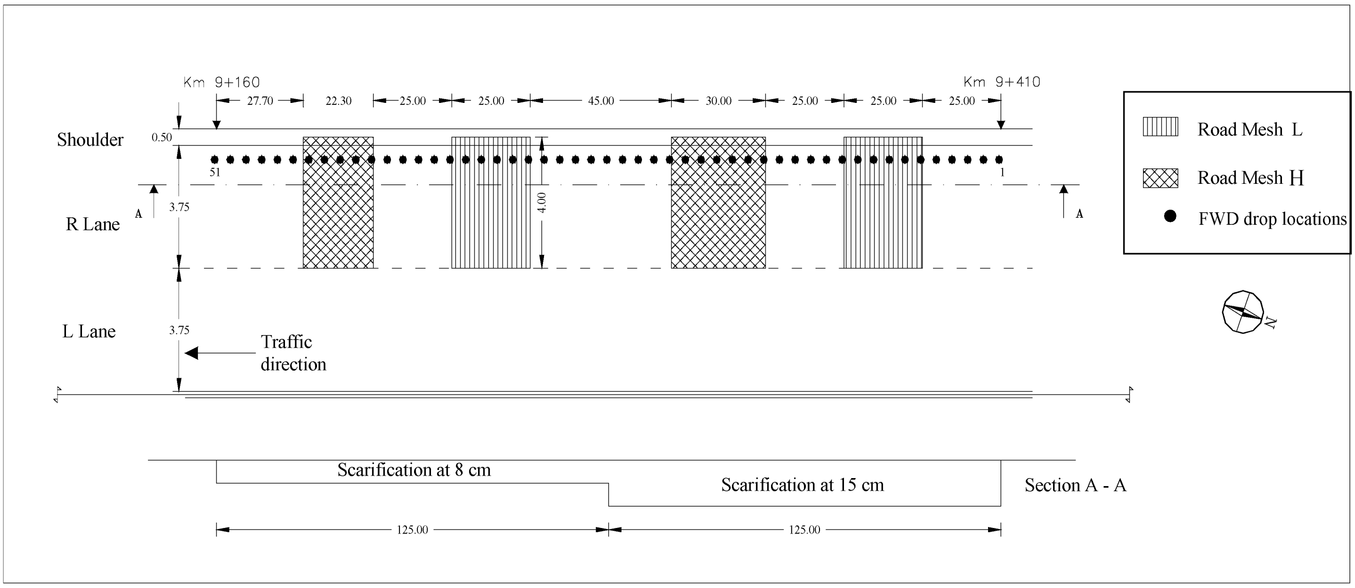

Fig. 1. Plan of the Experimental Stretch of Road.

Road Mesh Kind	Mesh opening [mm]	Distance between bars [mm]	Mesh diameter [mm]	Transverse steel diameter [mm]	k longitudinal stiffness [MN/m]	K transversal stiffness [MN/m]
Heavy H	83.5	165	2.7	3.4	28.7	11.5
Light L	83.5	165	2.4	4.4	22.7	19.34

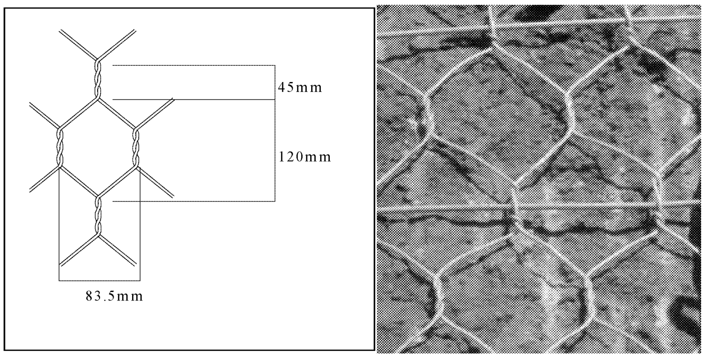

Fig. 2. Geometrical and Technical Characteristics of the Reinforcement Used.

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*m* between kilometers 9+410 and 9+160.

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

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 steel reinforcement used in the experimental sections are different in terms of longitudinal and transversal stiffness in relation with their weights as shown in Fig. 2.

