INVESTIGATION AND DESIGN OF DURABLE PAVEMENT STRUCTURE REHABILITATION

Márton Karoliny Senior Advisor EULAB Ltd., 1 Székesdűlő Str. Dunakeszi, Hungary, 2120. E-mail: karolnymarton@hotmail.hu

László Gáspár Research Professor, KTI Non-profit Ltd., 3-5 Thán Károly Str. Budapest, Hungary, 1119. E-mail: gaspar@kti.hu

[doi: 10.1515/ijpeat-2015-0002](https://doi.org/10.1515/ijpeat-2015-0002)

Abstract

Preservation of the appropriate quality of road assets needs timely rehabilitation of high-level design and construction. Since the actual life cycles of Hungarian road rehabilitation projects are often much lower than expected, research activities of the authors were concentrated on the development of an updated design technology of road pavement rehabilitation using scientifically based algorithms. The paper outlines the elements of a pavement rehabilitation design based on Hungarian and foreign literature survey, detailed own laboratory test series and trial section monitoring. The main steps of the design methodology comprise the Client's data supply and disposition, site condition evaluation by the designer, deflection measurement in carefully selected points, eventual additional laboratory tests, choosing design subsections, correction of the equivalent thickness of the new asphalt layer, calculation of strain in wearing course. Besides, relationships are presented between various condition parameter data like bearing capacity values, unevenness measuring data and rut depth values. The pavement rehabilitation design technique suggested here – if widely in Hungary – can significantly contribute to attaining a much longer life cycle of rehabilitated roads than by now, and it is (would be) extremely efficient due to the very limited funds available for highway purposes.

Introduction

Exclusively the public road networks of sufficient density and of good (at least acceptable) pavement condition are able to fulfil their national economy level tasks appropriately. In Hungary, the preservation of the suitable quality level of existing road pavements can be considered as the major challenge in road sector – in addition to the completion of expressway network and the construction of city by-passes. It is a general negative experience in Hungary that the actual life cycles of rehabilitated road pavement structures are often much shorter than expected. That is why every effort towards more durable rehabilitated road structures can be taken as important at national economy level. The ambition of the present paper is to out-line a more developed rehabilitation design methodology.

Some Road-Related Data

The optimum road rehabilitation works are considerably affected by the qualitative and quantitative features of road pavement structures, traffic parameters, road managing methods applied, as well as climatic, geological and hydrological effects.

Hungarian public network

The total length of Hungarian public network exceeds 200,000 km, comprising some 31,500 km national public and nearly 170,000 km local (municipality managed) road network.

The overwhelming share (more than 80%) of traffic load uses public roads that are practically totally paved (Megnyitó, 2011). The total length of expressways (mainly motorways) with high technical and quality standard amounts to 1,300 km, while that of main roads almost reaches 6,500 km. They are operated by national or network-type specialized road managing agencies. The non-expressways are operated by the county directorates of Magyar Közút Non-profit Share Company, while some 70% of expressways are managed by State Motorway Managing Share Company and the rest by 4 private concession companies.

Just 30% of local roads are paved, mainly the urban ones (Magyar, 2012). The local roads are managed by municipalities but its actual quality level can approach that of national public roads exclusively in Budapest and some major Hungarian cities due to the general scarce funding and lack of sufficiently experienced road experts.

During the past 60 years, the institutional system of the Hungarian road management has been radically changed several times, worsening its efficiency. In the preceding 30 years, a well-balanced system had been in operation which covered also the local roads. In such a way, the advantages of high level expertise and the uniform network managing approach could be utilized.

Main features of pavement structures

It is obvious that the pavement structures of public networks have rather heterogeneous constructions and condition levels, among others, because of their different ages.

Layer compositions

Figure 1 shows the evolution of pavement type shares on the Hungarian national public road network during the past half-century. A significant changing can be clearly seen since the early-70s; from that period on, the very high proportion of asphalt macadam pavements has gradually decreased, and the shares of dense asphalt pavements have become the typical pavement type on national roads. The old pavements after rehabilitation usually serve as base courses; presently, the total length of the pavement structures with hydraulically-bound layer amounts to some 10,000 km.

