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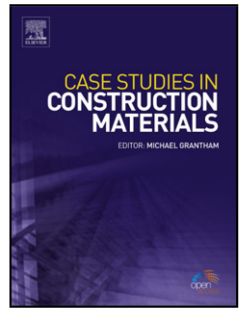

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Top-down cracking in Italian motorway pavements: a case study

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Highlights

- Specific criteria are proposed to identify different longitudinal crack types.
- Top-down cracking (TDC) can affect up to 20-30% of the slow traffic lane.
- TDC mainly affects open-graded friction courses, not dense-graded wearing layers.
- Due to frequent surface maintenance, TDC severity is generally low or medium.
- The concentration of cracks due to tire blowout is even higher than TDC.

Abstract

Top-down cracking (TDC) is a distress affecting asphalt pavements and consists of longitudinal cracks that initiate on the pavement surface and propagate downwards. In general, TDC is more critical in the case of thick pavements with open-graded friction course (OGFC), which are the typical characteristics of Italian motorway pavements. Recent surveys showed the presence of many longitudinal cracks potentially ascribable to TDC on Italian motorways. Within this context, this study has two main objectives: 1) to define reliable identification criteria allowing to distinguish between TDC and the other types of longitudinal cracks observed and 2) based on the developed criteria, to quantify TDC in Italian motorway pavements. In this regard, a 200 km long trial network (400 km considering both directions) was studied, taking into account the effect of several variables (e.g. geometric characteristics, traffic level, wearing layer type and climate). For this purpose, images of the trial network acquired during pavement monitoring were visually analysed and some control cores were taken. Specific criteria (which can be used in a pavement management system, PMS) were developed to distinguish between the main types of longitudinal cracks observed on the trial network, i.e. TDC, cracks due to heavy vehicles tire blowout and construction joints, based on their geometric features on the pavement surface. It was found that TDC can affect up to 20-30% of the slow traffic lane. Specifically, the highest TDC concentrations were observed for high traffic levels and OGFC, whereas TDC was absent in the case of a dense-graded wearing layer. Finally, surprisingly the concentration of tire blowout cracks was even higher than TDC. This study provides evidence on the fact that, for thick pavements with OGFC, TDC has to be considered a priority problem to be addressed in both pavement design and maintenance.

Key Words
Top-down cracking (TDC); Asphalt pavement; Motorway; Fatigue; Open-graded friction course (OGFC); Pavement Management System (PMS).

1. Introduction

Top-down cracking (TDC) is a distress that affects asphalt pavements [1]. It is ascribable to fatigue failure, which implies a progressive degradation of the material properties due to the application of cyclic stresses that are smaller than the material strength, and consists of longitudinal cracks that initiate on the pavement surface and propagate downwards. Thus, it is different from bottom-up cracking, which is the typical bending-induced fatigue cracking that initiates at the bottom of the asphalt layers due to critical tensile stress/strain conditions and propagates upwards. Bottom-up cracking is a well-known distress in pavement engineering, whereas TDC has begun to be reported in the last 20-30 years [2-9]. Therefore, TDC is not fully understood as much as bottom-up cracking, it is often underestimated in pavement maintenance and generally neglected in the traditional design approach (still widely adopted in several countries), which is mainly aimed at minimizing bottom-up cracking and rutting of the unbound layers.

In general, TDC evolves on the pavement surface in three stages [10-13], as schematized in Figure 1a. Initially, it typically appears on the pavement as a single crack close to the wheelpath. Afterwards, so-called "sister cracks", i.e. new longitudinal cracks parallel to the initial one, appear at a distance of about 0.3-1.0 m. In the third stage, the longitudinal cracks may be connected by short transverse cracks, leading to a cracking pattern that is very similar to that of bottom-up cracking. As for the evolution of TDC along the pavement thickness, the cracks evolve vertically until a certain depth, then they tend to form angles of 20-40° with respect to the vertical plane towards the center of the wheelpath, according to the orientation of the principal stress plane [14], as shown in Figure 1b.

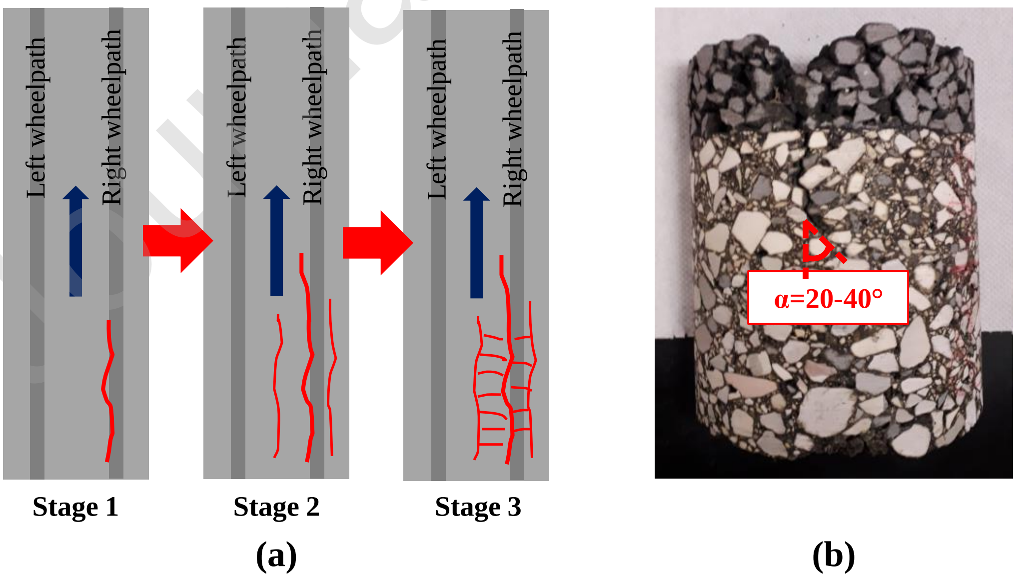

Figure 1 – Evolution of TDC: (a) three-stage evolution on the pavement surface (scheme), (b) evolution with depth (extracted core)