Pre and Post-Construction Testing and Evaluation

In 2001, two FWD surveys [8] 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. The surveys were carried out

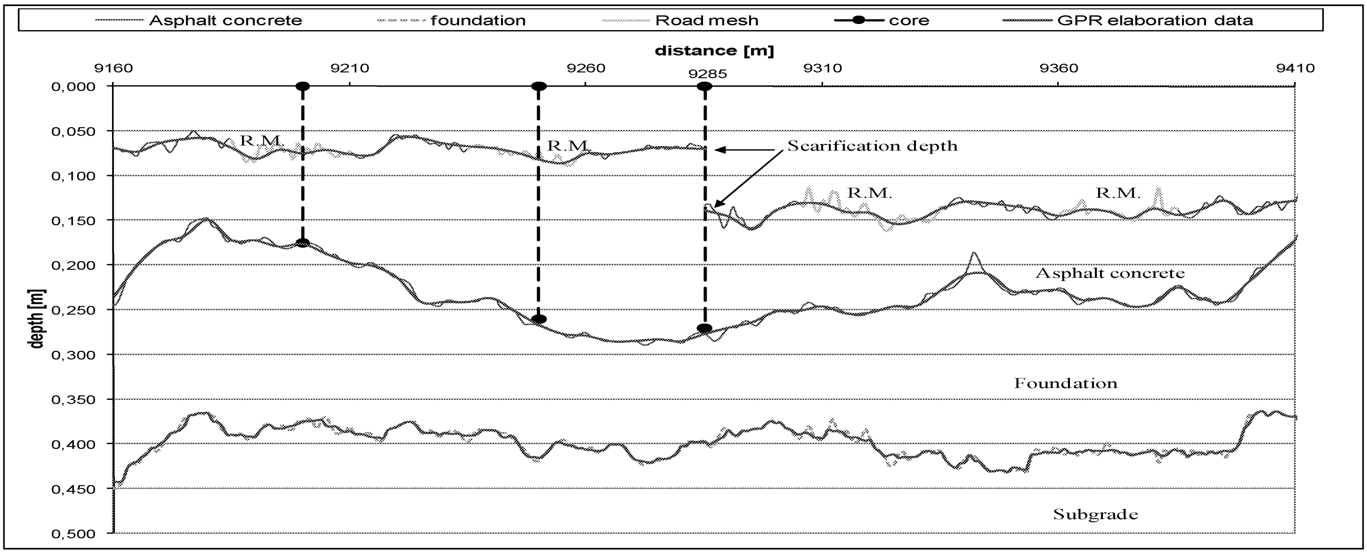

Fig. 3. Layer Thickness of the Experimental Road Stretch.

