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Mobile Laser Scanning System for Assessment of the Rainwater Runoff and Drainage Conditions on Road Pavements

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Abstract: Lack of runoff and drainage on a road surface, due to its unevenness and non optimal alignment, is a significant safety issue. In the presence of water, friction and skid resistance are markedly reduced compared with the dry value, with increasing risk of accident. An efficient maintenance programme, based on a high performance survey system, can identify the sections having the greatest risk. The technique, known as Mobile Laser Scanning System (MLS), can be a very useful tool, allowing a large amount of data to be acquired in a short time and at low cost. Based on a MLS survey, the authors used the obtained data to identify the critical issues related to drainage and water runoff, verifying gradients, evenness, proper design of the drainage elements and the surface characteristics of the pavement. In particular, they have implemented the calculation of the water depth in a GIS environment to understand the existing runoff conditions. A comprehensive analysis of the functional characteristics allows defining an appropriate maintenance. The case study demonstrated how the proposed approach can be used to rationalize operations, implement pre-emptive measures and thereby optimize timing, use of materials and road work.

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***Key words**: Maintenance; Mobile laser scanning system; Road alignment; Road drainage; Water depth.*

Introduction

Driving on wet road surface is always followed by a great risk. In fact, thick water film thickness on the pavement leads to a decrease of the available friction in the tyre-pavement contact area. In addition, the splash and spray of water, produced by the vehicle running over a flooded surface, causes the reduction of the driving visibility and this can decrease road safety.

In literature there are several research studies on the calculation of the water depth and its relationship with the geometric and surface characteristics of the pavement, that underline the effect of water on pavement structure and safety risk.

Domenichini et al. [1] presented a comparison between different water depth calculation measurements. All the formulations take into account the length of the stream line, the drainage gradient and the rain intensity; in some cases the mean texture depth is also considered.

Jeong [2] showed that the distribution of sheet flow is closely related to cross slope, longitudinal slope, rainfall intensity and road width. The analysis of sheet flow characteristics on superelevation transition areas suggests that the optimal longitudinal slope in the range of 0.3–0.4% minimizes the depth of storm-water runoff on the road surface.

Hsieh [3] investigated the profiles of surface water flow over a pervious pavement, for example a highway, during a uniform rainfall and employed a numerical technique to find the flow profiles on the pavement surface related to not only the rainfall excess, cross slope and road width but also the material and structure of the pavement.

Prevost [4] proposed a new way to estimate local water depths under the tyres as the car is running, with a direct measurement of the water droplets amount thrown from rotating tyres of the vehicle.

Moreover the safety risk is strictly related to the road friction of the pavement. Kuttesch [5] used accident and skid resistance data from the Virginia wet-accident reduction program as well as from sections without pre-identified accident or skid problems. He found a statistically significant effect of skid resistance on wet-accident rates indicating that wet-accident rates increase with decreasing skid numbers.

Beautru [6] showed the friction/water depth relationship, estimating local water depths trapped between the tyre and the road asperities and defining a so-called “critical” water depth which can be used for driver assistance systems.

Cenek [7] developed statistically relationships between rut depths and dry and wet road fatal and injury crashes on New Zealand’s state highway network.

An improper runoff of surface waters may lead to damage of the entire pavement structure. The presence of moisture combined with repeated traffic can adversely affect the performance of asphalt pavements. Moisture damage is caused by a loss of adhesion, commonly referred to as “stripping” of the asphalt film from the aggregate surface or a loss of cohesion within the asphalt binder itself, resulting in a reduction in asphalt mix stiffness [8]. Heavy traffic on a moisture-weakened asphalt pavement can result in premature rutting or fatigue cracking. The presence of moisture can also accelerate the formulation of potholes or promote delamination between pavement layers. Excessive standing water on roads surfaces can enter the surface of the asphalt mix from precipitation by gravity or hydraulic pressure from tyre action [9].

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Mobile Mapping System equipped with the Light Detection And Ranging Technology (LiDAR) was used, having functions for road inventory and road condition surveys, called Mobile Laser Scanning System (MLS_S). MLS_S System are recognized worldwide as being effective instruments to evaluate the condition of roads, as they provide a large amount of data with great potential and a wide range of interpretations.

Many researchers accurately describe and develop MLS systems that are perfectly capable of capturing the road network and all its functional elements, but the data are not implemented within an operating procedure that can manage the infrastructure efficiently [10-12].

Kingston et al. [13], for example, introduced a geo-referenced digital image capture and extraction system, which can perform the inventory of road infrastructure assets and their geometry (transverse slopes).

Findley et al. [14] compared roadside data collected using typical manual methods with data collected by vehicles moving with the traffic.

Di Mascio et al. [15] proposed a method to obtain the automatic and repeatable recognition of the geometric elements that compose the layout, both horizontal (tangents, circumferences and spiral curves) and vertical (vertical tangents and curves).