Multiple factors contribute to TDC, including traffic loadings, pavement structure, stiffness gradients, thermal effects, asphalt mixture properties and construction issues [1]. For thick asphalt pavements, the main TDC mechanism is related to the localized tire-pavement contact stresses, which determine the onset of tensile and/or shear stresses at or near the wheelpath [1]. Specifically, three-dimensional finite element analyses highlighted that the development of longitudinal cracks in the wheelpath is due to shear stresses, the tensile stresses due to transverse contact stresses are responsible for longitudinal cracks at a certain distance from the wheelpath, whereas the tensile stresses caused by longitudinal contact stresses can cause the opening of transverse cracks [11]. Such analyses also demonstrated that the longitudinal cracks in the wheelpath are the first to appear, whereas the longitudinal cracks distant from the wheelpath appear later together with the transverse cracks [11], which is consistent with the typical three-stage evolution of TDC on the pavement surface (Figure 1a). The contact stresses in turn strongly depend on the tire characteristics and, in this sense, the relatively recent diffusion of TDC is likely attributable to the growing use of wide base tires (or super-singles) in heavy vehicles instead of dual tires and to the concurrent introduction on the market of radial tires, which are progressively replacing bias ply tires. In fact, it is known that radial tires are responsible for greater contact stresses with the pavement as compared to bias ply ones, and the contact stresses are even greater in the case of wide base radial tires [15]. Conversely, a global bending-induced mechanism, linked to the pavement structural response to traffic loadings, is predominant in the case of thin asphalt pavements. In this case, the cracks tend to develop at a certain distance from the wheelpath, namely where the tensile stress induced on the pavement surface is maximum [16]. Nevertheless, in general, thin pavements are more likely to fail because of bottom-up cracking, whereas thick pavements may undergo a premature and unexpected failure due to TDC [16-18]. From a theoretical point of view, it is even possible to define a thickness of the asphalt layers above which TDC, and not bottom-up cracking, is the predominant fatigue failure mechanism [19]. In this regard, TDC can be more detrimental for robust pavements, i.e. the ones that can be found on the main road network and are designed to have – in theory – extremely long service life.

Moreover, open-graded asphalt mixtures are more prone to TDC as compared to dense-graded mixtures because of their high air void content, which determines lower mechanical properties and higher aging susceptibility. Consequently, pavements with open-graded friction courses (OGFCs) present extremely critical issues in terms of TDC [20]. For instance, some simulations have shown that, in the presence of a wearing layer with significantly lower stiffness than the underlying asphalt layers (as in the case of OGFC), in terms of fatigue behaviour the pavement tends to fail due to TDC rather than bottom-up cracking, regardless of the other boundary conditions [19].

As for the other factors involved in TDC development, stiffness gradients determined by mixture aging and climatic conditions [1, 10, 14, 16] as well as construction issues such as mixture segregation or poor compaction make the pavement more prone to TDC [2-4, 21]. On the contrary, TDC development due to thermal effects is generally considered negligible as compared to that determined by traffic loadings, except in the case of extreme climatic conditions [12, 16].

Based on the previous considerations, it is evident that TDC can be more damaging than other distresses (e.g. bottom-up cracking or rutting) for certain pavements, which thus should be expressly designed against TDC. At the same time, for existing pavements, the correct identification of TDC is essential to implement an effective pavement management system (PMS). On the one hand, in its early stages, TDC might be confused with other types of longitudinal cracks. On the other hand, in its advanced stages, TDC might be mistaken for bottom-up cracking. A wrong identification of the distress would lead to inappropriate maintenance/rehabilitation.

Italian motorway pavements are typical thick pavements, as they generally present a wearing layer of 4-5 cm, a binder layer of 7-10 cm, a base layer of about 15 cm and a 25 cm cement-bitumen treated or cement-stabilized subbase [22]. In addition, to improve the safety in wet conditions, most of the Italian motorway network presents an OGFC characterized by air void content between 15 and 25% . Consequently, Italian motorway pavements are potentially exposed to TDC. This was somehow confirmed by a series of surveys carried out on Italian motorways starting from 2018, which showed the presence of many longitudinal cracks close to the wheelpath.

Within this framework, this study has two main objectives: 1) to define reliable identification criteria allowing to distinguish between TDC and other types of longitudinal cracks and 2) based on the developed criteria, to quantify TDC in Italian motorway pavements. For this purpose, a representative portion of the Italian motorway network was analysed, taking into account also the effect of several variables, such as geometric characteristics, traffic level, wearing layer type and climate.

2. Methodology

2.1 Trial network description

The investigated trial network consisted of about 200 km belonging to four different motorways around the city of Bologna. Since both directions were analysed, about 400 km were surveyed, which is a representative portion of the Italian motorway network. Specifically, only the slow traffic lane was examined, as it is the most affected by heavy traffic.

The main characteristics of the trial network are summarized in Table 1. It can be observed that the motorway sections considered present different geometric characteristics in terms of number of lanes per direction as well as different traffic levels, qualitatively indicated as high, medium or low. In addition, it should be noted that S4 (mountain section) is characterized by a dense-graded wearing course and temperatures can often be below zero in winter, whereas the other three sections (S1, S2, S3) present a typical OGFC and a yearlong mild climate (temperatures below zero occur very rarely). The selected sections can be considered representative of the entire Italian motorway network, as they allow to evaluate the influence of the main variables involved (geometric characteristics, traffic level, wearing layer type, climate).

All the motorway sections analysed are characterized by a speed limit of 130 km/h, a design speed interval between 90 and 140 km/h, a lane width of 3.75 m, a minimum transverse slope in straight of 2.5%, a maximum transverse slope in curve of 7% and a maximum longitudinal slope of 5%, in compliance with the Italian functional and geometric standards concerning the construction of new roads and the modification of existing roads.

2.2 Trial network analysis

The trial network was visually surveyed using Autostrade Google Earth software, which provides various information about the motorway network managed by Autostrade per l'Italia S.p.A., including pavement conditions, geometric characteristics, accident data, etc. Specifically, the ARAN View output images were considered, where ARAN is an acronym that stands for *Automatic Road Analyzer*, which is an equipment used to monitor the regularity of the pavement surface through the *international roughness index* (IRI). In fact, during pavement monitoring, ARAN equipment acquires frames of the pavement with a pitch of about 5 m through a georeferenced camera. The analysed images dated back to the year 2019 and an example is shown in Figure 2. It should be pointed out that the visual analysis of the images was necessary because an automatic image analysis would not have allowed to effectively distinguish TDC and other longitudinal cracks. The definition of specific identification criteria (see Section 3.1) allowed to minimize subjectivity in the image analysis.

Based on the visual inspection of the images, the longitudinal length of the distress was recorded. In addition, TDC along the right wheelpath was distinguished from TDC along the left wheelpath, with the aim of identifying a possible wheelpath-related trend. Moreover, three objective TDC severity levels were defined, as follows:

- Low severity: single longitudinal crack with limited width, almost imperceptible;
- Medium severity: single longitudinal crack with considerable width or presence of parallel sister cracks;
- High severity: longitudinal cracks connected by transverse cracks (similar to bottom-up alligator cracking).

