ADAPTATION MEASURES TO THE CHALLENGES OF CLIMATE CHANGE IN HUNGARIAN ROAD CONSTRUCTION

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ABSTRACT

Climate change has been observed in the past decades, and its acceleration is expected. It is obvious that this continuously changing process has (can have) harming effects to road infrastructure, as well. Recognizing this very fact, an adaptation process to climate change in road construction (with special emphasis to asphalt pavements) has recently changed in Hungary with the following phases:
• review of the regional climate model(s) for the area of Hungary (Carpathian basin),
• selection of the climate change elements (like extreme air temperatures, very strong wind) influencing road (pavement) design, construction, maintenance, rehabilitation, management etc.
• selection of road elements specially sensitive to climate change,
• scrutinizing recent major road construction failures (e.g. unexpectedly low pavement performance) from the point of view of extreme weather events as one of the possible causes,
• review of valid Hungarian road specifications (harmonized EU-standards, national standards, road technical guidelines etc.) for identifying the possible needs for their modification as a response to climate change,
• financial calculation (estimation) of the expected losses (harms) in roads due to climate change, and estimation the medium-term adaptation costs to evaluate the cost-effectiveness of these measures.

The measures planned and already taken are to be presented in the conference paper.

Keywords: climate change, adaptation measures, asphalt roads, concrete roads, specifications

1. INTRODUCTION

One of the major challenges all over the world is the more and more obvious climate change. Regional climate models were developed to forecast the future changes in average temperatures and precipitations. Besides, the more frequent extreme weather events have been observed in every country recently.
There is a growing world-wide recognition about the importance of mitigation measures to stop or at least to alleviate the harmful climate change effects on various national economy branches. However, the adaptation activities are equally important to be prepared to the at least partly inevitable dangerous and/or costly consequences of climate change.
Following the practice of several countries, Hungarian investigations and analyses started in the topic some years ago, among others, in road engineering field. Some results of this activity are to be presented subsequently.

2. HUNGARY'S CLIMATE AND ITS REGIONAL CLIMATE MODEL

Hungary is in the temperate zone, in the heart of Europe and has a continental climate. This means that the weather characteristics is quite easily predictable and there are big differences between the weather in the four seasons. Summers are hot and winters are cold. Hungary is a flat area, placed in the Carpathian Basin, so Hungary is protected from the extremes of weather by the mountain ranges (Alps, Carpathians) encompassing it from almost all sides. The central and eastern areas of the Great Alföld ("Lowland") have the most extreme seasonal differences with hot and dry summers and cold windy winters. The warmest point in Hungary is the village of Gyula at the river Feher-Körös with yearly 2038 sunny hours a year; one of the highest in Europe. The south-western uplands are the wettest part of the country. Hungary has a rather low rainfall (600mm as an average) but the number of sunny hours is quite high. According to statistics, summers are warmer and drier than decades before. Many experts say it is the consequence of greenhouse effects. Temperatures may rise above 30 C^o in July and August, but this period generally do not last long. In winter heavy frost or snow is quite frequent. January and February are the coldest months, but their average temperatures do not fall below minus 5°C. Rainfalls are quite moderate throughout the year (average level is 600 mm per year). Rainy periods with common storms seasons are mainly at the beginning of spring and autumn.. All kinds of precipitation may occur during autumn months from drizzles and rains through mist, fog, and sleet to snow (Figure 1) [1].

Figure 1: Map of Hungary

Hungary has a continental climate, with hot summers with low overall humidity levels but frequent rains and mildly cold snowy winters. Average annual temperature is 9.7°C. Temperature extremes are 41.9 °C on 20 July 2007 at Kiskunhalas in the summer, and −35°C on 16 February 1940 at Miskolc-Görömbölytapolca in the winter. Average high temperature in the summer is 23°C to 28°C and average low temperature in the winter it is −3°C to −7°C [2].
Of the global climate models, project PRUDENCE plans more intensive warming for Hungary than the global average. For the period 2070 to 2099, the minimum yearly mean temperature is expected to increase by 1.4^{o}C, compared to that of 1961 to 1990. This increase is expected to be the highest (1.7^{o}C) in summer, and the lowest (1.1^{o}C) in spring.
Climate change poses in Hungary – as in most other countries – a serious challenge to every national economic branch including road engineering. Recently intensive research work has been launched to explore ways to eliminate or at least mitigate the detrimental effects of extreme weather events. At the same time, concentrated measures have been taken to reduce CO_2-emissions which are directly related to the phenomenon of climate change. The national economic significance of these activities can be emphasized by the fact that global warming in Hungary, according to the regional climate change model, exceeds the world average by 20%. Spring and summer weather in 2010 had 3 to 4 times more extreme events (hurricanes, deluge type precipitation) than the same period in preceding year. As a consequence, flooding resulted in road damages at an unprecedented level [3].