Figure 1. Evolution of national highway pavement type shares in Hungary since 1950 (Magyar, 2012)

Condition data

The condition evaluation methodology used regularly on the Hungarian national public network is of internationally high standard. Just 15 years after the development of the Ben-kelman-beam type bearing capacity measuring technique, the pavement deflection measurements were already completed on the whole Hungarian national public road network. Since then, this kind of survey – using FWD-devices lately – has been regularly repeated.

In the late-70s, the first sufficiency survey of the whole network covered a lot of parameters; in addition to the geometric features, many pavement structural and condition data were registered and/or evaluated, as well.

The visual surface condition (surface defects) assessment aided by a manual, keyboard-type condition data recorder (Road Master) has provided useful pavement surface quality information as cracks, potholes, bleeding, scaling (ÚT, 2008). This type of information can be readily quantified by surface defect notes (Figure 2).

Hungary has always been keen on introducing modern pavement condition measuring techniques (bearing capacity measurement using Lacroix-deflectograph, later various types of falling weight deflectometer; the characterization of surface condition parameters – longitudinal and transversal unevenness – by Swedish laser RST since the early-1990s).

However, the actual condition parameters of national highway network are usually available; their synthetic – e.g. time data series – investigations have been rarely performed.

Figure 2. 25-year time data series of the national average of Road Master-type surface defect notes (note 5 means excellent and note 1 very poor condition)

Environment

Meteorological features

Hungary is located in the central part of Carpathian-basin with a continental climate of ever increasing variability (Figures 3 and 4).

From the viewpoint of the topic investigated here, it has been a significant change that while, during the past decades, a major share (some 50-60%) of the precipitation could be detected in the late-autumn or winter, mainly as snow, nowadays it occurs rather in late-spring and early-summer, naturally as rain (Figure 5).

Figure 3. Evolution of yearly mean temperature in Hungary during the past 110 years, after (Országos, 2007)

Figure 4. Evolution of yearly precipitation in Hungary in the past 110 years, after (Országos, 2007)

Figure 5. Changing of 60-day cumulated precipitations in the past 50 years, after (Országos, 2007)

Geological and hydrological features

The near-surface soil, the usual material of the subgrade below pavement structures is distributed in Hungary as follows: some 40% silt (mainly loess), 30% granular material (sand or gravel), some 20% cohesive soil, while dense or crumbled, slaty rock can be found in about 10% (Magyar, 1981). In the countries located in the river-basin of Danube, there are a lot of natural and artificial water-courses. Close to their intersections, the actual geological features are rather heterogeneous. These soil types are susceptible to wetting and loss of bearing capacity in case of high moisture content; they need the use of refined geotechnical methods. The share of areas without outlet is rather high where critical geotechnical conditions can take shape even for several months.

Traffic

The car ownership ratio in Hungary is one of the lowest ones in the EU-countries (Figure 6).

Figure 6. Car ownership ratios (car/1000 inhabitants) in EU-countries, after (EURO-STAT, 2013)

The heavy vehicle traffic volume that is critical for the durability of road pavement structures has been considerably grown due to the ever increasing transit traffic. The recent important traffic growth of motorways has been promoted by the completion of new sections (Figure 7).

Figure 7. Evolution of the traffic performance of heavy vehicles in several road categories since 1996, after (Magyar, 2011)

Main Features of the New Road Rehabilitation Design Methodology

Principle of pavement strengthening

In Hungary, the strain limitation at the bottom of asphalt layers due to the wheel load of a 100 kN single axle is applied as design criterion to prevent the fatigue cracking after the design load repetition number (Nemesdy, 1992). The valid rehabilitation design instructions (ÚT, 2005) use the same design criterion. Accordingly, the objective of pavement strengthening – the increase of the critical pavement strength of a design subsection – is the meeting of the design criterion for new structures at the bottom of the asphalt layers, taking into account the actual and forecast mechanical properties of the pavement structure to be rehabilitated.

The strength can be increased by the following procedures or their combinations specified by the designer:

- after the identification of locally low-strength spots, replacement of the uppermost subgrade layer and/or of base course, or improving its condition by more effective drainage solutions,
- strengthening by new unbound or hydraulically bound layers,
- changing (improvement) of existing pavement structural layers' mechanical proper-ties, their recycling,
- strengthening using new asphalt layer(s).