Dondi et al. [16] (2011) used laser scanners and video imaging technology to measure road surface conditions objectively. By combining various types of distresses, a standardized index was produced to draft priority maintenance lists for specific road sections. A semi-automatic method was tested on various sites and validated by comparing the results obtained with those from the standard manual calculation of the index.

Puente et al. [17] wrote a review of mobile mapping and surveying technologies, highlighting the current performance of some of the most important mobile terrestrial laser scanning systems. They concluded that the Road Scanner system, which will be used in the application described in this paper, offers good performance and it is one of the most effective solutions among the systems reviewed, especially for road inspections.

This paper shows how drainage and runoff issues in motorways can be addressed by processing data of Mobile Laser Scanning.

Research Purpose

The purpose of this research study is to provide a methodology of analysis that can be used to define the optimal maintenance for roads with a lack of rainwater drainage and non-optimal runoff. The proposed approach has the aim to rationalize operations, optimize timing, use of materials and road works. All these factors contribute towards enabling a sustainable approach to infrastructure management and the optimization of resources, by intervening on road surfaces through both preventive and rehabilitative activities. For this purpose, authors used data to study the road surface characteristics and other data from MLS to better define all the functional aspects of the pavement.

The adopted process looks for the causes of failure among the main aspects related to runoff and drainage in order to provide possible solutions. It is firstly verified whether the proper design of the road alignment comply with the Italian standards [18, 19]. The significant elements to check are the ratio between the radii of two consecutive curves, the minimum and maximum lengths of the straights and curves, and the inspection of cross slopes and drainage gradients, which are necessary for the stability of the vehicles in motion and for rainwater disposal, respectively. Further parameters analyzed are the evenness of the road surface according to the IRI parameter (International Roughness Index) [20], calculated by means of profilometer mounted on the MLS, and the skid resistance of the pavement by considering the Sideway Force Coefficient (SFC) values obtained by periodic SCRIM surveys (UNI CEN/TS 15901-6 [21]). The combined effect of gradient and crossfall is the input for the subsequent examination of the runoff and drainage capacity. The former is evaluated by calculating the depth of water at all points of the road, while the latter is assessed by verifying the efficiency of the drainage system.

Based on the Digital Terrain Model (DTM), authors implemented the calculation of the runoff in ArcGIS environment [22], in order to identify type and direction of flow during the rainfall event, and recognize areas subject to rainfall pools, forming on a road surface, due to its unevenness and insufficiency in storm water runoff. Weaknesses in homogeneous sections are highlighted and a comparison was made between the current situation and the hypothetical project solutions.

Once the causes of the failure are known and a complete knowledge of the problem is achieved, it is possible to define the most appropriate maintenance for each section. In order to assess whether the work will involve the deeper road layers, the road bearing capacity needs to be investigated.

Lidar Technology and Data Management Software

Mobile mapping systems that use Light Detection and Ranging (LiDAR) technology as their main imaging unit, called mobile laser scanning systems, are the most recently developed type. LiDAR technology, which is based on laser range-finding measurements of the distance between the sensor and the targeted object, provides a significant increase in the number of data points of exceptional accuracy over traditional data capture methods [17]. The MLS vehicle used for the present study is the “Road-Scanner” (RS). The vehicle is equipped with a wide range of state-of-the-art sensors and devices to carry out a rapid survey of a road infrastructure with all its appurtenances, by automatically acquiring large amounts of data. The RS combines the following technologies: GPS and Inertial Positioning System (INS), medium-to-high resolution 5/8 front-mounted colour TV cameras (1400×1000 or 1024×768) and a rear-mounted vertical TV camera, a Dynatest RSPIV profilometer, a 2 GHz IDS georadar, an odometer and a Faro Photon 120 helical laser scanner (Fig. 1).

During the survey, the subsystem formed by GPS, odometer and inertial platform geo-references the vehicle’s position, and the TV cameras acquire video frames of the road and its appurtenances every 2-4 m. The laser scanner acquires a cloud of laser points distributed on a helicoid at a step of 20-40 cm and lastly, the rear TV camera provides a continuous plane view of the road surface of around 4 m in width. Photogrammetric measurements are precise to 10 cm, while the relative accuracy obtained by the laser scanner (distance between 2 points) is of 2 mm. The data acquired by all

Fig. 1. Mobile Laser Scanning System.