Each TDC distress along the right/left wheelpath was associated with the corresponding severity level, in order to get an overall picture of the pavement conditions in terms of TDC.

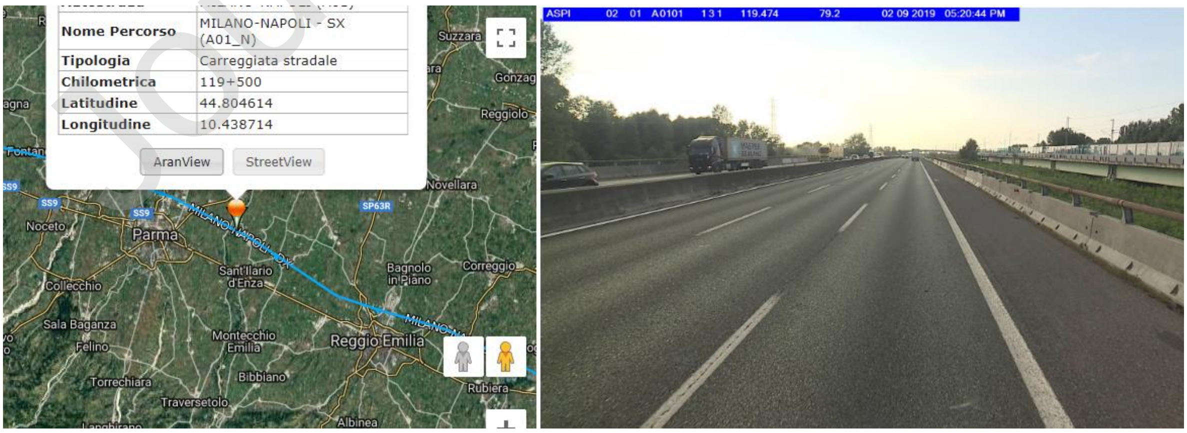

Figure 2 – Example of ARAN View output from Autostrade Google Earth software

3. Results and analyses

3.1 Identification criteria

From the visual analysis of the images and the extraction of some control cores from the cracked areas, three types of longitudinal cracks were observed on the trial network, as schematized in Figure 3: TDC, cracks due to heavy vehicles tire blowout and cracks related to construction joints. It should be noted that in this study (which is part of a larger project focused on TDC) the control cores were just visually examined with the aim of distinguishing the different types of longitudinal cracks. Further cores were taken afterwards to be subjected to an in-depth characterization in a subsequent phase of the project, as better explained in Section 5.

The peculiar evolution of TDC with depth (see Figure 1b) makes such distress easily recognizable from cores. However, reliable identification criteria are still needed to properly (and quickly) identify the distress from a visual inspection of the pavement. Since TDC is ascribable to fatigue failure, it progressively evolves affecting increasing portions of the asphalt layer thickness and gradually compromising the pavement structural properties. Consequently, in the perspective of pavement maintenance, the pavement can be rehabilitated only by milling the asphalt layer thickness affected by TDC and laying new asphalt. A timely rehabilitation allows minimizing pavement damage as well as maintenance costs [14, 23].

The cracks due to heavy vehicles tire blowout are caused by the direct contact between rim and pavement, which is a consequence of the tire blowout. In fact, most heavy vehicle drivers have the bad habit of keeping driving for some km after the tire blowout, in order to exit the motorway at the first useful exit. However, unlike TDC, tire blowout cracks are just incisions on the pavement surface. Therefore, they do not represent a structural distress for the pavement and sealing may be sufficient to prevent more severe distresses (the incision may represent a weak point promoting the development of cracks or ravelling).

The formation of cracks due to construction joints can be avoided, in general, through proper construction techniques and/or sealing. Construction joint cracks may be either superficial or deep: in the second case, the cracks are caused by the reflection of deep construction joints. Nevertheless, usually they are not considered as a structural distress, as they do not directly affect the pavement structural properties.

Based on these considerations, it is clear that identification criteria are needed in order to effectively distinguish non-structural longitudinal cracks and TDC, which is a structural distress.

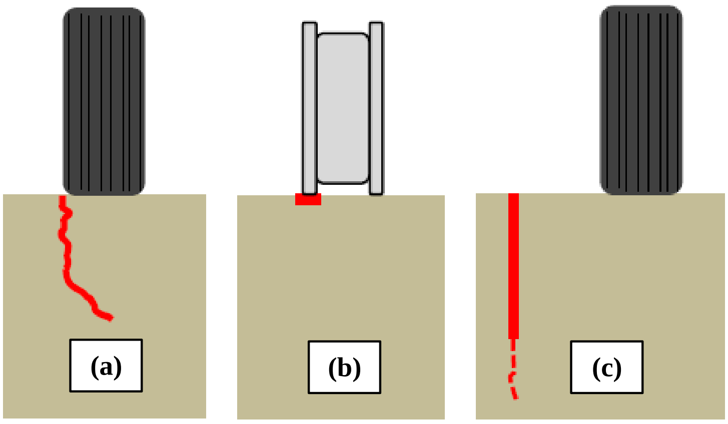

Figure 3 – Types of longitudinal cracks observed on the trial network (scheme): (a) TDC, (b) crack due to tire blowout, (c) construction joint

The following criteria were developed to identify TDC:

- A top-down crack appears rectilinear at a global observation scale, whereas – as compared to the other types of longitudinal cracks observed on the trial network – it presents a more irregular pattern at a small observation scale, following the edge of coarser aggregate particles;
- In advanced distress stages, TDC can be recognized by the peculiar presence of sister cracks and/or longitudinal cracks connected by multiple transverse cracks. For this reason, it is unlikely that a single top-down crack reaches lengths greater than 100 m (as an order of magnitude);
- In addition, for control purposes, it is recommended that cores taken from pavement areas affected by TDC have a diameter of at least 150 mm, because smaller diameters may not allow to properly identify the crack due to the material loss caused by coring operations.

Figure 4 shows an example of TDC, confirmed by the extraction of a core presenting a crack initiated at the pavement surface and propagated downwards. As can be seen from the figure, in order to better analyse the crack, the core was cut vertically perpendicular to the wheelpath direction.