During the design, the initial strength is increased using one of the four methods mentioned above or by their combination, then the necessary asphalt thickness is determined. This methodology presupposes that the fatigue reserve of the existing pavement structure is very small or none; in such a way, the methodology is conservative, simplifying for the sake of safety.

If the remaining layers of the pavement section to be strengthened are presumably of good quality (mainly in case of expressways), it is allowed to use a different specification in the Client's disposition for increasing the efficiency. This time, however, it is a must to determine the mechanical (mainly fatigue) properties of the remaining and collaborating asphalt layer and its remaining life time with sufficient accuracy with the use of specially trained experts and testing laboratories (Magyar, 2013).

Environmental effects considered in the methodology

Temperature

The actual strength of a bituminous bound road pavement structural layer is influenced by its temperature. The properties of other pavement structural layers are practically not dependent on their temperature, except for the strength increase coming from the freezing of layers (mainly subgrade) with high moisture content. However, this phenomenon is rather rare among our climatic conditions.

Reference temperatures

Reference temperature should be chosen which is used in the conversion of measured deflection values and in the mechanical calculation. Figure 8 is based on the results of a measurement series when the temperature of an asphalt layer was registered in various depths in every hour for more than a year (Karoliny, 2002). 20°C happened to be the most common temperature; that is why it was selected as reference temperature.

Figure 8. Hourly distribution function of asphalt temperatures

Correction of deflection values

It is evident that the necessary temperature correction of deflection values has to adjust to reference temperature. Using the results of comprehensive research works (Spoof et al., 2000) and a measuring data series (Magyar, 2013), the effect of correction can be shown in Figure 9.

Figure 9. Deflection values corrected due to temperature as a function of the distance from axle

Figure 9 proves that the correction comprises a major part of the deflection bowl characterised by falling weight deflectometer; however, no correction is needed from 800 mm distance on. These results were successfully validated in a case when the asphalt layers were removed in several steps, in various points of time. The results obtained after the correction were practically identical to the ones calculated using the suggested methodology

Date of deflection measurement

It had already been revealed a long time ago that the date of deflection – more precisely the moisture content of subgrade at the time of measurement – basically influences the results. In Hungary, the pavement deflection values have been adjusted to the „critical” (early-spring) ones since the 1950s (Boromisza, 1959) using a correction factor as a function of the month of measurement. This methodology has been useful; however, it cannot be applied in the present, rather variable (unsteady) climate anymore. Figure 5 shows how much has changed the yearly precipitation distribution during the past decades, the long-term prognoses (Tímár, 2013) forecast further changing. In accordance with the results of a relevant research work (van Gurp, 1995), the subgrade dependent part of pavement deflection value is determined by the volume of precipitation before the actual measurement, as well as the evaporation conditions of the site, naturally as a function of subgrade properties. This approach is, however, too complicated, impractical.

Interesting consequences could be drawn when the results of the deflection data series were evaluated coming from the frequently performed pavement deflection

measurements on trial sections selected of the Hungarian national road network (Figure 10).

Figure 10. Relationship between central pavement deflection and subgrade loading capacity indicator

It can be seen from Figure 10 that the central deflection measured in various points of time are strongly dependent on the difference between the deflection values obtained in 300 and 600 mm distance from the loading axle (the diagram shows the data of 8 years). This relationship comes from Boussinesq equations (Van Cauwelaert, 2003), it proves that the performance of multi-layer pavement structures can be generally modelled supposing an indefinite half-space.

Since no condition improving measures had been performed on the pavement structure monitored, the differences between the deflection (strength) values are connected with the strength of the layer at the given depth, due to the reciprocity features. That is why the difference in deflections can be taken as a strength indicator which is characteristic – due to the considerable depth – for the subgrade. It is also evident that subgrade strength is mainly de-pendent on the actual moisture content and the volume of precipitation before the measurement. (Figure 11).