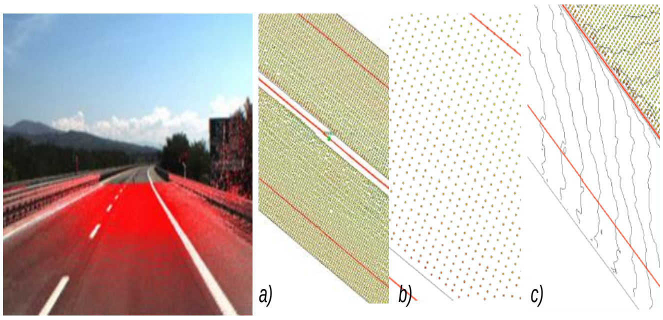

Fig. 2. Reconstruction of the DTM from the MLS Scan.

these devices are then post-processed and stored in an easily queryable database. The post-processing system used was a software, which offers photogrammetry functions and the superimposing of the laser scanner lines for measuring distances, perimeters and areas on and adjacent to the roadway. Videos are the fastest way to look at the state of the road surface without the need for on-site inspections. Indeed, the videos are intended as a backup for the photogrammetry measurements.

By overlaying the videos, it is possible to carry out topographical measurements on the points acquired by the laser scanner, thereby providing more precise measurements of any distress revealed. Such measurements are finally combined with information on road evenness and pavement structure obtained from the other onboard instruments, such as georadars and profilometers.

All data is geo-referenced using a powerful inertial positioning system. A post-processing software is able to combine all the information collected in an optimal way and calculate the differential GPS corrections with high quality and the absolute coordinates are accurate to the order of decimetres. The data returned by the MLS are already commonly used in the field of engineering design.

Data Analysis

The data analysis is based on the digital model of the road surface generated from the point cloud obtained by the laser scanner (Fig. 2).

The points are aligned on a regular grid with rectangular step (Fig. 2(a)). The amount of points returned from the laser scanner is too high to be handled in a Digital Terrain Model (DTM), as well as being superfluous for identifying water runoff problems. For these reasons, the first phase involves re-sampling the laser points (Fig. 2(b)), i.e., modifying the original survey to reduce the number of points in the scan, through a filtering operation to eliminate all the points not belonging to the road surface.

This procedure mainly entails automatic filters but, in some circumstances, the manual intervention of the operator may also be necessary. The filter automatically eliminates all the points over 15 cm above the road surface, therefore leaving aside any car that overtakes the Road-Scanner vehicle during survey operations. The pitch of the mesh model is fixed at 20 cm. The reference altitude is derived from a statistical average of all the points within the range. The colour scale used to represent the points is based on the difference in altitude between each point and the interpolating plane previously defined.

Based on this grid, a DTM is created for each carriageway. The single DTM, consisting of approximately 2,300,000 points, is used to rebuild the road alignment of the section under study, and this fundamental data will serve as a support for the whole subsequent processing.

The laser scans the road sections with an angular extension of 320° and a depth of 150 m. The scan line, i.e. the number of points measured for each rotation of the mirror of the laser scanner, has a variable acquisition step of 20 to 30 cm, depending on the speed of travel. Around 2,000 points, including 700 on the road, are acquired for each scan line, giving an accuracy of 2 mm. Accordingly, sections are defined and all their geometrical parameters are well know, in particular that of the slope. For its calculation is chosen a baseline, representative of the width of the roadway, avoiding comprise edges that could affect the result obtained; the point cloud is then interpolated by a linear regression law, based on the method of least squares. The digital model of road surface is an essential tool for the hydraulic analysis of the highway. The contour curves of the road (Fig. 2(c)), spaced 2 cm apart altimetrically, are determined and are based on the altitude of the individual cells of the DTM. The frequency and direction of these curves provide information on the slope and on the flow direction of the runoff as well as water depth. Based on the DTM, the authors developed a module for graphical display of the runoff and of the water depth that is formed on the pavement road surface. After evaluating the absolute value of each cell and establishing the direction of flow, an iteration algorithm assigns the amount of water for each cell to the next, for a specified storm return period.

The flow path iteration algorithm selects among adjacent cells the one with the highest vertical drop, up to the side of the road. If it does not find the path that leads to an accumulated area, it repeats the iteration to another adjacent cell taking into account the new water level reached. A low drainage gradient leads to standing water forming on the road surface, which can undermine user safety by introducing the well-known effects of spray and aquaplaning. Indeed, for a damp surface the water prevents the formation of molecular bonds between surface particles and tyre rubber and the hysteresis of the latter become the primary source of tyre/surface friction. When the water layer thickness and vehicle speed increase the hydroplaning phenomenon appears. So, the tyre is lifted from the road surface due to the pressure created by water under tyre [23]. The developed module can help identifying the runoff type on the pavement with chromatic scale indicating the amount of water depth (WD) that is formed on the road surface during a defined rainfall event. Several types of analytical flow models are available in literature for predicting the water depth on the pavement surface in steady-state flow conditions [1].

Authors choose the WD model developed by Roses and Russam [24] and applied it to the DTM by way of ArcGIS [22] software:

$$WD = 0.015\frac{(L\,I)^{0.5}}{S^{0.2}} \quad (1)$$

where L represents the length of the stream line [m], S the drainage gradient [%] and I the intensity of rain [mm / h], determined from the intensity duration frequency curve (IDF), which correlates the rainfall intensity to the duration of the event that occurs at every assigned return time. This is constructed by analyzing years of rainfall records registered by the weather station closest to the road.

