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SURFACE DRAINAGE AND AQUAPLANING RISK IN ROAD INFLECTION ZONES

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Abstract

According to Federal Highway Administration, up to 70% of weather-related accidents occur on wet pavement or in inclement weather. Consequently, surface drainage is one of the most challenging road safety problems. Efficiency of pavement surface drainage depends on numerous factors: pavement surface geometry, rainfall intensity and duration, pavement hydraulic properties etc. In general, the most critical locations are those where the low pavement cross grades are combined with shallow longitudinal grades of the road. This is typical for inflection zones (central parts of reverse curves) in flat terrain, where gentle longitudinal grades are applied. In these areas, insufficient total pavement grades induce thicker water film, increasing the risk of aquaplaning. Most of the analytical tools for the assessment of water film depth on the pavement surface originate from distant countries, countries with the climatological conditions and even design practices differing greatly from the European ones. According to some of the most relevant analytical procedures, even the range of surface flow path lengths is inadequate in comparison to the long surface flow paths in the inflection zones of the European motorways. Moreover, climatic changes taking place in recent years must be addressed as well. This paper presents plan of investigating surface drainage and aquaplaning risks in the road inflection zone, with the final goal of augmenting and updating national standards.

Keywords: aquaplaning, water film depth, surface flow path length, infection zones, climate changes

1 Introduction

Providing efficient drainage of pavement surfaces is one the most challenging road safety problems, especially on motorways and roads with wide carriageway. Generally, the most severe surface drainage problems might be expected at the locations where low pavement cross grades are combined with shallow longitudinal grades. This is typical for road inflection zones (central parts of reverse, or “S”, curves) where the pavement cross grade changes its direction from left to right and vice versa. With the pavement surface getting wider (motorway case) and in flat terrain (shallow longitudinal grade) surface drainage conditions are getting worse [1]. Poor surface drainage conditions, combined with high operating speeds on motorways, might cause aquaplaning (or hydroplaning) and severe traffic accidents.

In order to avoid preconditions of aquaplaning in road inflection zones, variety of measures (ranging from geometrical design and construction methods to traffic control) can be undertaken. German motorway design guidelines [2] recommend a set of measures to be applied in the zones with poor surface drainage. Recently, a comprehensive research study on the se-

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lection of appropriate measures of eliminating/mitigating aquaplaning occurrence in motorway inflections zones was published [3]. In this study, range of solutions regarding durability, physical characteristics, construction methods and investment costs, were examined and evaluated. Also, the study demonstrated that the selection of optimal solution depends on local conditions, such as number of lanes, type of pavement structure (asphalt or concrete pavement) and longitudinal and cross grades.

Aquaplaning risk assessment includes two steps. The first step is calculating the depth of a flow (water film thickness) over pavement surface. The second step is comparison of calculated water film thickness and critical water film thickness. Critical water film thickness is the depth for which, for exact operating speed, aquaplaning occurs. Among road geometry, pavement texture and rutting, rainfall intensity and tyre tread depth, previous studies [4-7] clearly state that the water film depth (WFD) stands out as the most important factor causing aquaplaning. For WFDs of 3 to 4 mm aquaplaning potential rises, while for the WFDs of 4 to 6 mm the risk of aquaplaning gets very high [8].

In 1970s, West European motorway network was expanding rapidly. During that time, the first studies investigating relationship between geometrical parameters of the road and WFD were published [9]. Superelevation concept has the most profound effect on the total gradient, on the length of the surface flow path and, consequently, on WFD. Due to its importance for aquaplaning risk assessment, this topic has been addressed in the paper.

2 The use of Gallaway formula for water film depth assessment

Several theoretical and empirical methods were developed to predict the depth of the water film over pavement surface. The most popular method was developed by Gallaway et al. [10, 11] for the USA Federal Highway Administration (FHWA). In this method WFD is calculated by the following equation Eq. (1):

$$D = \frac{0.103 \times T^{0.11} x\, L^{0.43} x\, I^{0.59}}{S^{0.42}} - T \tag{1}$$

where:

D – water film depth above the top of pavement texture (mm)
T – average pavement texture depth (mm)
L – length of surface flow path (m)
I – rainfall intensity (mm/h)
S – grade of surface flow path (%)

Previous formula represents the metric version of the equation used for WFD calculation by Gallaway method. However, since the Gallaway equation is an empirical formula based on the experimental results, it has certain limits regarding the range of values that can be used as input parameters:

- surface flow path length of up to 14.6 m
- rainfall intensity of up to 50.8 mm/h
- grades up to 8%

It should be emphasized that Gallaway method is one-dimensional and it can be used only to assess the depth of flow along a single (zero width) flow path [12]. The Gallaway formula cannot produce correct WFDs in cases where the flow of surface water changes its direction due to superelevation (due to cross grade changes). Though national road authorities in the majority of the US federal states and Australia [13] still recommend application of the Gallaway method for calculating WFD, its application in most of the European countries with dense motorway network is highly questionable. New Zealand Transport agency does not recommend the application off Gallaway equation either [14].

For the city of Belgrade in Serbia, the 2-year return period rainfall (duration of 10 min and the rainfall intensity of 145 lit/s/ha) is taken as critical one for the design of stormwater drainage systems for local streets. This corresponds to precipitation of 52.2 mm/h, which is already slightly above the maximum criteria for Gallaway's formula. What is more, stormwater drainage system of motorways has to be designed with the 10-year return period rainfall. Consequently, it is obvious that Gallaway's formula is incompatible with the expected rainfall intensities in Serbia and the neighbouring countries. The maximum total grade of the pavement (8%) is generally compatible with the roads in Western Balkan region. However, the maximum length of the surface flow path (14.6 m) is definitely incompatible with the road network in the region.

3 Surface flow path lengths in superelevation transition section

In Fig. 1 surface flow path in the inflection zone of a 2 x 11.5 m motorway is shown. Single pavement (carriageway), 115 m long, is presented. Upper section presents the carriageway with the longitudinal grade s = 0.5%, while lower section presents the carriageway of longitudinal grade s = 4%. Superelevation rate of 0.5% is applied in both cases, with the centerline (axis of pavement rotation) aligned with pavement inner edge.

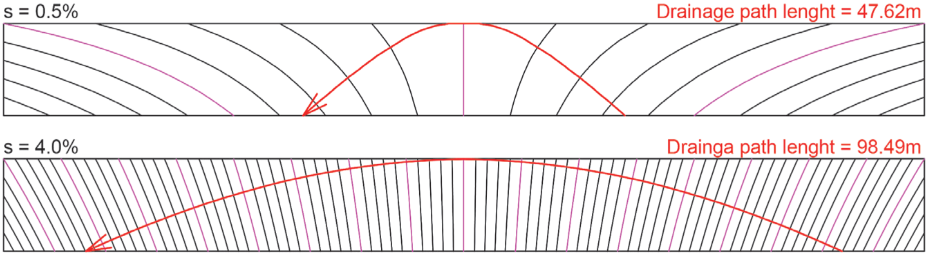

Figure 1 Surface flow path in the motorway inflection zone

As the longitudinal grade increases, the total gradient vector of the pavement surface gets more aligned with the direction of the longitudinal grade vector. As a consequence, in the inflection zones located on steep longitudinal grades, surface flow path length gets significantly longer (lower section in Fig. 1).

Fig. 2 shows how the surface flow path length vary with longitudinal grade, for three different carriageway categories. Roadway width of 8 m and 11.5 m represent expressway and motorway carriageway, respectively. Both pavement surfaces are superelevated around the inner carriageway edges. Width of 7.2 m refers to the two-lane road which is superelevated around its central axis. From Fig. 2 it can be concluded that the surface flow path length increases with both the longitudinal grade and the pavement width.

The application of the Gallaway's formula on the three previously analysed road carriageways (B = 11.5 m, B = 8 m, B = 7.2 m), with variable longitudinal grades, is shown in Fig. 3. The rainfall intensity of 52.2 mm/h (slightly above the maximum rainfall intensity recommended by Gallaway 50.8 mm/h) is used. It should also be stressed that the values of surface flow path lengths are significantly larger than the maximum length applicable with Gallaway formula (14.6 m).