Figure 11. Relationship between subgrade strength and the cumulated precipitation during the period before the measurement

Figure 11 proves that the correlation between the cumulated precipitation during the period before the measurement and subgrade strength indicator is rather close. If sufficiently long data time series are available, this correlation can be very tight. Since it is rather rare that long deflection data time series are available, deflection correction values can be determined for the Hungarian soil types and precipitation volumes using the results of trial section monitoring.

Main steps of the methodology

The steps of the methodology are in strictly logical connection, that is a new step needs all of the information collected during the preceding phase; thus, the order of the steps is unambiguously defined. The interpretation of the steps necessitates the presentation of the pavement strengthening methods applied (Table 1).

Table 1. Pavement rehabilitation methods considered

Type	Short description
Overlaying	Overlaying using asphalt mixtures in accordance with Road Technical Directives ÚT 2-3.302
	Overlaying using asphalt mixtures in accordance with Road Technical Directives ÚT 2-3.302, after partial removal of old pavement structure
Strengthening with site recycling	Site hot recycling using Remix Plus method
	Site hot recycling using Remix Add method
	Site cold recycling without adding new material
	Site cold recycling adding new material
Strengthening (increasing life) by local repair	Local repair without a new wearing course

Client's data supply and disposition

The suggested methodology makes it necessary that the Client provides a lot of information of predefined type. In case of the Hungarian national public highways, these data are generally available. However, the information stored in the road data bank are often appropriate just for network level needs due to their insufficient details and/or the lack of data time series; the requirements of project level can be fulfilled after expedient computerized data processing. It is hoped that the future road data storage in Hungary would meet these higher level needs, as well.

In case of pavement strengthening, the Client's disposition is much more important than for new constructions, since the consideration of local conditions has higher economic advantages here; at the same time, the lack of knowledge on local conditions can result in the over-determinedness during the subsequent phases. (For example, problems can come up when the design pavement width is 6.0 m, the actual one is less by 0.1-0.2 m, the elevation of road surface level by 80-100 mm is needed as a function of strengthening requirements but the Client's disposition does not include pavement widening).

The probability of problem arising can be considerably reduced if the disposition is compiled by an expert who is familiar with the local conditions, preferably managing the road section in question. (It often occurs that the Client is not identical with the road manager).

Data processing and site condition evaluation

It is the first step of diagnosis when the designer learns the data made for him (her) available, then (s)he evaluates the actual site conditions with appropriate drawings.

Selecting pavement deflection measuring points, carrying out the measurement, evaluation of results

Based on the condition information presented also on drawings, the measuring points are chosen in necessary frequency. (It is the first case where the importance of the order of steps can be highlighted). After having completed the actual measurement, the normalisation and correction of the results due to temperature and precipitation follow. Then the results of visual condition evaluation are compared to the pavement deflection ones.

Laboratory tests

The next step is the selection of the sampling sites for additional laboratory tests that are destined for the approval or rejection of diagnostic results to date.

Further correction of deflection data

Based on the results of subgrade laboratory tests and pavement deflection measurements, the deflection results can be corrected where the subgrade condition necessitates major local intervention (soil replacement, drainage improvement etc.). The deflection results of these points are to be improved because of the expected much better condition that is the advantages coming from the additional expenditure should be utilized.

Selection of pavement structure strengthening methods

If, for example, the existing asphalt layers have high deformation, poor stiffness and/or layer adhesion properties, they have to be removed at the wrong spots. The thickness values of old pavement structure give information for the selection between recycling and overlaying alternatives. (This case, it is obvious again how important is to follow the order of this up-to-date diagnostic).

Choosing design subsections

Taking into consideration the section boundaries of various strengthening methodologies applied, based on the corrected deflection values, sufficiently homogeneous sections – design subsections – should be selected. For doing this, the methodology includes statistical methods and criteria.

Correction of the equivalent thickness of new asphalt course

As a function of the strengthening method applied (e.g. new layer after milling), the equivalent surface modulus values calculated using deflection results have to be corrected. For the correction, suitable and rather simple formulae (Magyar, 2013) are available for the determination of the effects of thickness increase in the case of layer removal or recycling methods.