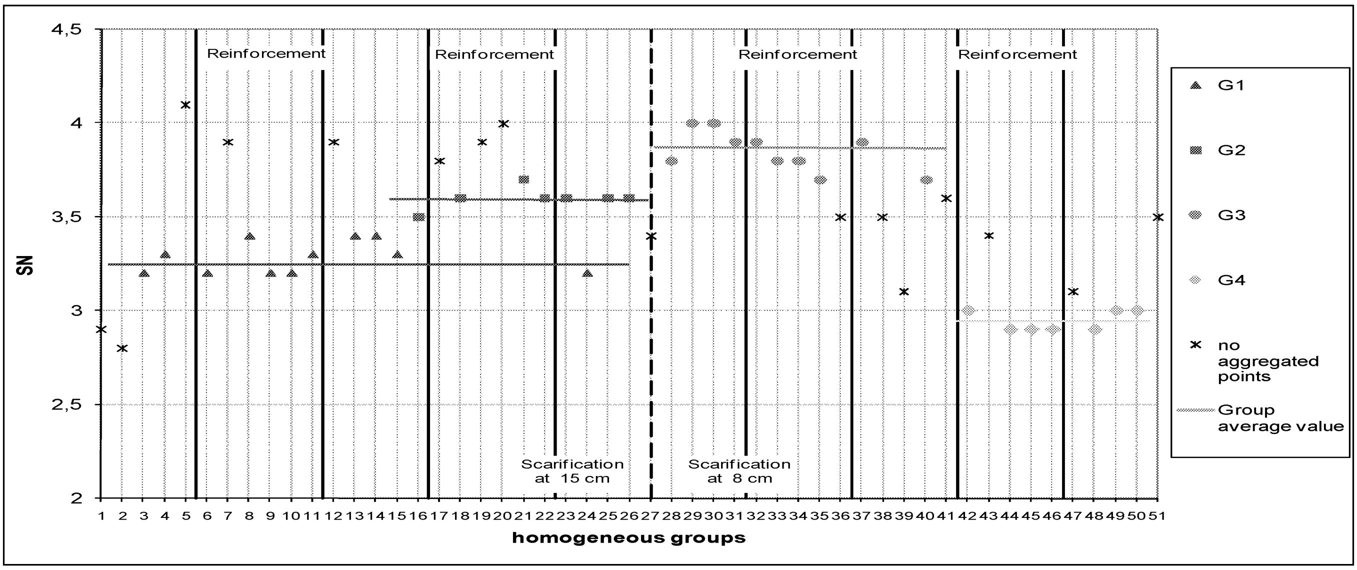

Fig. 4. Homogenous SN Groups Starting from the Pre-Construction FWD_B01 Survey.

using deflectometer Dynatest Model 8000 with a load plate 300*mm* in diameter and nine spaced geophones starting from the load application axis up to a maximum distance of 1.8*m*.

A Ground Penetrating Radar survey was also carried out in order to identify the total depths of the AC layers (new and old) and of the granular foundations (Fig. 3). At the same time the suitability of this technology as a means of discovering the presence of reinforcement mesh (R.M.) and its displacement was tested, obtaining good results and adequate precision. In the experimental section a multi-channel acquisition system was used, equipped with three dipolar, air-coupled, monostatic antennas (two at a central frequency of 1200MHz and one at a central frequency of 300MHz).

As the first step, the pavement was represented with a three layer system corresponding to an AC upper layer, a granular material foundation layer, and subgrade. The average backcalculated moduli values were about 160*MPa* for the foundation and 90*MPa* for the subgrade [7].

Then, 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. 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 American Association of State Highway and Transportation Officials (AASHTO) direct structural capacity prediction procedure [9]. 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 (Fig. 4). However, Group 4 was excluded from further processing due to positioning defects of the mesh during pavement reconstruction.

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

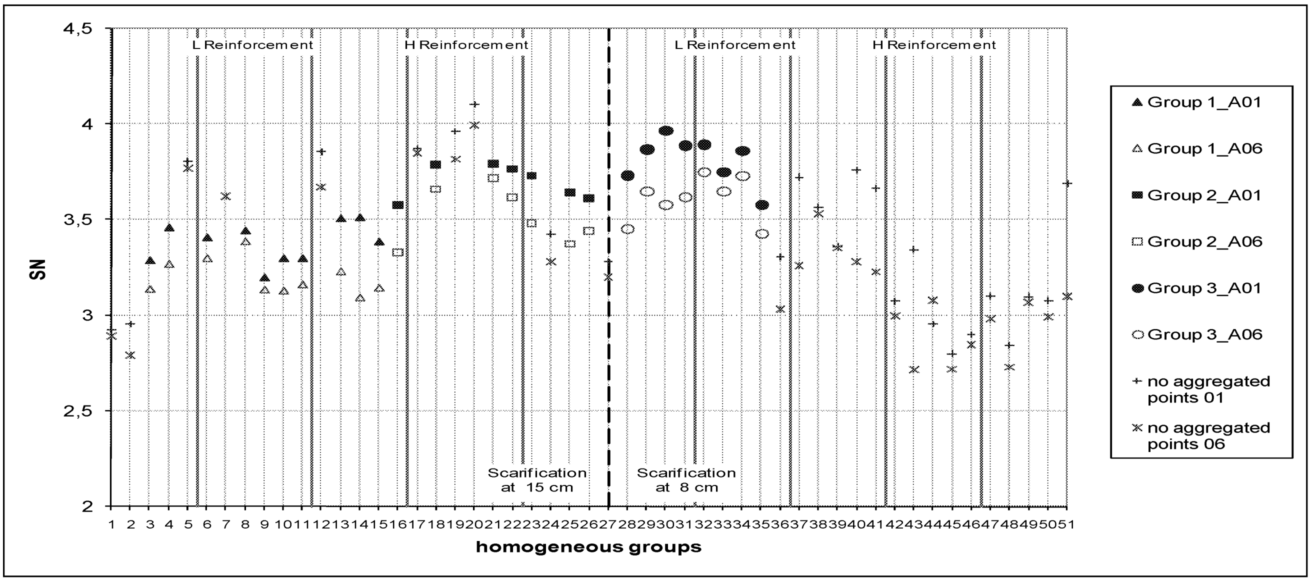

Fig. 5. Comparison between SNs Immediately Post-Construction and After Five Years of Service.