3. MAJOR CLIMATE CHANGE CHALLENGE IN ROAD ENGINEERING

The problems connected with climate change can induce two types of measures. Firstly, the so-called mitigation actions to reduce the negative effects by targeting the decrease of greenhouse gas emissions which are considered to be the main cause of climate change. The other group of measures is that of adaptation which envisages countermeasures for the elimination of or at least the reduction of the negative climate change consequences.
Identification of dangerous climate change elements to highway pavements:

a.) extreme high air temperature,
b.) extreme low air temperature,
c.) extreme precipitation,
d.) extreme hydrological features,
e.) excessive wind-storms.

ad a.) An important climate change element is global warming.
Based on these climate forecasts, global warming highlights cement concrete road pavements to asphalt variants. (The resistance of asphalt pavements to permanent deformation decreases in those more unfavourable environmental conditions). The condition of concrete pavements made with hydraulic binders is not influenced by increases in mean summer temperature. If the asphalt variant is selected, the use of a harder and/or modified bituminous type binder with higher softening point, and the design of a binder content lower by some 0.1 mass% than the commonly used value come into consideration. Besides, cement concrete pavements are endangered by blow-up effect in high temperature.

ad b.) The road sector has to be prepared to manage the more frequent occurrence of air temperatures below -15^{o}C, which are taken as being extremely low for the region of Hungary. Here, also cement concrete pavements come into the foreground. Good performance can be expected even in these climatic conditions, due to the insensitivity of this pavement type to extreme temperatures. If asphalt pavements are built their favourable cold performance should have a major role.
In very cold periods, the danger for frost increases. Slightly cohesive soils, especially calciferous loess, can be considered frost susceptible. The frost depth of dry soils exceeds that of wet, cohesive soils. When selecting a road pavement type, it should be taken into account that asphalt pavements have higher heat-insulating ability than other pavement types resulting in an elevated frost line because of reduced frost penetration. This fact can be significant particularly for pavement structures on low-volume roads. As a consequence of the Hungarian hydro-meteorological conditions, anti-frost layers have not been incorporated into new pavement structures when the total thickness of the pavement structures exceeds 500 to 600 mm independent on sub-grade soil type.
One of the "positive" consequences of climate change in Hungary is a reduction in the frequency of spring freeze-thaw cycles, thus having a lesser impact on pavement structures than before.

ad c.) Two forms of extreme precipitation can be considered: a significant increase in yearly precipitation (higher probability of intensive rain or snow) or significantly less precipitation than before.
More lengthy and/or locally very intensive rain can directly damage the road pavement structure or indirectly at a later stage. Intensive rain makes road construction or maintenance activities difficult or, eventually, impossible. The highest resistance to this phenomenon can be expected from hydraulically bound pavement layers.
Effective road drainage systems will become even more important than before, such as longitudinal or transversal slopes and superelevation of pavement surfaces; shoulders with higher transversal slopes and even surfaces; ditches and public utility networks with adequate performance; well functioning culverts, chutes, collecting (belt) ditches etc.
Traffic safety can be influenced – as it is well-known – by the following pavement defect types: insufficient skid resistance of pavement surface, deep ruts, potholes or local subsidence's of pavement surface; the first two can increase the risk for serious accidents on wet pavement surfaces.
One of the consequences of climate change can also be a decrease in total precipitation, however, rather rarely the rain can be very intensive. Consequently, hotter and longer dry periods can be expected with the following consequences for road engineering:

- the construction season for cement concrete pavements shortens,
- newly laid asphalt pavements cool more slowly due to the high ambient temperature, and may delay the opening of the road to traffic,
- on the surface of asphalt pavements, the asphalt mortar is pushed out to the surface of asphalt pavements more frequently after the passing by of heavy vehicles which could cause serious traffic hazard in terms of skidding,
- unprotected slope surfaces dry out, and may crack due to the hot air temperature, jeopardizing the water impermeability and stability of slopes.

ad d.) Global climate change also influences the hydrological conditions since sustained, high intensity precipitation can increase the discharge in water-courses, endangering the nearby road infrastructure. As a consequence, sub-grades can come saturated resulting in a significant loss in bearing capacity which can lead to the quick deterioration of pavement structures. If the flooding is above the pavement surface, the whole pavement structure may fail needing total reconstruction.

Changes in the hydrological conditions can decrease the efficiency of the road drainage system. The high quantity of precipitation can also lift the groundwater level which can considerably increase the water content in sub-grade and/or unbound base layers reducing the bearing capacity of the pavement structure.

ad e.) Another frequent extreme meteorological event can be severe wind-storms, such as hurricanes (this kind of high-velocity winds have occurred in Hungary recently where the wind speeds resulting in fatalities approximated those of a hurricane). Strong wind can be a major obstacle to road construction, rehabilitation and/or maintenance. It is recommended that the contractor contacts meteorological forecasts in order to prepare itself for such events.

Road travelling can be dangerous during very windy periods since dust coming from the shoulder, and nearby agricultural fields can significantly reduce visibility. Also, the stability of two-wheeled vehicles is directly endangered by strong side-wind. Hurricane-like winds can break roadside trees or columns which, falling on the pavement surface can cause to fatalities.

4. PROPOSAL FOR THE MODIFICATION OF EXISTING HUNGARIAN ROAD SPECIFICATIONS

The KTI Institute for Transport Sciences Nonprofit Ltd., Budapest reviewed road-related Hungarian standards and technical specifications to assess whether further developments were needed to account for more frequent, extreme weather events resulting from climate change. The critical issues were identified, and the direction of changes to the criteria was proposed in broad terms.

4.1 Design oriented regulations

Among the regulations concerning road pavement structure, earthworks and drainage systems, we the most general one titled “Road Planning” (KTSZ) has been first reviewed [4]. It describes in detail how the road sections with different traffic loads should be designed, including their alignment as well as their traffic engineering and pavement structure elements.

Climate change elements can influence several factors in the cross section design of the road. The technical regulations specify the minimum side slope angle of road pavements to be 2.5%. Naturally, the violent rainfalls produce an increased amount of water flow which if it is successfully diverted from the pavement avoiding the formation of water-film on the surface can significantly improve traffic security. That is why it is advisable to rethink the values of minimum side slope angles, or to use road pavement structure variants of rough surface which due to their ability to divert the water from the road surface can prevent the phenomenon of hydroplaning or at least significantly can reduce the chance of its happening.

The KTSZ specifies the embankment slope angle to be designed and used taking the height of the fill or the depth of cuts, the design category and the environmental factors into account. Among the expected effects of the climate change, violent rainfalls can damage the surface of the embankment, since the sudden vast amount of rainwater can was away embankment material. Therefore for the design of embankment angles – beyond simply ensuring their stability – sudden intensive rainfalls have to be taken into account and embankment has to be effectively protected.

Considering the fact that among the environmental factors affecting public road traffic, intensive rainfalls have major impacts on road traffic, drainage regulations should earn even more importance. The topic is addressed in the Road Technical Regulation (UME) titled „Drainage Planning of Road” [5]. It includes the intensity, frequency and duration of rain falls to be considered, they should be revised taking into account the growing number of sudden high intensity rains.

The rain water flowing into the drainage system has to be drained at an angle that prevents the damage of drainage bed material by the kinetic energy of water. Steeper slope results in higher drained water volume and necessitates the paving of the drainage bed. It is planned to review the present 3-10% slope limits of the regulation.