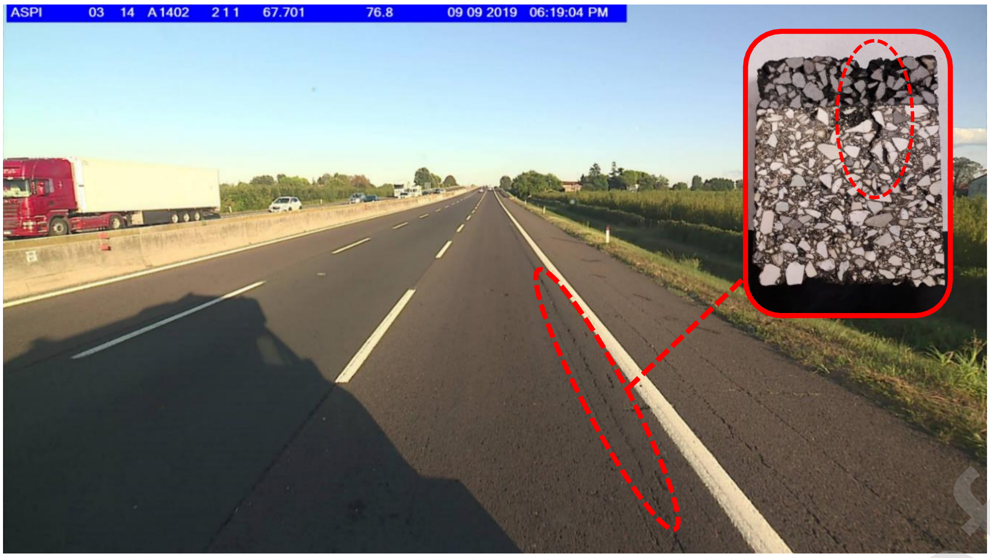

Figure 4 – Example of TDC

Cracks due to tire blowout are usually located in the wheelpath area and thus they may be wrongly identified as TDC. In order to avoid this, the following criteria were developed:

- In many cases the tire blowout crack deviates to the right because the driver progressively turns towards the emergency lane, a parking area or the motorway exit;
- Many tire blowout cracks are dashed because of the discontinuous contact between rim and pavement;
- A typical tire blowout crack appears as a straight incision on the pavement surface without any irregularity both at global and small observation scales;
- In the case of tire blowout cracks, the aggregates are evidently scratched due to the contact with the metal rim.

An example of a crack due to tire blowout is shown in Figure 5 together with the corresponding cores. It can be observed that the cores do not exhibit any crack along the pavement thickness but only an incision on the surface, accompanied by scratched aggregates.

Figure 5 – Example of crack due to tire blowout

Conversely, the identification of construction joints was relatively easy because of the following reasons:

- Most of the construction joint cracks are found distant from the wheelpath, typically at the horizontal markings between the lanes;
- Only in few cases construction joint cracks may be located close to the wheelpath, for instance in the presence of entry/exit lanes or narrow emergency lanes as well as in the case carriageway widening;
- As compared to TDC, construction joints are characterized by a more regular pattern at a small observation scale.

As an example, Figure 6 shows a construction joint in the wheelpath area due to the presence of an entry lane.

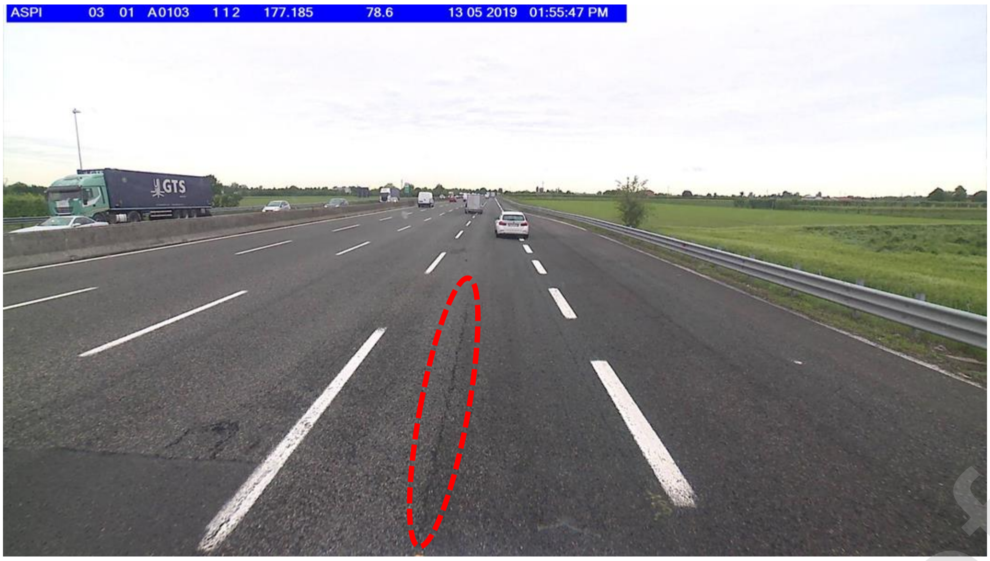

Figure 6 – Example of construction joint in the case of an entry lane

The proposed identification criteria, which aim at minimizing subjectivity in the visual analysis of the pavement surface, can be extremely useful to implement the assessment of TDC distress at a network level in a PMS. The extraction of one core every 100 m of longitudinal crack (as an order of magnitude), combined with the observation of the pavement surface based on these criteria, should be sufficient to confirm the different types of longitudinal cracks.

3.2 Top-down cracking quantification

Based on the identification criteria presented in Section 3.1, total TDC was quantified as follows:

$$TDC\ (\%) = \frac{l_{TDC}}{l_0} \cdot 100 \qquad (1)$$

Where *TDC* (%) is TDC total concentration (i.e. related to both the right and left wheelpaths) on the slow traffic lane, l_{TDC} is TDC cumulated length (related to both the right and left wheelpaths) on the slow traffic lane, l_0 is the length of the analysed section.

The results are shown in Figure 7, where the sections are coded as follows (see Table 1):

- The first part of the code (S1/S2/S3/S4) indicates the motorway;
- The second part of the code (N/S/E/W) indicates the motorway direction (i.e. carriageway);
- The third part of the code (2/3/4) indicates the number of lanes per direction.

Except for the isolated case of S3_E_2, the highest TDC concentrations (up to 20-25%) were generally observed for section S1, which is the only one characterized by a high traffic level. This finding confirms that traffic loadings are the main factor contributing to TDC, as widely acknowledged in literature [1, 12, 16]. However, it should be pointed out that these results may be underestimated, because large portions of section S1 underwent recent rehabilitation. In fact, it was observed that several older portions of the pavement, included between two portions recently rehabilitated, presented TDC. It is likely that, before rehabilitation, TDC affected larger portions of the pavement.