In the software the stream line, i.e. the length of the runoff, is identified by the sequence of the individual cells to which the longitudinal and transverse slopes are associated. The exact knowledge of the horizontal and vertical alignment of the road means that it is possible to introduce several theories for designing drainage systems. Among these, the theory of Wooding [25], under certain conditions [26], is used to study the runoff process from a flat surface by means of an approximation of the De Saint Venant equations. The rain duration that causes the critical condition of maximum runoff, a function of the road alignment and the IDF curve, is first calculated. The maximum flow rate flowing out in the generic section (q_0) can therefore be obtained.

Once the geometry of the receiving elements such as water channels (and hence their capacity Q) is known and a flow width on the carriageway is fixed, the maximum spacing between the outflow elements (road gullies and batter drains) is calculated as the ratio between Q and q_0. Using the data obtained by the MLS_S, it is possible to analyze the effectiveness of the drainage system for both the runoff towards the kerb shoulder and the runoff towards the median shoulder. This analysis is carried out for all possible horizontal and vertical alignment configurations (A.C.), which are identified by the average slope values measured for each horizontal alignment and its gradient. It is then possible to compare the current spacing of road gullies and batter drains, determined from the geo-referenced videos, with the maximum allowable spacing for the system to function correctly in its current state. In the case of negative feedback, it is then possible to identify the alignment configurations on which to work.

The longitudinal evenness is examined using the Dynatest class I profilometer [27], which provides three values for IRI with a measurement interval of 10 m. These values are displayed directly on the geo-referenced images or tabulated as a function of the distance.

Case History

Results

Shown below are the results obtained by applying the above methodology to a 15 km stretch of highway located in a mountainous area and subjected to dangerous water build up and ponding, which, in the event of rainfall, represent a threat to driver safety. The road was built in the 1970s and does not reflect current Italian regulation (set out in Ministerial Decree 5/11/2001 [18]). As pointed out by Ministerial Decree 22/04/2004 [19], this legislation is not binding for existing roads, but has to be used as a reference for maintenance operations.

Table 1. Homogeneous Sections Based on IRI Values.

Section	Direction 1 Length [m]	Direction 1 IRI Value [mm/m]	Section	Direction 2 Length [m]	Direction 2 IRI Value [mm/m]
1A	6413	1.21	1R	907	1.33
2A	250	1.98	2R	737	2.3
3A	973	1.38	3R	5100	1.18
4A	250	1.92	4R	802	2.04
5A	1287	1.31	5R	7746	1.11
6A	188	2.09	Average		1.59
7A	229	1.27			
8A	99	1.94			
9A	340	1.3			
10A	120	1.99			
11A	4464	1.27			
12A	408	1.98			
Average		1.64			

The horizontal alignment is composed mainly of straight stretches and curves with large radii. Maintenance work has been carried out on various sections of the road over the years. The maintenance work included both superficial e.g. restoring friction and smoothness of the pavement surface as well as structural. The road is formed of two separate carriageways (called Direction 1 and Direction 2), each with a slow and an overtaking lane plus an emergency lane. The Annual Average Daily Traffic (AADT) is about 20,000 vehicles. Initially, to determine the structural properties of the road, a series of investigations were carried out using a Falling Weight Deflectometer (FWD), providing elastic modulus values for the asphalt layers exceeding 3000 MPa at 20°C, largely sufficient to ensure an adequate structural strength in relation to traffic volumes. Structural interventions were therefore avoided, with attention focused only on restoring the functional properties of the road.

In order to evaluate road evenness (using IRI), in compliance with ANAS 2008 [28] technical standards, the roadway was divided into uniform sections, defined as road stretches in which the IRI values were statistically less dispersed around a mean value. Twelve homogeneous sections for Direction 1 were identified and five for Direction 2 (Table 1).

With the exception of the sections 6A, 2R and 4R, the values generally did not exceed 2 mm/m, with an average value over the whole roadway, considering only the slow lane of, respectively, 1.64 mm/m and 1.59 mm/m for Directions 1 and 2. The relative standard value fixes an upper limit of 2.68 mm/m.

Afterwards the road alignment characteristics were compared with the criteria set out in Ministerial Decree 5/11/2001 [18]. The results are shown in Table 2.

Table 2 shows the average value of the slope (e) and drainage gradient (DG) (defined as the combined slope due to road surface cross slope and longitudinal), computed for all the sections surveyed belonging to the single horizontal alignment, the values calculated according to the above decree (e_d, DG_d) and the difference in slope (Δe) to be recovered with the maintenance work.

Table 2. Cross Slope and Drainage Gradient: Current Situation vs. Legislative Requirements.