The design of the road bases are regulated by the UME entitled “Unbound and bound road base courses“[6].It also deals with the design of earthworks, mentioning the necessity for ensuring 4% side slope for earthworks in the construction phase. The draining of the increased volume of water from sudden rainfalls has to be taken into account in order to avoid the soaking (wetting) of earthworks which could result in the forced suspension of the construction works.

The thicknesses of unbound base courses presently are not designed [6], however, the increased water draining requirement due to climate change would need the revision of this kind of specification.

One of the reasons for the cracking of hydraulically-bound bases is the temperature fluctuation in the environment. It is well-known that the climate change which is already clearly noticeable in Hungary, brings about extremely sudden drops and increases the temperature. In order to account for this phenomenon and avoid stability problems, the base course design regulations need to be altered.

Currently there are no regulations concerning the susceptibility of road pavement structures to thaw damage. The more and more frequent occurrence of this phenomenon (due to an earlier increase in spring temperature) is one of the climate change consequences. Therefore it would be advantageous to take into consideration the decrease in bearing capacity due to thaw damage as well as the techniques can reduce this phenomenon (e.g. using geopolymers).

4.2 Construction oriented regulations

The technical regulation dealing with the construction of base courses titled „Road Bases without and with Hydraulic Binders for Pavements. Construction Requirements" [7] specifies the test types and frequencies for various base course types. It would be worth to include the tests of water pressure effects and/or of the effects of freezing/thawing to the qualifying system.

Asphalt pavements are regulated by the UMEs entitled „Bituminous Mixtures for Road Constructions" and „Asphalt Pavements Courses for Road Constructions. Building Conditions and Quality Requirements" [8, 9]. They specify the qualifying tests for various asphalt types, as well as the evaluation of their results. The following elements need revision reacting to the expected consequences of climate change:

- the behaviour of asphalt types under extreme (extremely high or low) temperatures,
- the rheological characteristics of various asphalt mixtures depending on environmental conditions,
- the use of water permeable (drain) asphalt and its durability.

Considering the continental climate of Hungary, a primary concern of asphalt mixture design when mixture is used as wearing course is that it has to withstand both very high temperatures in summer and extremely cold ones in winter without damage. Since one of the most characteristic features of climate change is that extreme temperatures (both hot and very cold periods) tend to be more frequent, the effective design of various asphalt layers becomes is a more difficult task than before. The mixture design procedures of both technical specifications – and to a certain extent – even the qualification system should be revised based on the above mentioned principles.

The technical specifications [9] for the construction and quality requirements of asphalt layers deals also with the load types to be considered, here more emphasis should be placed on environmental factors. The macro roughness of the road surface should be characterized as a factor of its susceptibility for water-film formation. The effectiveness of water drainage from the road surface as well the adhesive quality of the surface should be characterized during the draining process. It is important to explore the possible use and effectiveness of porous (water permeable or drain) asphalts in Hungary. (Their use is presently widespread in some European countries like the Netherlands).

Unlike asphalt, concrete surfaces are not susceptible to the negative effects of extreme temperatures due to their rigidity. The only exception is the danger of blow-up during very hot summer days. However, during construction, high temperatures (can) make several difficulties. Besides, timely, careful and thorough curing becomes a central question. However, the probability for cracking is higher and the optimum time period for joint cutting shortens. Thus climate change has a significant effect on the design of concrete mixtures which should be taken into account during the revision of the technical specification „Construction of Concrete Pavements Specifications. Requirements" [10].

The road pavement is also loaded by the increase in the temperature gradient during the operation of the concrete pavements, as well as the tension resulting from the strain due to quick drying after a sudden rainfall. This fact should be taken into account during the revision of the technical specification „Structural Design of Rigid and Composite Pavements" [11].

4.3 Maintenance and operation oriented regulations

The actual performance of road pavement structures also depends on the time and efficiency of maintenance activities. When reviewing the technical specifications on road maintenance, it should be investigated, whether some elements of climate change necessitate any change or improvement in the regulations.

The technical specification (UME) „Structural Design of Rigid and Composite Pavements" [12] deal with the maintenance works of rolled asphalt, mastic asphalt, asphalt macadam and surface dressing road surfaces. It covers the development of winter pavement damages, thaw damages as well as their repair techniques. The increased possibility of flood due to intensive precipitation in the future increases the chance of this kind of damages, as well. Therefore, in the course of the revision of the specification, more emphasis has to be placed on the prevention and repair of this type of damages.