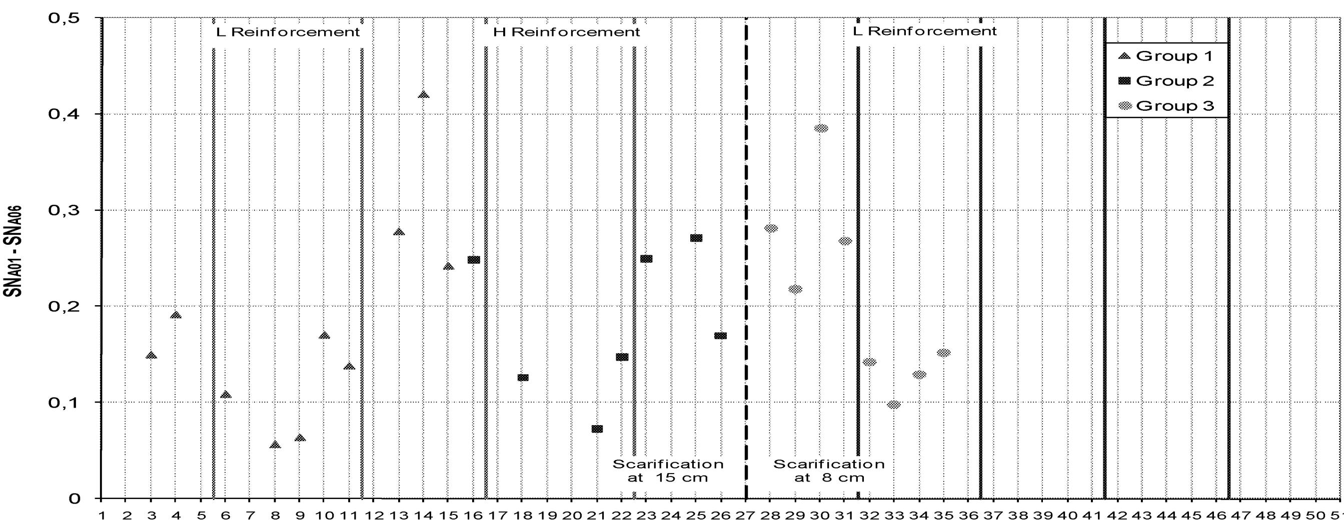

Fig. 6. Difference between SNs After Construction and After Five Years of Service.

placed (subgroups type G). Within the homogeneous groups the comparison between SNs, "pre" and "post"-installation of the steel reinforcement, 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 steel reinforcement produces a slight increase in the load distribution of the pavement structure capacity [7]. 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.

In-Service Testing and Evaluation

Over the last five years the experimental stretch has been monitored to value 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 (Equivalent Single Axle Loads) 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 and 21°C during the winter and 11 and 34°C during the summer. However, no problem of frost was registered.

Falling Weight Deflectometer Testing and Evaluation

In 2006, the survey (FWD_A06) was carried out at the same 51 points positioned every 5*m* 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. Analyses were carried out on structural capacity and Residual Life (RL). To define the residual structural capacity of the pavement expressed in terms of SN, the AASHTO direct structural capacity

Table 1. Difference between SNs After Construction and After Five Years of Service.

Subgroups	Points	SN_A01	SN_A01	SN_A06	SN_A06	D SN	D SN	D SN [%]	t test - p value[%]
G1	3	3.29	3.43	3.1	3.18	0.15	0.26	7.5	2.0
	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	1.4
	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	0.5
	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			

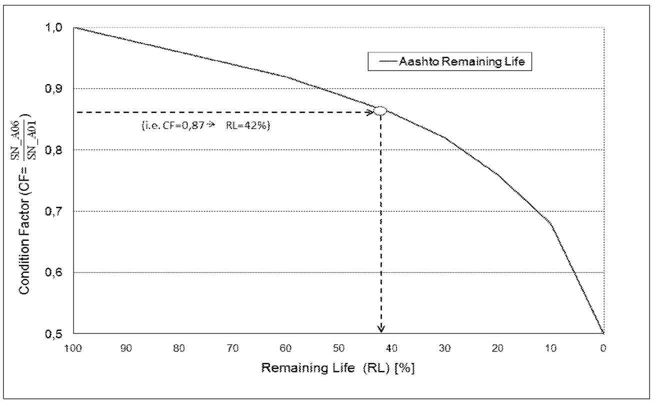

Fig. 7. Calculation of the Residual Life (RL).

prediction procedure was applied [9] using data from the same measurement points on the homogenous groups. In Fig. 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.