Despite a medium but still significant traffic level, lower values of TDC concentration were found for section S2, probably because of the shorter age of the pavement. This outcome highlights that, under important traffic loadings, the asphalt mixture aging may play a major role in TDC development, as already demonstrated by several authors [1, 10, 14, 16].

On the contrary, the high TDC concentration observed for section S3, characterized by a low traffic level, may likely be attributed to the old in-service age of the pavement and the consequent asphalt mixture aging. Moreover, it cannot be excluded that other factors such as stiffness gradients, thermal effects and/or construction issues may have contributed to the extremely high TDC concentration observed for S3_E_2 (more than 30%).

It is worth noting that, even though the pavement age is a key factor in TDC development, in this context it would be extremely difficult to report the age of each single pavement stretch, because the sections analysed (like most of the Italian motorway network) are characterized by numerous surface maintenance interventions (i.e. patches) with length of 100 m or even less. The in-depth analysis of the effect of age for limited pavement portions is currently under study, as briefly described in Section 5.

Conversely, the mountain section S4, the only one presenting a dense-graded wearing course, did not exhibit any TDC despite a medium traffic level and a cold winter climate. As expected, the presence of an OGFC, characterized by reduced mechanical properties as well as possible accelerated aging, promotes TDC initiation and propagation, whereas the distress is much less likely to occur in the case of dense-graded wearing courses. The effect of the climate appears to be limited.

Overall, the previous observations underline that TDC cannot be neglected in the design and maintenance of Italian motorways, especially in the case of OGFC.

Finally, no clear correlations between TDC and motorway direction or number of lanes per direction emerged. However, it is worth pointing out that, in the sections characterized by 4 lanes per direction, some sporadic longitudinal cracks ascribable to TDC were observed from the analysed images also on the second lane. This data, observed qualitatively but not quantified, could be explained considering that heavy vehicles tend to travel also the second lane when the motorway presents a greater number of lanes per direction and the volume of heavy traffic is high.

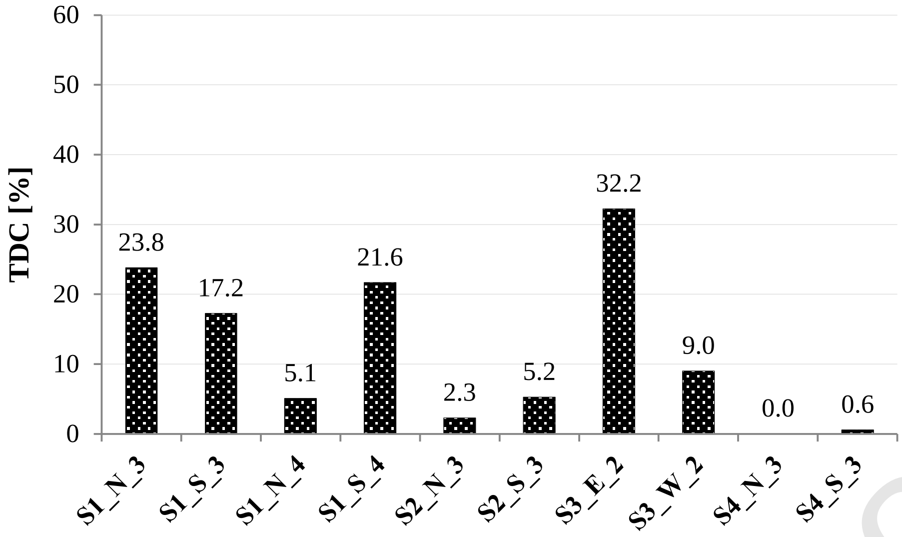

Figure 7 – Total TDC amount

As anticipated in Section 2.2, TDC along the right wheelpath and TDC along the left wheelpath of the slow traffic lane were differentiated and quantified as follows:

$$TDC_{right/left}\,(\%) = \frac{l_{TDC\_right/left}}{l_0} \cdot 100 \tag{2}$$

Where $TDC_{right/left}$ (%) is TDC concentration along the right/left wheelpath on the slow traffic lane, $l_{TDC\_right/left}$ is TDC cumulated length along the right/left wheelpath on the slow traffic lane, l_0 is the length of the analysed section.

It should be specified that, in the calculation of TDC total concentration (Equation (1)), the pavement portions in which TDC was observed along both the right and the left wheelpaths were computed only once (not twice). Consequently, the following relationships exist between *TDC* (%), TDC_{right} (%) and TDC_{left} (%):

$$max\{TDC_{right}\,(\%), TDC_{left}\,(\%)\} \leq TDC\,(\%) \leq TDC_{right}\,(\%) + TDC_{left}\,(\%) \tag{3}$$

Figure 8 shows that there is no well-defined trend, as the distress is more concentrated along the right wheelpath in some cases and along the left wheelpath in other cases. Once again, it is worth noting that these results are affected by the numerous recent patches observed on the network (which make the previous TDC position unknown) and it cannot be excluded that a more evident trend existed before patching. However, inertial effects in curve can be considered negligible due to the high minimum planimetric radius for the sections examined (equal to 339 m), which makes a statistical analysis related to the planimetric characteristics pointless. Therefore, it can be reasonably concluded that the distribution of the distress is random, likely determined by the local pavement/mixture characteristics.

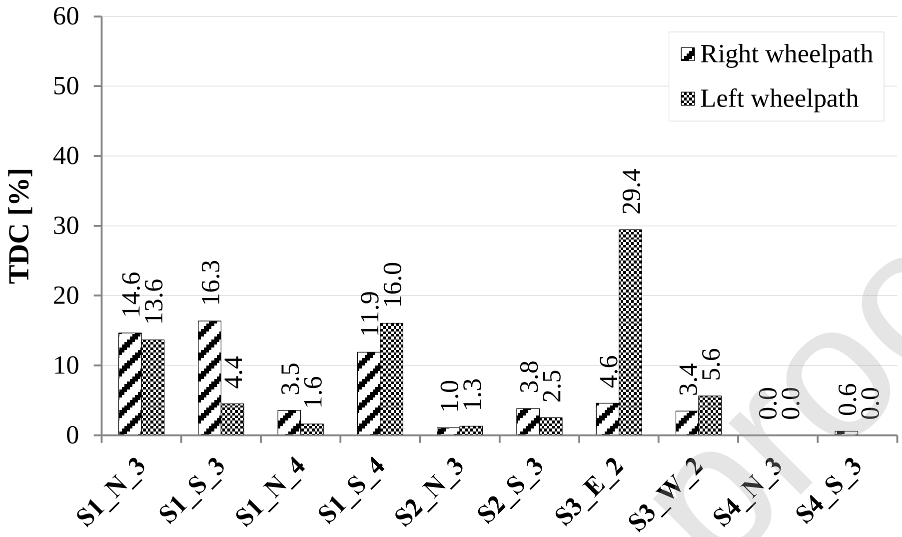

Figure 8 – TDC amount along the right and left wheelpaths

The results presented in Figure 8 were further analysed to distinguish different TDC severity levels (defined as in Section 2.2), as follows:

$$\%\,TDC_{right\_LOW/MEDIUM/HIGH} = \frac{l_{TDC\_right\_LOW/MEDIUM/HIGH}}{l_{TDC\_right}} \cdot 100 \quad (4)$$