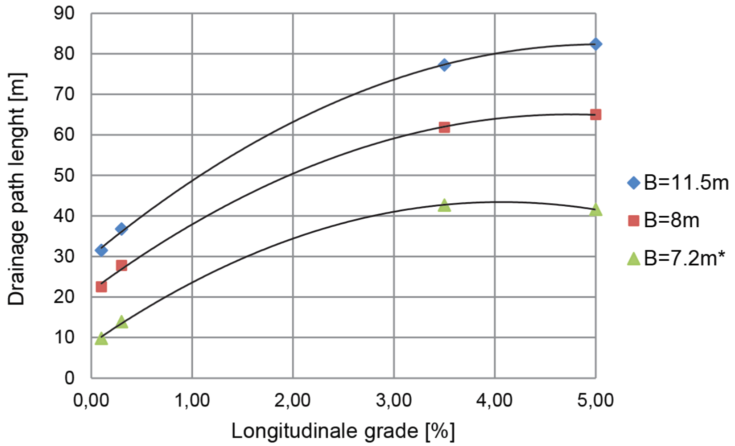

Figure 2 Surface flow path length vs. longitudinal grade

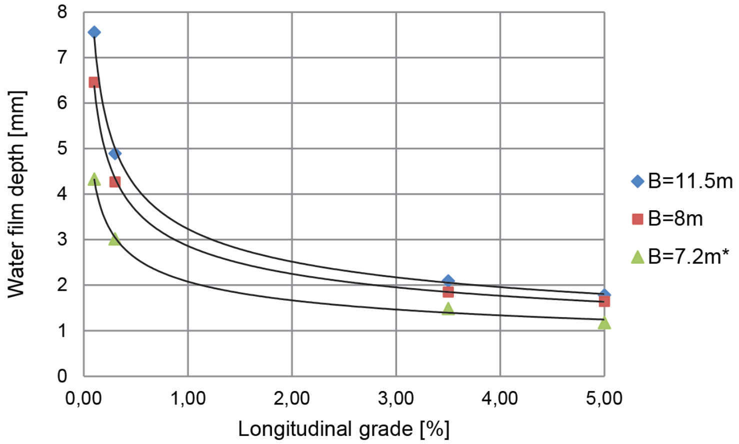

Figure 3 WFD calculation according to Gallaway's formula

4 Longitudinal grade impact

Longitudinal grade profoundly influences surface drainage conditions and, consequently, aquaplaning risk. Nevertheless, only in a few national road design standards, exact instructions relating aquaplaning risk to longitudinal grade are given. In a detailed study [1] it is found that the maximum ponding depth (maximum WFD) is not too sensitive to longitudinal grade, while the exact location of maximum ponding depth on the pavement surface is much more dependent on the longitudinal grade.

Serbian road design guidelines [15, 16] determine the minimum longitudinal grade for the road that is to be constructed on the fill and for the road to be placed in the cut. However, there are no limitations regarding minimum longitudinal grades that should be implemented in motorway inflection zones, depending on the carriageway width and the adopted superelevation concept.

5 Climate change impact

Numerous studies addressing the impact of climate change on transportation infrastructure have been published. In general, due to significantly higher thermal stresses induced by the rise in average yearly temperatures, concrete pavements are more susceptible to climate changes than flexible pavements [17]. However, a very few of the studies discuss possible impact of climate change on the pavement superelevation and aquaplaning [18]. Rainfall intensity, representing one of the key input parameters for WFD assessment, has also been changed in recent decades. Gallaway equation is based on the experimental research carried out in the 1970s. Since the rainfall intensities have changed considerably, not only in the USA, but also in the rest of the World, new data on rainfall intensities must be separately collected for specific climate zones.

6 Conclusion

In this paper influence of road anatomy on surface drainage and aquaplaning risk in the road inflection zone is analysed. Surface flow path length, as the decisive parameter influencing the water film depth (WFD), is specially addressed.

It was clearly demonstrated that Gallaway's formula is not reliable method for WFD calculations, as the surface flow path length applicable by Gallaway is by far shorter than the length expected in the European motorway inflection zones. With the increase in both carriageway width and longitudinal grade, the differences in surface flow path lengths become even higher, thus seriously undermining the application of the Gallaway's formula for any new motorway projects.

Additional concern is reliability of stormwater data, especially rainfall intensities, which also represents a key input parameter for precise WFD. This issue becomes more significant if climate change trends and their devastating impact on road infrastructure are taken into consideration.

In future research, due to its importance for mitigation of aquaplaning potential, the author team plans to investigate how the longitudinal grade affects the amount of ponding in the motorway inflection zones for various pavement superelevation concepts and different carriageway widths. The results and findings obtained will be used to update Serbian road design guidelines.

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