Fig. 6 shows a general reduction in SN with the highest decrease being observed in the G1, G2, and G3 sub-groups without mesh (an average drop of 0.26 and a 7.1% average reduction of the initial value) as compared to the GR1, GR2 and GR3 subgroups with mesh (an average drop of 0.12 and a 3.2% average reduction of the initial value). Moreover, the t test (Table 1) confirmed that the SN reduction is statistically different between the subgroups G and GR with a level of confidence higher than 95%.

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 RL in 2006 (RL_A06) was calculated using the graph (Fig. 7) reported in the AASHTO guide [9].

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

$$\Delta RL(01\_06) = 100 - RL\ [\%] \quad (1)$$

The comparison between RL values obtained for groups with and without mesh is shown in Table 2. 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 steel reinforcement

The t test confirmed that the RL is statistically different between the subgroups G and GR with 95% level of confidence. However 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.

Visual Inspection Testing and Evaluation

A surface pavement inspection was carried out using the "image acquisition and analysis system" set up by the Department Of Civil and Environmental Engineering (DICA) at the University of Catania [10]. Considering the type of analysis and the need to be able to overlap images acquired in different periods with extreme precision, the acquisition system was used in stationary mode.

For each of the three homogenous groups referred to above, two inspections units were defined: one with and one without steel mesh. Each unit was 7.5*m* long and was marked on the pavement using four markers set at 2.5*m* intervals, placed at about 10*cm* from the

Table 2. "Mesh and No Mesh" Residual Life (RL) and Dissipated Life (ΔRL).

Subgroups	Points	SN_A01	SN_A06	CF	RL _A06 [%]	D RL (01-06) [%]	Av. D RL [%]	st. dev. [%]	t test -p value[%]
	3	3.29	3.1	0.95	78.5	21.5			
	4	3.46	3.27	0.94	73.8	26.2			
G1	13	3.51	3.23	0.92	62.4	37.6	34.2	11.8	
	14	3.51	3.09	0.88	48.0	52.0			
	15	3.39	3.15	0.93	66.1	33.9			1.5
	6R	3.41	3.30	0.97	84.9	15.1			
	8R	3.45	3.39	0.98	92.3	7.7			
GR1	9R	3.20	3.14	0.98	90.6	9.4	15.3	7.0	
	10R	3.30	3.13	0.95	75.6	24.4			
	11R	3.30	3.16	0.96	80.2	19.8			
	16	3.58	3.33	0.93	67.0	33.0			
G2	23	3.73	3.48	0.93	68.2	31.8	30.6	5.8	
	25	3.64	3.37	0.93	64.6	35.4			
	26	3.61	3.44	0.95	77.7	22.3			1.1
	18R	3.79	3.66	0.97	84.2	15.8			
GR2	21R	3.79	3.72	0.98	90.9	9.1	14.5	4.9	
	22R	3.76	3.62	0.96	81.4	18.6			
	28	3.73	3.45	0.92	64.3	35.7			
G3	29	3.87	3.65	0.94	73.3	26.7	35.3	8.1	
	30	3.96	3.58	0.90	53.9	46.1			
	31	3.89	3.62	0.93	67.3	32.7			0.5
	32R	3.89	3.75	0.96	82.7	17.3			
GR3	33R	3.75	3.65	0.97	87.7	12.3	16.4	3.2	
	34R	3.86	3.73	0.97	84.2	15.8			
	35R	3.58	3.43	0.96	80.0	20.0			