Where % $TDC_{right\_LOW/MEDIUM/HIGH}$ is the percentage of TDC with low/medium/high severity along the right wheelpath on the slow traffic lane, $l_{TDC\_right\_LOW/MEDIUM/HIGH}$ is TDC cumulated length with low/medium/high severity along the right wheelpath on the slow traffic lane, l_{TDC_right} is TDC cumulated length along the right wheelpath on the slow traffic lane. An analogous formula was considered for TDC along the left wheelpath.

Figures 9 and 10 show that, in most cases, TDC severity was low (single longitudinal crack with limited width) or medium (single longitudinal crack with considerable width or sister cracks). For instance, as regards the high TDC concentration along the left wheelpath for section S3_E_2 (almost 30%), 95% of the distress presented low severity. High severity level (longitudinal cracks connected by transverse cracks) was basically found only on the older pavement portions of section

S1 (the one with the most significant heavy traffic level). The prevalence of low severity distress is attributable to the frequent surface maintenance carried out on the motorway network.

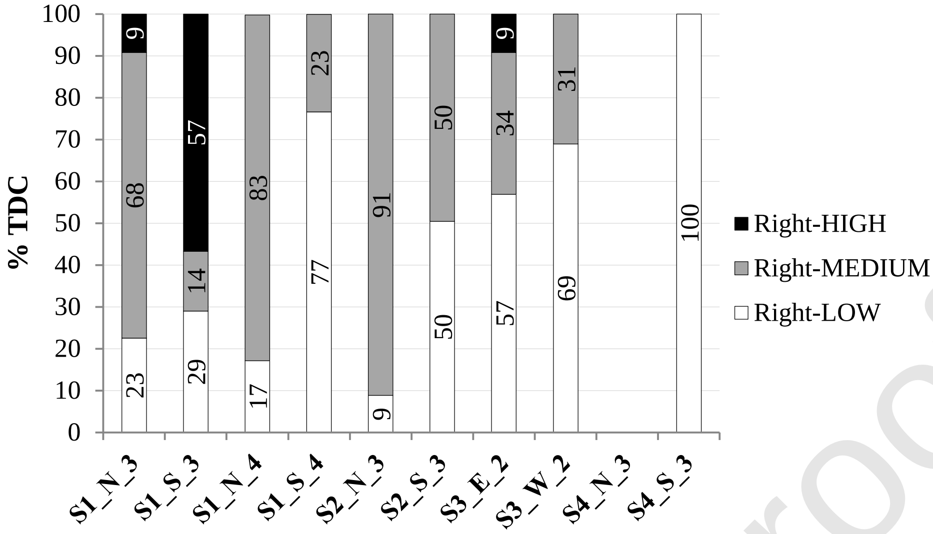

Figure 9 – TDC severity, right wheelpath

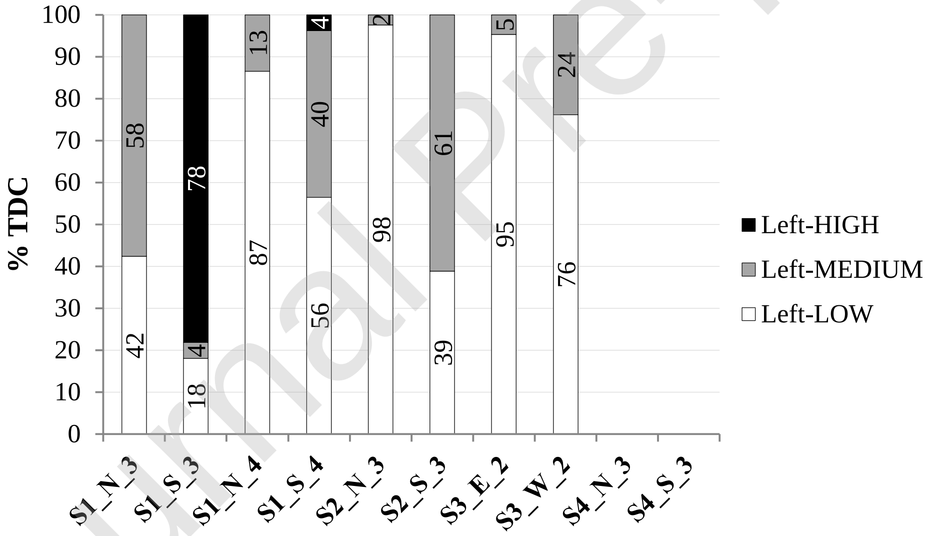

Figure 10 – TDC severity, left wheelpath

In addition, during the analysis of the ARAN View images from Autostrade Google Earth software, a remarkable diffusion of cracks due to tire blowout was observed. Therefore, their concentration on the slow traffic lane of each section was quantified as follows:

$$Cracks\ due\ to\ tire\ blowout\ (\%) = \frac{l_{TBC}}{l_0} \cdot 100 \quad (5)$$

Where l_{TBC} is the cumulated length of cracks due to tire blowout on the slow traffic lane and l_0 is the length of the analysed section. As can be noted from the comparison between Figure 11 and Figure 7, surprisingly the concentration of cracks due to heavy vehicles tire blowout was even higher than TDC (in some cases, up to 40-50%). This finding highlights once again the importance of defining specific identification criteria which allow to distinguish between TDC and other types of longitudinal cracks in the perspective of pavement maintenance/rehabilitation (i.e. in a PMS).