	Direction 1					Direction 2				
Alignment	e	e_d	Δe	DG	DG_d	e	e_d	Δe	DG	DG_d
Tangent 1	-0.47	-2.5	2.03	0.99	2.65	1.09	2.5	1.41	1.42	2.66
Curve 1	-0.59	-3	2.41	0.95	3.09	-1.58	-3	1.42	1.72	3.07
Tangent 2	-0.45	-2.5	2.05	0.83	2.6	0.88	2.5	1.62	1.28	2.67
Curve 2	2.7	4	1.3	2.71	4	0.92	4	3.08	0.92	4
Tangent 3	0.31	-2.5	2.81	0.32	2.5	1.14	2.5	1.36	1.16	2.51
Curve 3	-1.85	-6	4.15	1.88	6.01	-2.78	-6	3.22	2.81	6.01
Curve 4	3.25	5.5	2.25	3.29	5.53	1.9	5.5	3.6	1.92	5.51
Tangent 4	-0.62	-2.5	1.88	0.64	2.51	1.14	2.5	1.36	1.2	2.53
Curve 5	-0.7	-2.5	1.8	0.93	2.58	0.99	2.5	1.51	1.31	2.64
Tangent 5	0.01	-2.5	2.5	0.39	2.53	1.03	2.5	1.47	1.2	2.57
Transition 1	1.41	2.5	1.09	1.45	2.52	1.17	2.5	1.33	1.22	2.52
Tangent 6	-0.73	-2.5	1.77	0.74	2.5	0.87	2.5	1.63	0.87	2.5
Curve 6	-0.75	-2.5	1.75	0.75	2.5	0.93	2.5	1.57	0.95	2.51
Tangent 7	-1.16	-2.5	1.34	1.59	2.72	0.67	2.5	1.83	1.3	2.74
Curve 7	-1.11	-2.5	1.39	1.38	2.63	0.88	2.5	1.62	1.21	2.63
Tangent 8	-1.01	-2.5	1.49	1.25	2.61	0.87	2.5	1.63	1.11	2.59
Curve 8	-0.81	-2.5	1.69	2.41	3.38	0.6	2.5	1.9	2.39	3.4
Curve 9	2.51	4	1.49	3.48	4.68	0.87	4	3.13	2.56	4.67
Average			1.96					1.93		

The carriageways in Directions 1 and 2 had an average crossfall of 1.96% and 1.93%, respectively. The comparison, on all sections, showed that only 3% of the roadway met the standard criteria, while, for the drainage gradients, the values met the requirements in all cases.

The hydraulic verification was preceded by the construction of two curves defining the area's rainfall pattern, IDF and DDF. These describe the variation in rainfall height and intensity in relation to the duration of the rainfall itself with a return period set at 25 years (Fig. 3).

The dots represent the values of depth and intensity with the assigned duration and return period, processed by Gumbels' probabilistic law. These points were then interpolated using the least squares method, obtaining the parameters "a" (49.89 mm / h^n) and "n" (0.43).

The current runoff on the road surface is illustrated in Fig. 4, in which the authors have applied the Roses and Russam model to ArcGIS software. Three critical cases were found along the pathway on site.

Fig. 4(a) shows case 1 defined by zones with reduced longitudinal and transverse slopes and an apparently absent runoff. There are great distances and irregularities between the contour lines, describing a low slope (below 1%): it follows that there is difficulty of a proper runoff and a likely build-up of water on the road surface. Fig. 4(b) shows case 2 defined by zones with contour curves parallel to the cross section, with a consequent runoff of water in the same direction of the road (longitudinal slope more predominant than the cross slope). The water does not find a way to escape and, depending on the gradient, the runoff can reach high speeds and consequently large flows. Case 3 (Fig. 4(c)) shows a flow directed towards the road shoulder, but affected by the reduced slope of the sections. The contour lines are oriented in an optimal manner where the flow is smooth and consistent, but relatively low. Nevertheless, the slow lane is defined by non-negligible water depth values, with the consequent risk of aquaplaning.

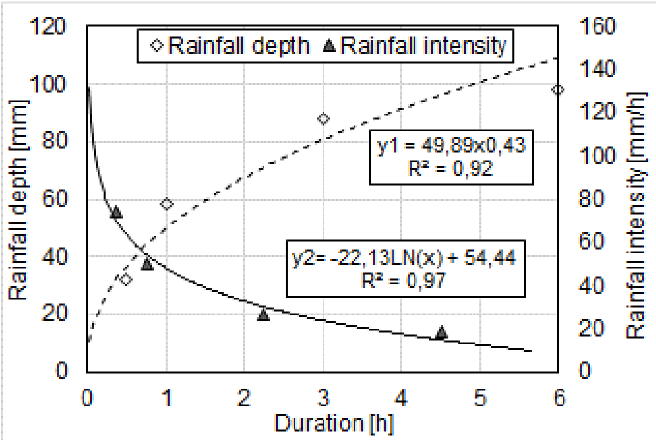

Fig. 3. Rainfall IDF and DDF Curves.