Calculation of the thickness of new asphalt layer

Expedient, simplified equation is available for the determination of the necessary thickness of asphalt layers made of mixtures with four different stiffness values and two different fatigue properties in every measuring point. (The equations were calculated by the help of SHELL – BISAR programme). In such a way, the layer thicknesses of eight asphalt mixture types can be calculated theoretically in every point of the road section considering the number of load passes; thus the most economical solution can be selected using this rather simple economic comparison.

Calculation of strains in wearing course

It is well-known that in case of relatively stiff pavement structures – strains present themselves also in the wearing course (van Gurp and Wennink, 1997). It should be controlled that this strain does not exceed the boundary value in the final structure.

Pavement structure diagnostic

For the design and realisation of the necessary local repairs, the diagnostic, that is the identification and the reason revealing of surface defects on the pavement section for ensuring the sufficiently long life cycle of rehabilitated pavement. At the same time, diagnostic has to be closely connected with the regular pavement condition evaluation. The signs of deterioration cannot be always identified visually but the analysis of condition data time series are able to characterize the process helping diagnostic a lot. (The analogy with the connection between the screening type medical tests and the individual diagnosis in case of a concrete complaint is obvious). Accordingly, the applicability of the pavement monitoring data was also investigated leading to rather interesting results; some of them will be presented.

Conclusions drawn from condition data

Next some useful relationships are presented that were drawn from the results of two pavement condition evaluation types (characterization of pavement surface geometry – IRI-value and rut depth – using laser technique, as well as bearing capacity measurement by falling weight deflectometers) carried out on national public road network.

Condition data time series

Figures 12 and 13 present the results of pavement surface geometry measurements on expressways using laser technique. The IRI-values on Figure 12 distinctly follow – by high correlation coefficient – the trends, which are more or less equal to the results of engineering considerations; partly they continuously grow (deterioration), partly the expected difference can be shown between the data time series of traffic lanes with significantly different traffic loads. Very similar trends were identified by a detailed investigation covering a lot of pavement sections with rather high total length; so, these relationships can be utilized for the condition forecast of road sections (prediction of the time of critical pavement condition).

Figure 12. Equalized IRI time data series measured on the surface of two traffic lanes

Figure 13. Equalized rut depth time data series measured on two traffic lanes

On the same road section, rut depth values follow trends with similarly close relationships. (When processing the measuring data, the compression of large data mass needed special mathematical-statistical considerations).

Relationship between condition data

When evaluating and processing pavement condition data, the relationships between the results coming from various evaluation methods concentrating on totally different physical parameters can be highly important. Figure 14 illustrates the deflection and IRI-values of the same road section.

Based on the data series patterns of Figure 14, the relationship between the results of the two pavement condition parameters is obvious, however, the relationship is just stochastic and valid exclusively for the given road section. If the cumulated sums of condition parameter values are investigated (van Gurp, 1995), another type of relationship can be revealed. The method of cumulative sums is a simple statistical method for the investigation of the homogeneity of data which are sorted in space and time. The sections with nearly identical directional tangents are taken as homogeneous sections. It can be clearly seen on Figure 15 that the homogeneous sections of the two pavement condition parameters mainly coincide. This relationship has a real physical background, since the regressions used for the forecasting of IRI-values (Haas et al., 2009) usually use the deformation calculated at subgrade surface as an independent variable, consequently there is some kind of connection between subgrade loading capacity and the IRI-value of pavement surface. This relationship was validated on various road sections several times, that is if IRI-values are known, the homogeneous sections from the view-point of pavement bearing capacity can be estimated with sufficient accuracy.

Figure 14. Relationship between bearing capacity and longitudinal unevenness data series

Figure 15. Relationship between homogeneous road sections from the view-points of IRI and pavement deflection

Processing Condition Data for Diagnosis

There are several diagnostic areas where the sufficiently processed pavement condition data can be utilized. One of the most critical diagnostic problems is the eventual deformation ability of the asphalt layers that can be evaluated just by lengthy and expensive laboratory tests. Using the results of laser pavement surface geometry investigation, the need for testing can be significantly decreased. The Swedish RST-apparatus characterizes the rut depth values also inside the traffic lane.