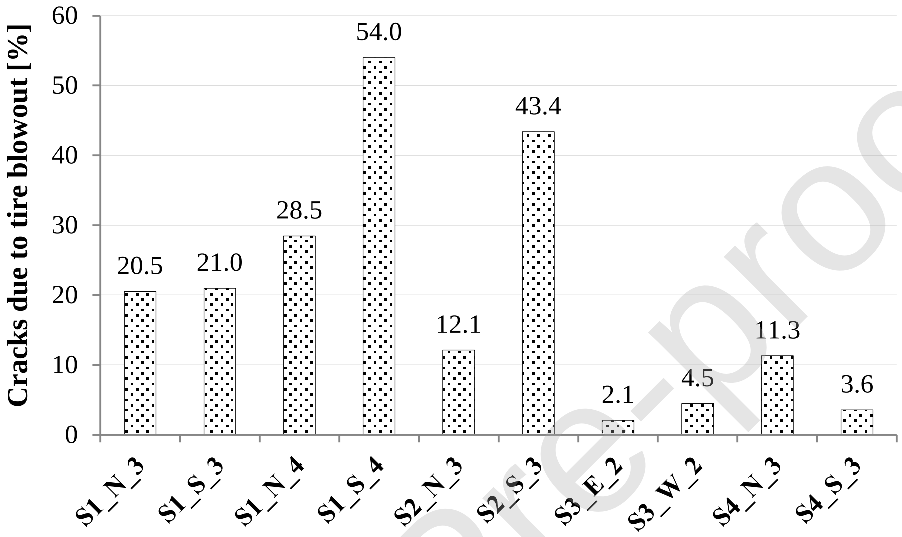

Figure 11 – Amount of cracks due to tire blowout

4. Conclusions

This paper presented a case study concerning top-down cracking (TDC) in Italian motorway pavements. A trial network consisting of 200 km (400 km considering both directions) belonging to four different motorways was surveyed, by visually analysing images acquired during pavement monitoring. The effect of several variables was assessed, including geometric characteristics, traffic level, wearing layer type and climate.

The analysis of the images, supported by the extraction of some control cores, indicated the diffusion of three types of longitudinal cracks: TDC, cracks due to heavy vehicles tire blowout and construction joints. In order to avoid that the latter two types (non-structural distresses) were wrongly identified as TDC (structural distress), rational unambiguous identification criteria were proposed, which can be useful for the implementation of TDC in a pavement management system (PMS).

The analysis of the trial network, based on the proposed identification criteria, led to the following conclusions:

- Depending on the traffic level, the wearing course type and the pavement age, TDC can affect up to 20-30% of the slow traffic lane. Specifically, the highest TDC concentrations are observed on the older portions of the trial section characterized by high traffic level and open-graded friction course (OGFC), whereas TDC is totally absent in the trial section with dense-graded wearing layer.
- TDC is more concentrated along the right wheelpath in some cases and along the left wheelpath in other cases, i.e. the distribution of the distress appears to be random, likely determined by the local pavement/mixture characteristics.
- Due to frequent surface maintenance, TDC severity is generally low (single longitudinal crack with limited width) or medium (single longitudinal crack with considerable width or sister cracks). High severity level (longitudinal cracks connected by transverse cracks) is observed only on the older pavement portions of the section with the most significant heavy traffic level.
- Surprisingly, the concentration of cracks due to heavy vehicles tire blowout is even higher than TDC (in some cases, up to 40-50% of the slow traffic lane), further highlighting the importance of the developed identification criteria.

In summary, this study provides evidence of the importance of TDC distress, especially for pavements with certain characteristics (e.g. thick pavements with OGFC). Based on the results emerged, road agencies should be fully aware of considering TDC as a priority problem in the perspective of pavement design and maintenance, thus adopting adequate measures to implement TDC in the common design practices as well as in PMSs. Finally, it should be noted that the identification criteria were validated based on selected control cores. Refining of the proposed criteria could lead to a more precise quantification of TDC and other longitudinal cracks.

5. Future work

As a follow-up of the survey described in this paper, a series of cores were taken both from the wheelpath areas and the intact pavement areas of the trial sections.

Currently, the cores affected by TDC are being examined in order to define possible correlations between crack depth and number of applied traffic loadings and/or between crack depth and crack width. Preliminary observations have shown that, in the case of OGFC, it is difficult to assess the crack width due to the mixture ravelling at the edge of the cracks (as an example, see the upper part of the core in Figure 1b).

Meanwhile, the cores from the intact pavement areas are being subjected to an in-depth characterization aimed at correlating the TDC performance of the OGFC with factors such as the volumetric and mechanical properties of the mixture and the pavement age. The experimental characterization of the TDC performance of asphalt mixtures is requiring some efforts, because at the moment there are no laboratory test methods universally acknowledged as suitable to assess whether a mixture is more or less prone to TDC. Most of the test methods proposed for TDC are currently used to study the cracking performance of asphalt mixtures in terms of bottom-up cracking or reflective cracking [13, 24], whereas a small part of the proposed methods study the shear properties of the asphalt mixture [25, 26]. Other methods have been specifically developed for TDC [27, 28], but they are less consolidated.

The results of these ongoing studies, which could lead to TDC decay models/laws useful for pavement design and maintenance purposes, will be the focus of future papers. Specifically, such models/laws could allow to assess the evolution of TDC depth over time and, in the perspective of a PMS, to define TDC rehabilitation depth while simultaneously minimizing the number of control cores needed.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] Luo X., Gu F., Ling M., Lytton R. L., "Review of Mechanistic-Empirical Modeling of Top-Down Cracking in Asphalt Pavements", Construction and Building Materials, 191, 1053-1070, 2018.

[2] Baladi G. Y., Schorsh M., Svasdisant T., "Determining the Causes of Top-Down Cracks in Bituminous Pavements", Michigan Department of Transportation, Final Report, 2003.

[3] Harmelink D., Aschenbrener T., "Extent of Top-Down Cracking in Colorado", Colorado Department of Transportation, Final Report, 2003.

[4] Pellinen T., Rowe G., Biswas K., "Evaluation of Surface (Top Down) Longitudinal Wheel Path Cracking", Indiana Department of Transportation, Final Report, 2004.

[5] Matsuno S., Nishizawa T., "Mechanism of Longitudinal Surface Cracking in Asphalt Pavement", Proceedings of the 7th International Conference on the Structural Design of Asphalt Pavements, 1992.

[6] Wambura J. H. G., Maina J., Smith H. R., "Kenya Bituminous Materials Study", Transportation Research Record: Journal of the Transportation Research Board, 1681, 129-137, 1999.