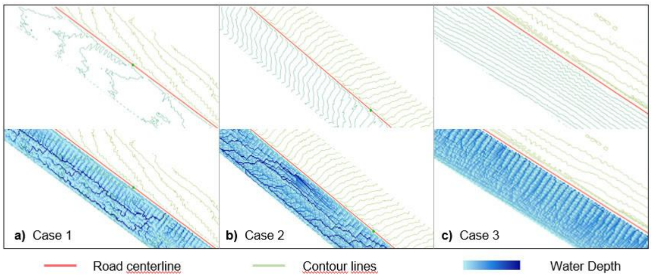

Fig. 4. Critical Issues of Water Runoff.

Table 3 shows the extension of such areas along the path. In particular, 40.4% of the road has longitudinal runoff, 32.3% has transversal runoff with a reduced slope, while only 7.4% has no

Table 3. Different Types of Runoff.

Runoff	Carriageway				Total	
	Direction 1		Direction 2			
	[m]	%	[m]	%	Total [m]	%
Optimal	4313	28.79	1653	11,02	5966	19.91
Case 1	857	5.71	1370	9.13	2227	7.42
Case 2	6636	44.2	5495	36.63	12131	40.41
Case 3	3194	21.3	6482	43.22	9676	32.26

drainage. The data thus confirms what was suspected: only 19.9% of the road has a regular runoff.

Once the runoff conditions along the road surface are fully understood, the efficiency of the drainage devices, shown in Fig. 5, was investigated by using the hydrological parameters previously calculated.

In curves, the water flowing out from the higher carriageway is collected from a channel located at the base of the median guardrail, from where it is intercepted by gullies placed at a distance of about 80 m. In the lower carriageway (and in both carriageways where there are straight stretches) a small dyke avoids draining water forming a runoff down the fill batter slope; the water is then conveyed away from the embankment by the batter drains, placed at variable spacing.

Two conditions were considered: runoff towards the kerb shoulder and runoff towards the median shoulder. For the latter, it was verified that the incoming volume of water in the concrete channel could easily be contained without spreading over the carriageway.

The maximum considered flow width on the shoulder was 1.5 meters from the dyke.

In Fig. 6, for Direction 1, the relationship is shown between the current batter drain spacing, determined by geo-referenced images, and the cross slopes of each alignment configuration, in order to verify the efficiency of the current system.

Each point indicates an alignment configuration. The curves represent the different road gradients and were computed by interpolation of points having the same longitudinal slope and different cross slope with an $R^2 = 1$. Full dots indicate the current situation, empty dots the maximum batter drain spacing allowable for the current slopes. The greater the cross slope, the greater the water containable. The greater the road grade, the less there is build-up of water. In both situations, the distances are shown to be more than the distance allowed in each case. The comparison shows that the allowable distances are always less than those present in situ. Depending on the dyke height, therefore, the water tends to invade the shoulder or even the lane, or starts to flow towards the bottom of the batter, causing erosion. Considering the current slopes, it is possible to observe that the proper disposal of runoff water would occur when the distance between the drains is of a few meters only. This suggests the need for a proper profiling of the slopes.

Proposed Maintenance Method

As a result of the survey carried out with MLS_S and examination of the slopes in place, it was possible to plan the maintenance for homogeneous areas, in order to bring the slopes in line with

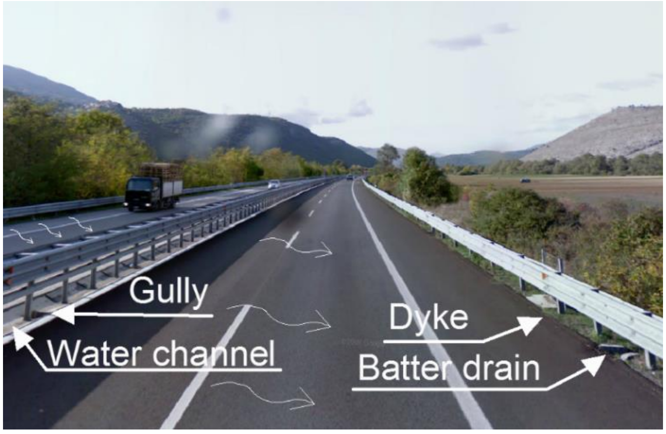

Fig. 5. Road Drainage System.