Based on the results of measurement data series in Figure 16, it can be concluded that the significant difference in rut depth is not originated from the poor asphalt performance (the asphalt layers inside a given traffic lane are generally nearly homogeneous) but it comes from the variation in subgrade stiffness (moisture content is typically higher below the pavement edge).

Figure 16. Comparison of outer and inner rut depth value series

It can be concluded that, after a suitable processing of pavement condition data, such condition parameter values can be estimated with an appropriate accuracy which have not been measured at all.

Deflection Measurements

In accordance with the valid relevant Hungarian specifications, pavement deflections can be measured using devices based on Benkelman beam principle or seismic type falling weight deflectometers. However, the systematic bearing capacity measurement of national public road network is done using falling weight deflectometers; in case of the rehabilitation design of local public roads, Benkelman beams are preferred due to their relatively low costs. Our experience proves that the differences between the results obtained using the two method-ologies come mainly from the problem of the base level of measured deflections in the case of Benkelman-procedure.

At the same time, this base is actually a point of the deflection bowl; in such a way the so-called sole-error, a systematic error is made (Boromisza, 1959). The principle of this error can be seen in Figure 17. The actual value of sole-error depends on the distance of base from loading axle (beam length of deflectometer) and the so-called shape factor of deflection bowl (Primusz and Tóth, 2009). The value of sole-error can be determined at a rather high accuracy if the deflection is measured in at least three points of deflection bowl. (It can be performed by various available methods).

The specification (Magyar, 2013) presents the calculation method based on which Figure 18 presents the relationship between the value of sole-error and the central deflection value. Figure 18 clearly shows that the value of sole-error strongly depends

on the beam length, and it can be a rather high value in the case of small deflection value.

Figure 17. Sole-error of deflection measurement done by Benkelman-beam

Figure 18. Relationship between the sole-error correction factor of deflection measurement, the beam length of Benkelman beam and central deflection value

Necessary Laboratory Tests

Table 2 gives the list of the types and frequencies of the laboratory tests needed for the efficient design of road rehabilitation (pavement strengthening) as a function of the methodology selected. A laboratory test should be carried out for every 500 m length (even if it is shorter) of each traffic lane.

It is obvious that it is a solution with compromise to envisage the minimum number of the necessary tests already in the Client's disposition of the planned project. When designating the test points, the experiences of visual condition evaluation and deflection measurements are to be considered, as well, the points should not be distributed evenly.

Table 2. Types and frequencies of the necessary laboratory tests for different strengthening methods

Strengthening method	Asphalt layers				Hydraulically bound layers		Granular layers		Subgrade (from test pit below pavement structure or shoulder)		
	thickness	adhesion between uppermost 3 asphalt layers	stiffness (uppermost 3 layers)	resistance to deformation (uppermost 3 layers)	composition	thickness	thickness	grading	soil class	natural water content	estimated optimum water content
Overlying											
Site warm recycling											
Site cold recycling											
Repair of local defects											

Concluding Remarks

One of the most severe tasks (challenges) of Hungarian road engineering is the condition preservation of the nearly completed highway network. Due to the continuously growing traffic and environmental load, the need for the rehabilitation (strengthening) of the pavement structure of road sections is more and more urgent. The road proprietors and managers have a duty imposed by law to ensure an undisturbed traffic flow which – among the rather limited available financial means – specially stresses the need of the use of long-term cost-effective pavement rehabilitation methods. However, this kind of technique can be selected if the intervention is based on an up-to-date design method that uses scientifically based relationships and algorithms, and utilizes fully the detailed condition parameters of the pavement section. The paper outlines the elements of a pavement rehabilitation design which is based on Hungarian and foreign literature survey, detailed own laboratory test series and trial section monitoring. The authors of the publication hope that this design technique will be used widely and significantly contributes to

attaining a much longer life cycle of rehabilitated roads than by now which would be highly advantageous for the road users, even for the whole national economy.

References

Boromisza T. (1959) „Útburkolatok behajlása” Mélyépítéstudományi Szemle 1959.december („Deflection of road pavements” Civil Engineering Review December 1959).