[7] Hugo F., Kennedy T. W., "Surface Cracking of Asphalt Mixtures in Southern Africa", Journal of the Association of Asphalt Paving Technologists, 54, 454-501, 1985.

[8] Dauzats M., Rampal A., "Mechanism of Surface Cracking in Wearing Courses", Proceedings of the 6th International Conference on the Structural Design of Asphalt Pavements, 1987.

[9] Gerritsen A. H., van Gurp C. A. P. M., van der Heide J. P. J., Molenaar A. A. A., Pronk A. C., "Prediction and Prevention of Surface Cracking in Asphaltic Pavements", Proceedings of the 6th International Conference on the Structural Design of Asphalt Pavements, 1987.

[10] Svasdisant T., Schorsch M., Baladi G. Y., Pinyosunun, S. "Mechanistic Analysis of Top-Down Cracks in Asphalt Pavements", Transportation Research Record: Journal of the Transportation Research Board, 1809, 126-136, 2002.

[11] Gu F., Luo X., West R. C., Taylor A. J., Moore N. D., "Energy-Based Crack Initiation Model for Load-Related Top-Down Cracking in Asphalt Pavement", Construction and Building Materials, 159, 587-597, 2018.

[12] Ling M., Luo X., Chen Y., Hu S., Lytton R. L., "A Calibrated Mechanics-Based Model for Top-Down Cracking of Asphalt Pavements", Construction and Building Materials, 208, 102-112, 2019.

[13] Chen C., "Validation of Laboratory Cracking Tests for Field Top-Down Cracking Performance", PhD Dissertation, Auburn University, 2020.

[14] Myers L. A., Roque R., "Top-Down Crack Propagation in Bituminous Pavements and Implications for Pavement Management", Journal of the Association of Asphalt Paving Technologists, 71, 651-670, 2002.

[15] Myers L. A., Roque R., Ruth B. E., Drakos C., "Measurement of Contact Stresses for Different Truck Tire Types to Evaluate Their Influence on Near-Surface Cracking and Rutting", Transportation Research Record: Journal of the Transportation Research Board, 1655, 175-184, 1999.

[16] Roque R., Zou J., Kim Y. R., Baek C., Thirunavukkarasu S., Underwood B. S., Guddati M. N., "Top-Down Cracking of Hot-Mix Asphalt Layers: Models for Initiation and Propagation", NCHRP Web-Only Document 162 (NCHRP Project 1-42A), 2010.

[17] Uhlmeyer J. S., Willoughby K., Pierce L. M., Mahoney J. P., "Top-Down Cracking in Washington State Asphalt Concrete Wearing Courses", Transportation Research Record: Journal of the Transportation Research Board, 1730, 110-116, 2000.

[18] Mun S., Guddati M. N., Kim Y. R., "Fatigue Cracking Mechanism in Asphalt Pavements with Viscoelastic Continuum Damage Finite Element Program", Transportation Research Record: Journal of the Transportation Research Board, 1896, 96-106, 2004.

[19] Nikolaides A., Manthos E., "Determination of Asphalt Layer Thickness above which Load-Induced Strains Initiate Top-Down Cracking and the Effect of Asphalt Stiffness Variation between Wearing Course and Rest of Asphalt Layers", Proceedings of the 7th International Conference 'Bituminous Mixtures and Pavements' (7ICONFBMP), 2019.

[20] Chen Y., Tebaldi G., Roque R., Lopp G., Su Y., "Effects of Interface Condition Characteristics on Open-Graded Friction Course Top-Down Cracking Performance", Road Materials and Pavement Design, 13 (sup1), 56-75, 2012.

[21] Harmelink D., Shuler S., Aschenbrener T., "Top-Down Cracking in Asphalt Pavements: Causes, Effects, and Cures", Journal of Transportation Engineering, 134, 1-6, 2008.

[22] Stimilli A., Frigio F., Canestrari F., Sciolette S., "In-Plant Production of Warm Recycled Mixtures Produced with SBS Modified Bitumen: A Case Study", Transport Infrastructure and Systems - Proceedings of the AIIT International Congress on Transport Infrastructure and Systems, TIS 2017, 143-151, 2017.

[23] Kumara M. W., Gunaratne M., Lu J. J., Dietrich B., "Methodology for Random Surface-Initiated Crack Growth Prediction in Asphalt Pavements", Journal of Materials in Civil Engineering, 16 (2), 175-185, 2004.

[24] Zhou F., Newcomb D., Gurganus C., Banihashemrad S., Park E. S., Sakhaeifar M., Lytton R. L., "Experimental Design for Field Validation of Laboratory Tests to Assess Cracking Resistance of Asphalt Mixtures", NCHRP Project 09-57 Final Report, 2016.

[25] Ma Z., Liu L., Sun L., "Investigation of Top-Down Cracking Performance of In-Situ Asphalt Mixtures Based on Accelerated Pavement Testing and Laboratory Tests", Construction and Building Materials, 179, 277-284, 2018.

[26] Sun L., Wang G., Zhang H., Liu L., "Initiation and Propagation of Top-Down Cracking in Asphalt Pavement", Applied Sciences, 8 (5), 774, 2018.

[27] Roque R., Birgisson B., Drakos C., Dietrich B., "Development and Field Evaluation of Energy Based Criteria for Top-Down Cracking Performance of Hot Mix Asphalt", Journal of the Association of Asphalt Paving Technologists, 73, 229-260, 2004.

[28] Chen Y., Tebaldi G., Roque R., Lopp G., "Development of a Composite Specimen Interface Cracking (CSIC) Test for Top-Down Cracking", Journal of Testing and Evaluation, 41 (4), 625-634, 2013.

Table 1 – Characteristics of the trial network

Section	S1	S2	S3	S4
Motorway	A1 MILANO-NAPOLI (DT3)	A14 BOLOGNA-TARANTO (DT3)	A14 DIRAMAZIONE RAVENNA (DT3)	A1 MILANO-NAPOLI (DT4)
Section	Ponte Fiume Enza - All. A14	All. Dir. Ravenna - A14	All. A14 - S.S. Romea	Sasso Marconi - All. Variante di Valico
From km	119+500	56+700	0+000	210+100
To km	188+900	143+900	29+800	220+000
Length [km]	69.4	87.2	29.8	9.9
Directions	North/South	North/South	East/West	North/South
N. lanes/direction	3 (km 119+500 - 155+500) 4 (km 155+500 - 188+900)	3	2	3
Traffic level	High	Medium	Low	Medium
Wearing course	OGFC	OGFC	OGFC	Dense-graded
Climate	Mild	Mild	Mild	Cold winter