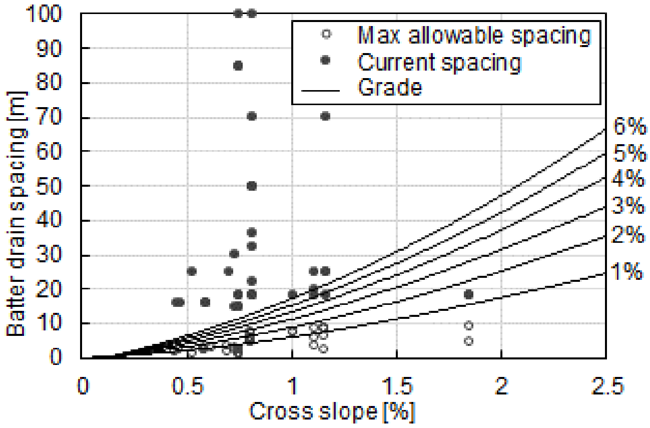

Fig. 6. Comparison between Present and Maximum Allowable Spacing of Batter Drains.

Ministerial Decree 05/11/2001 [17] and improve the efficiency of the drainage system.

In the definition of the proposed intervention, it was necessary to consider the constraint imposed by the solid central traffic divider. It was installed on a concrete curb, and the demolition entailed high costs and rather long processing times. Therefore, in order to achieve the measured altitude values, the proposed intervention work would involve changing the level of the shoulder.

Concerning the drainage works, Fig. 7(a) illustrates the design of the batter drain spacing, where the calculations use the cross slope reconstructed according to Ministerial Decree 05/11/2001 [17]. This is reported using an example, with the calculation for Direction 1.

The characteristic curves represent a longitudinal gradient with constant boundary conditions equal to a runoff coefficient of 0.9, rainfall intensity of 110 mm/h (corresponding to a rainfall duration of 5 minutes) and flow width of 1.5 m. These curves were computed in the same way of curves of Fig. 6. The reported values represent therefore the design of correct spacing between the batter drains for each A.C., starting from a minimum cross slope of 2.5%. Fig. 7(b) shows the comparison between the current and the design spacing, calculated using design cross slopes. The points above the 45° line indicate the sections where it was necessary to intensify the spacing.

At the end, the average water depths were calculated for each A.C. of both the current and the post-intervention situations. The results

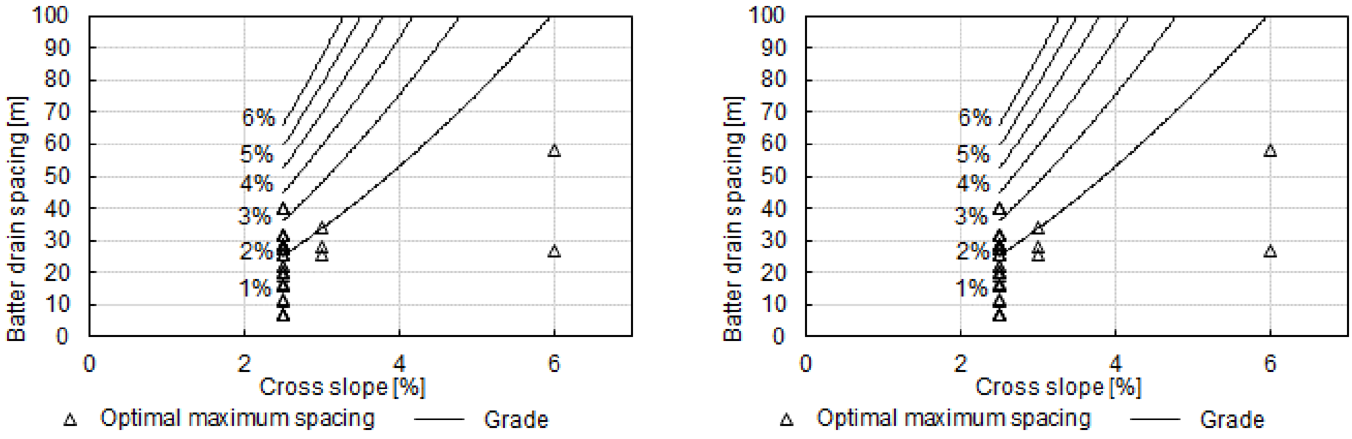

Fig. 7. Batter Drain Spacing Design (a) and Comparison between Current Situation and Design Solution (b).

Table 4. Water Depth: Present Situation vs Design Solution.

Lane	Overtaking	Slow	Hard Shoulder	Dyke	Abatement %
Maximum Values [mm]					
Pre	8.12	7.04	8.91	9.62	-
Post	4.65	4.06	5.13	5.55	42.49
Average Values [mm]					
Pre	3.58	5.11	5.88	7.07	-
Post	2.62	3.64	4.12	5.05	28.51
Standard Deviation [mm]					
Pre	1.16	1.11	2.21	1.56	-
Post	0.88	0.31	1.24	0.34	54.54

are reported in Table 4, for the fast lane, the slow lane, the right shoulder and the dyke. These values were calculated using the mean slope of each geometric element and are to be considered in the middle of each lane.