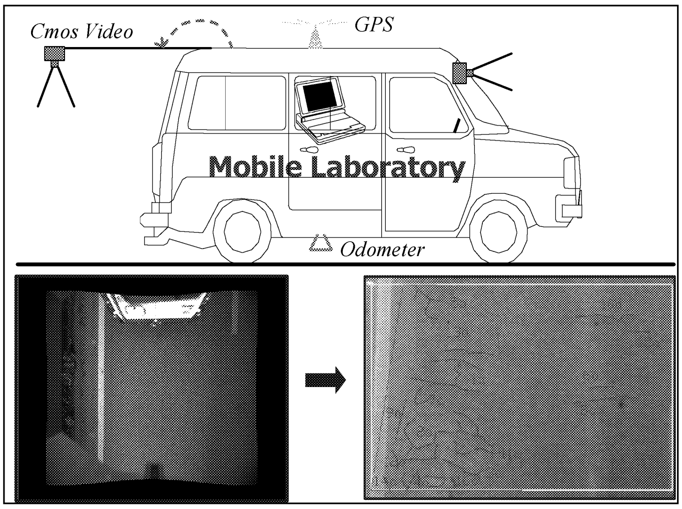

Fig. 8. DICA Mobile Laboratory and Example of Image Acquisition.

horizontal marking on the right shoulder of the roadway (inspection area = 27.5m^2). Each pair of markers was used as are ference for overlapping the images acquired at different times. Since 2001 an annual survey had been carried out, acquiring and cataloguing three images for each unit (Fig. 8), even if it was only from the survey in 2005 that the first distress was highlighted, characterized by slight cracking along the wheel paths. In each acquisition process the deterioration within the inspected unit was surveyed and its extension, type, and severity were evaluated according to standard procedures [11].

Table 3 presents a summary of the information recorded relating to the last three years. An initial analysis of the surface deterioration

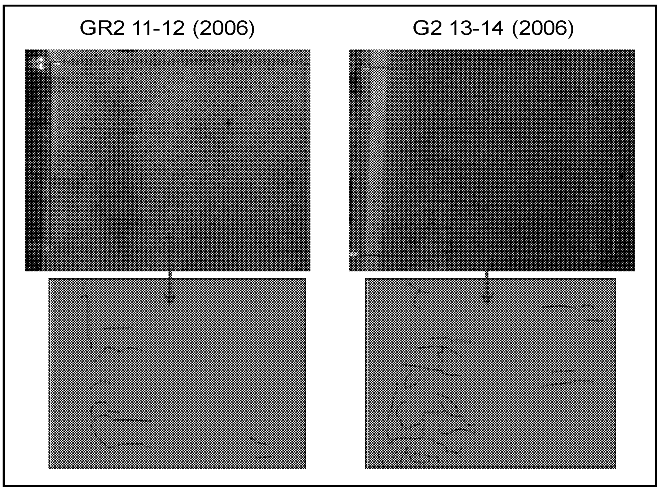

Fig. 9. Difference in Crack Detection.

which characterizes the experimental stretch made it possible to highlight a different damage situation in the sections with mesh as compared to the sections without mesh. In all cases the latter have a more extensive surface damage.

The distress surface was computed starting from the captured images. The percentage of distress surface was computed as a ratio of the distress surface connected with each group and the inspection area.

With particular reference to surface cracking, the comparison of the images (Fig. 9) acquired in the last two years made it possible to arrive at some conclusions regarding the characteristics of the cracks in the pavement with reinforcement as compared to that without. Specifically, with reference to groups 2 and 3, which display the most extensive surface distress, a comparison of the

Table 3. Distress Visual Inspection.