EUROSTAT (2013) „Transport statistics at regional level” http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Transport_statistics_at_re-gional_level

Haas, R. et al. (2009) „Measurable Performance Indicators for Roads: Canadian and International Practice” Paper Prepared for Presentation at the “Best Practices in Urban Transportation Planning: Measuring Change” Session at the 2009 Annual Conference of the Transportation Association of Canada, Vancouver, British Columbia.

Karoliny M. (2002) „Nyári hőmérsékletek az aszfaltrétegekben Magyarországon” Előadás a MAUT – FSV workshopon, 2002. november 6. Győr. („Summer temperatures in asphalt layers in Hungary” Presentation at MAUT-FSV workshop, 6 November 2002, Győr).

Magyar Állami Földtani és Geofizikai Intézet (1981) „Magyarország földtani atlasza” <http://loczy.mfgi.hu/flexviewer/atlasz200/> (Hungarian State Geological and Geophysical Institute (1981) „Geological Atlas of Hungary”).

Magyar Közút Nonprofit Zrt (2010) „Önkormányzati utak adatai” (Hungarian Road Non-profit Share Company (2010) „Data of local roads”).

Magyar Közút Nonprofit Zrt (2011) „Országos közúti keresztmetszeti forgalomszámlálási eredmények 1996-2010” <http://internet.kozut.hu/Lapok/forgalomszamlalas.aspx> (Hungarian Road Non-profit Share Company (2011) „National road traffic census results 1996-2010”).

Magyar Közút Nonprofit Zrt. (2012) „Országos közúthálózat információs eredménytáblái OKA 2000 alapján” (Hungarian Road Non-profit Share Company (2012) „Information tables based on National Highway Data Bank” 2000.

Magyar Közút Nonprofit Zrt (2013) „A „Fenntartható utak” projekt, Technológiai tervezési albizottság zárójelentése” kézirat (Hungarian Road Non-profit Share Company (2013): „Project „Sustainable roads”, final report of sub-committee Technological Design” manuscript).

Megnyitó előadás (2011) „Közúti üzemeltetési és fenntartási napok” Sopron. (Introductory presentation. „Road Operation and Maintenance Days”, Sopron).

Nemesdy E. (1992) „Az új magyar típus-útpályaszerkezetek mechanikai méretezésének háttere” Közlekedés és Mélyépítéstudományi Szemle 1992/8.

(„Background of mechanical design of new Hungarian standard road pavement structures.”Transport and Civil Engineering Scientific Magazine 1992/8).

Országos Meteorológiai Szolgálat: (2007) „Magyarország éghajlata 1991-2000” (National Meteorological Service (2007) „Climate of Hungary 1991-2000”).

Primusz P., Tóth Cs. (2009) „A behajlási teknő geometriája” Közlekedésépítési Szemle 2009. december (“Geometry of deflection bowl” Traffic Construction Review December 2009).

Spoof, H., Petäjä, S. and Ruotoistenmäki A. (2000) „Pudotuspainolaitemittaus 2000” TPPT Menetelmäkuvaus.

Tímár A. (2013) „A klímaváltozás hatása az országos közúthálózat állapotára” A 38. Útügyi Napok előadása, Hajdúszoboszló. („Influence of climate change on the condition of national public road network” Presentation at 38th Road Conference, Hajdúszoboszló).

ÚT 2-1.202 [e-UT 06.03.13] (2005) „Aszfaltburkolatú útpályaszerkezetek méretezése és meg-erősítése” („Design and strengthening of road pavement structures with asphalt surfacing”).

ÚT 2-2.118 [e-UT 09.02.26] (2008) „Burkolatfelület állapotának minősítése Roadmaster rendszerrel” („Condition evaluation of pavement surface using Roadmaster system”).

Van Cauwelaert, F. (2003) „Pavement design and evaluation. The required mathematics and its applications” Federation of the Belgian Cement Industry.

Van Gurp, Ch. (1995) „Characterization of seasonal influences on asphalt pavements with the use of falling weight deflectometers” PhD Thesis, Delft.

Van Gurp, Ch., Wennink, P.M. (1997) „Design, structural evaluation an overlay design of rural roads” (in Dutch) KOAC – WMD consultants; Apeldoorn.