Fig. 8 shows the development of water depth along each element. The comparison of before-after water depth values, shown in Fig. 8, can help the road manager in choosing in which sections to intervene. Indeed, it gives an idea of which section will gain most in terms of water depth reduction after the restoring of the original slope.

The data show that the new paving results in a lower average water depth of 28.51%. Furthermore, the 42.49% reduction of the maximum values indicates that the new road surface would eliminate particular situations and could compromise the safety of the road users.

In Fig. 9, in order to understand which configurations are at a greater risk of aquaplaning, the relationship between water depth (WD) and the Sideway Force Coefficient (SFC) is shown. Thresholds were set both for WD, 5 mm, and SFC, 55, according to ANAS Italian technical standard and therefore four different zones were identified (A, B, C, D). A includes road stretches with high WD and low SFC, consequently with high risk of aquaplaning; on the other hand, D includes those configurations having the highest

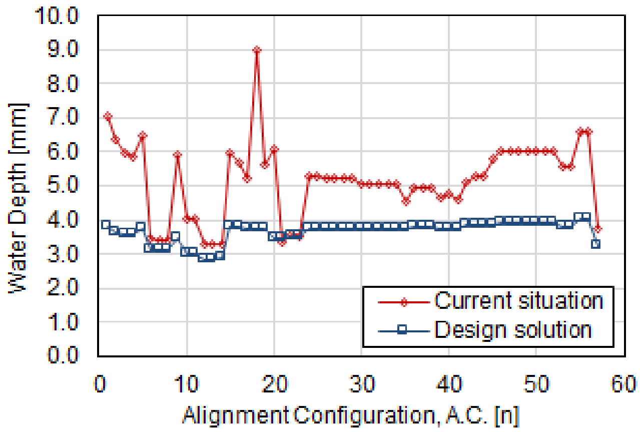

Fig. 8. Medium Expected Water Depth Versus Road Alignment Configuration.

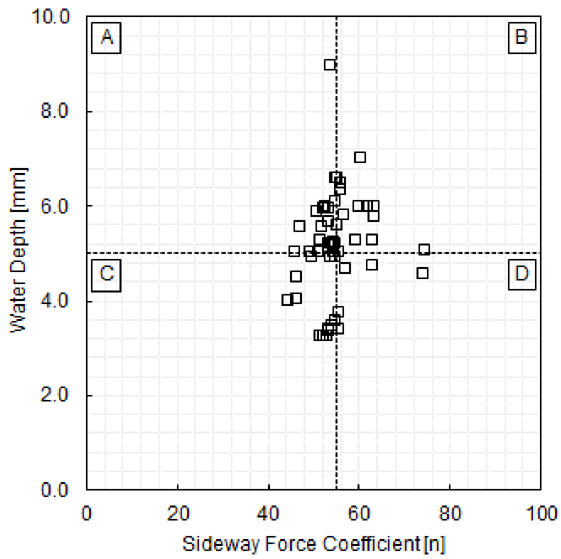

Fig. 9. Medium Expected Water Depth vs. Sideway Force Coefficient.

safety rate. B and C areas should be carefully analyzed, as the effects of WD and SFC are opposite on the sliding risk.

Conclusions

In this paper, it was possible to validate MLS as a survey tool used for resolving water related issues on roads and consequently choosing specific maintenance work. As a large amount of data can be collected and subsequently processed, the road surface condition in the presence of water can be determined, comparing significant parameters. In particular, based on the work carried out, the following remarks can be made:

- by detecting the slopes, the actual geometry of the roadway can be reconstructed and a comparison can be made with standard requirements;
- by applying a specific model to the DTM, it is possible to reconstruct the actual runoff water on the road surface, highlighting the critical cases. The weakest areas are the same as found by case histories of the road;
- the calculation of the water depth and the comparison between current and design situation allows the reduction of aquaplaning risk to be quantified;
- sections characterized by a greater risk of accident can be identified by combining friction measurements with calculated water depth;
- based on horizontal and vertical alignments, it is possible to define the efficiency of the existing drainage system and to quantify the effect of possible maintenance work, providing simple batter drain spacing graphs.

Concluding, it is shown how data extracted by MLS technique can be used to look for the causes of failure among the main aspects related to runoff and drainage, in order to provide possible solutions that are impossible with traditional tools. MLS technology, together with data processed by the operator, is therefore an effective tool to establish reliable maintenance operations specific to the problems encountered in the field. The usefulness of the procedure is clear and fundamental but it has to be commensurate with the importance of the infrastructure to maintain. The survey and subsequent data processing require a financial commitment and the use of qualified personnel. In any case, insufficient awareness about the conditions of the infrastructure could lead to funding allocated inappropriately and to incorrect intervention work. This approach can be used to rationalize operations, implement pre-emptive measures and thereby optimize timing, use of materials and road work. All these factors contribute towards enabling a sustainable approach to infrastructure management and the optimization of resources, by intervening on road surfaces through both preventive and rehabilitative measures.

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