Image			Distress			Distress Surface [m^2]			Distress Surface [%]		
Subgroups (area=27.5m^2)	ID	Data	Type	Severity	Density [m^2]	2004	2005	2006	2004	2005	2006
GR1	1-2	2004	-	-	0.00	0	0	0	0	0	0
		2005	-	-	0.00						
		2006	-	-	0.00						
	2-3	2004	-	-	0.00						
		2005	-	-	0.00						
		2006	-	-	0.00						
	3-4	2004	-	-	0.00						
		2005	-	-	0.00						
		2006	-	-	0.00						
G1	5-6	2004	-	-	0.00	0	0.66	2.37	0	2	9
		2005	-	-	0.00						
		2006	-	-	0.00						
	6-7	2004	-	-	0.00						
		2005	-	-	0.00						
		2006	-	-	0.00						
	7-8	2004	-	-	0.00						
		2005	Potholes	M	0.66						
		2006	Potholes	M	2.37						
GR2	9-10	2004	-	-	0.00	0	0.00	10.5	0	0	38
		2005		-	0.00						
		2006	Cracks	L	3.65						
			Potholes	M	1.99						
	10-11	2004		-	0.00						
		2005		-	0.00						
		2006	Potholes	M	2.93						
	11-12	2004	-	-	0.00						
		2005		-	0.00						
		2006	Cracks	L	1.94						
G2	13-14	2004	-	-	0.00	0	3.75	15	0	14	55
		2005	Cracks	L	0.82						
		2006	Cracks	M	4.09						
	14-15	2004	-	-	0.00						
		2005	Cracks	L	2.12						
		2006	Cracks	H	5.34						
	15-16	2004	-	-	0.00						
		2005	Cracks	L	0.81						
		2006	Cracks	M	5.59						
GR3	21-22	2004		-	0.00	0	0.67	6.23	0	2	23
		2005	-	-	0.00						
		2006		-	0.00						
	22-23	2004		-	0.00						
		2005	Cracks	L	0.20						
		2006	Cracks	L	1.60						
	23-24	2004	-	-	0.00						
		2005	Cracks	L	0.47						
		2006	Cracks	M	4.63						
G3	17-18	2004	-	-	0.00	0	0.08	10.9	0	0	40
		2005	Cracks	L	0.08						
		2006	Cracks	M	3.21						
	18-19	2004		-	0.00						
		2005	-	-	0.00						
		2006	Cracks	M	2.66						
	19-20	2004		-	0.00						
		2005	-	-	0.00						
		2006	Cracks	M	5.00						

Table 4. Distress Surface Analysis.

Year	Subgroups	Marker	Ltot	n° cracks	Av. Length	Mean	t Test
2004	GR	all	0	0	0	0	-
	G	all	0	0	0	0	-

Year	Subgroups	Marker	Ltot	n° cracks	Av. Length	Mean	t Test
2005	GR2	9-10	2.68	6	0.45	0.32	48%
		10-11	1.22	4	0.31		
		11-12	0.88	4	0.22		
	G2	13-14	1.42	4	0.36	0.32	
		14-15	2.67	8	0.33		
		15-16	1.64	6	0.27		
	G3	17-18	0.71	3	0.24	0.33	20%
		18-19	0.64	2	0.32		
		19-20	0.86	2	0.43		
	GR3	21-22	0.00	0	0.00	0.20	
		22-23	0.72	4	0.18		
		23-24	2.54	6	0.42		

Year	Subgroups	Marker	Ltot	n° cracks	Av. Length	Mean	t Test
2006	GR2	9-10	12.00	18	0.67	0.65	1%
		10-11	3.50	5	0.70		
		11-12	5.18	9	0.58		
	G2	13-14	13.10	16	0.82	0.79	
		14-15	19.32	25	0.77		
		15-16	10.02	13	0.77		
	G3	17-18	9.13	8	1.14	0.95	6%
		18-19	7.51	9	0.83		
		19-20	12.12	14	0.87		
	GR3	21-22	0.00	0	0.00	0.44	
		22-23	3.32	6	0.55		
		23-24	18.51	24	0.77		

number (n°) and length (Ltot) of the cracks (Table 4) found in 2006 demonstrated a significant difference in the average length of the cracks which in the reinforced sections are shorter than in those sections without reinforcement where the pavement surface was characterized by longer and more widespread cracks.

Conclusions

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 through NDT monitoring and visual inspection techniques.

A previous study by the authors highlighted how the experimental variability of FWD data 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 immediately after construction.

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.

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 7.1% average reduction of the initial value) as compared to the subgroups with mesh (a 3.2% average reduction of the initial value). With the aim of relating this variation in SN to pavement performance, the 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 steel reinforcement.

Visual inspection monitoring further confirmed the conclusions reported above. The comparison of the surface distress in subgroups with and without mesh highlighted a more extensive damaged surface in the sections with no reinforcement which had more widespread and longer cracks.

Although the data set is a little limited in order to draw absolute considerations, all the experimental analyses confirm that the installation of steel reinforcement 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 an 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.

The obtained results refer to the efficiency of the steel mesh in relation of the pavement fatigue damage. Lateral support to stave off or reduce rutting may be expected too. However in all the experimental section rutting damage was not observed so any comparison was not possible.

Further researcher target will be the extension of the analysis until the sections have been resurfaced or reconstructed. Moreover, road agencies convenience to install a reinforcement have to be checked by the way of a life cycle benefit/cost analysis considering besides the extension of Residual Life also the increase of construction costs (reinforcement installation costs could be valued about 10 euros/m^2).

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