The specification [12] deals with the use of so-called cold pot-hole repair mixtures. It is expectable – and the planned UME revision has to react to it – that the forecasted extreme weather conditions would lead to a fast erosion of these types of pot-holing mixtures, therefore their use would become uneconomical.

In the case of permanent pot-hole repairs as a consequence of climate change, it will be increasingly important to use a pot-hole repair mixture as similar to the wearing course material as possible (in order to reduce the chance of material erosion because of extreme weather condition).

Another part of the UME concentrates on repair technologies – among others – those on rues. As a consequence of the effects of climate change, more emphasis has to be placed on these types of maintenance-rehabilitation techniques, since the more and more frequent rainwater accumulation in ruts can lead to the extremely dangerous phenomenon of hydroplaning (aquaplaning).

One of the Sub-chapters of the technical specification [12] deals with rehabilitation technology options. One of their reasons is the significant transversal or longitudinal deformation of road surface. Due to climate change, hot weather conditions are more likely to occur which can lead to further surface deformation shortly after the rehabilitation. In order to prevent this - as a part of the expected UME revision [12] – special attention should be paid to thorough laboratory testing before the operation, the results of which could identify which asphalt layers have to be replaced to improve the resistance of the pavement structure to deformation.

The Appendix of the UME [12] – among others – specifies the maximum periods before the repair of pavement damages. As a part of the planned revision, it would be advisable to shorten these periods, since sudden, intensive rains could soon deteriorate further the already existing pavement damages, thereby multiplying the cost of the repairs.
Its Appendix [12] presents also the acceptable rut depth levels for various asphalt layers expressed in % of asphalt layer thickness and determined by wheel tracking test, and listed in the technical specification "Asphalt mixtures for road construction " [8]. Permanently high air temperatures are among the expected effects of climate change, therefore these thresholds should be reduced, especially when the pavement structure in question is loaded by canalized heavy truck traffic.

The UME "The filling of cracks and gaps in asphalt pavements" [12] deals with filling and closing the cracks and joints of asphalt concrete and mastic asphalt pavements using water tight materials.

5. CASE STUDIES

Two Hungarian case studies from the past 3 years can be highlighted for presenting the possible major damages due to extreme weather conditions.

In 2009, the pavement of motorway M1 collapsed in an area of 1.5 m^2 creating a pit of nearly 1 m depth (Figure 2). The reason of the damage – resulting in nearly 3 day of traffic closure in one of the motorway carriageways – was the inability of a culvert of 800 mm diameter crossing the motorway embankment to drain the vast amount of water coming from the sudden flood of nearby water course after an unprecedented, 2 day long, intensive rain. The embankment material in the vicinity of overloaded culvert was eroded causing the collapse of the thick semi-rigid pavement structure (some 200 mm asphalt layers + 2-layer cement stabilization of 350 mm thickness).

Figure 2: Collapsed section of motorway M1 in 2009 (Hungary)

The location of the other case study is another Hungarian motorway. This section of motorway M6 was completed and opened to traffic in 2010. Some months later, an about 2.0 m^2 fraction of its paved shoulder collapsed with some parts of embankment slope (Figure 3). The subsequent investigation proved that the former very intensive rain can be blamed for the severe pavement damage. (However, the locally poor construction quality has also contributed to the deterioration of motorway paved shoulder)

Figure 3: Collapsed paved shoulder in motorway M6 in 2010 (Hungary)

6. CONCLUDING REMARKS

It is obvious that the mitigation and adaptation activities reacting to the recognized climate change have been more and more intensive all over the world. This statement is also valid for the road engineering and for Hungary. First, the climate change elements which can be harmful for the roads were identified by Hungarian experts that was followed by listing of the expected pavement and earthwork damages. The related Hungarian standards and technical regulations (specifications) were also reviewed, then some of their criteria were identified which would need as adaptation measures to future climate change challenges. The actual changing of specifications in question has to be preceded by careful investigation together with cost/benefit analysis.

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