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Innovative Solutions – Benefiting Society

12TH INTERNATIONAL SYMPOSIUM ON CONCRETE ROADS 2014

September 23–26, 2014
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PROCEEDINGS



RESEARCH INSTITUTE OF BINDING
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Tuesday, September 23, 2014

13:00–20:00	<i>Registration</i>	
18:00–18:30	Opening speech	Hall 1
18:30–20:00	Opening Ceremony & Welcome Cocktail	Hall 1
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08:00–18:00	<i>Registration</i>	
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10:15–10:40	<i>Coffee break</i>	
10:40–12:20	General Reports	Hall 1
12.20–12:30	ISCP speech	Hall 1
12.30–13:30	<i>Lunch</i>	
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13:30–15:15	Session 2 Theme 2 – Solutions for Urban Areas	Hall 2
13:30–15:15	Session 3 Theme 3 – Design and Construction	Hall 3
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15:45–17:30	Session 4 Theme 1 – Sustainable Pavements	Hall 1
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15:45–17:30	Session 6 Theme 4 – Maintenance and Rehabilitation	Hall 3
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Thursday, September 25, 2014		
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09:00–10:30	Session 9 Theme 1 – Sustainable Pavements	Hall 3
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11:00–11:45	Session 10 Poster Session	Hall 1+2
11:45–12:15	Information to technical visits	Hall 1
12:15–13:30	<i>Lunch</i>	
13:30–18:00	Technical visits	
20:00–23:00	Symposium Gala Dinner	
09:00–14:00	<i>Accompanying Persons' programme</i>	
Friday, September 26, 2014		
09:00–10:45	Session 11 Theme 3 – Design and Construction	Hall 1
09:00–10:45	Session 12 Theme 2 – Solutions for Urban Areas	Hall 2
09:00–10:45	Session 13 Theme 3 – Design and Construction	Hall 3
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11:15–12:30	Session 14 Theme 3 – Design and Construction	Hall 1
11:15–12:30	Session 15 Theme 1 – Sustainable Pavements	Hall 2
11:15–12:30	Session 16 Theme 4 – Maintenance and Rehabilitation	Hall 3
12:30–14:00	<i>Lunch</i>	
14:00–15:30	Plenary closing session	Hall 1
	DUT conference report	
	Best Technical Paper Award	
	Best Marketing Paper Award	
	Conclusion	
15:30–16:00	Closing of the Symposium	
09:00–13:00	<i>Accompanying Persons' programme</i>	



FULL PAPER

To see a FULL PAPER in a PDF format,
click anywhere on the page on which the respective abstract is located.



ABSTRACTS

ORAL PRESENTATIONS

THEME 1 – SUSTAINABLE PAVEMENTS SESSION 1

THE ADVANTAGES OF CONCRETE PAVEMENTS IN TUNNELS

(ID 14)

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A 21 km long motorway is planned to be constructed through the western suburban of Stockholm. The motorway will mainly be localized in tunnels with a total length of 18 km. The intention is that the tunnel pavement shall be constructed as a jointed plain concrete pavement (JPCP) resting on an asphalt-treated base. Compared with the asphalt pavement, the concrete pavement has both advantages and disadvantages. Important advantages are load-carrying capacity, resistance to concentrated long-term loads and high temperatures, wear resistance, durability, and brightness. High durability means low maintenance costs. Weaknesses are brittleness in tension, shrinkage, high construction costs, and complicated repair if necessary. Some of the advantages and disadvantages change when the concrete pavement runs through a tunnel. The load-carrying capacity increases, the subgrade is more even, the thermal stresses are reduced, and the shrinkage is reduced whereas the importance of brightness and fire safety increases. The bright surface needs less energy for illumination and the consequences of a fire are much more severe in the tunnel than outdoors. The full paper discusses these factors and several minor ones more in detail. Recent studies show that the fuel consumption is less when a vehicle runs on a concrete pavement than on an asphalt pavement. Despite the fact that the difference is limited to 1 percent for personal cars and 2 percent for lorries, the savings in consumed fuel will be substantial during the service life due to very high anticipated number of vehicles.

KEYWORDS

CONCRETE PAVEMENTS / TUNNELS / ADVANTEGES / COMPARISONS / STOCHOLM
BYPASS PROJECT

CONCRETE PAVEMENT CONTRIBUTION TO FIRE SAFETY IN ROAD TUNNELS (ID 6)

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In recent years, several high-profile road tunnel fires have taken place across Europe. These fires inevitably led to important structural damages and even loss of lives. In all of these tunnels, national mandatory safety regulations were implemented. Nevertheless, disasters could not be averted.

Apart from a deep knowledge of safety and fire equipment within a tunnel that is subjected to a fire, it is also essential for firefighters to have a profound knowledge of the fire dynamics inside tunnels and the influence of all the elements that contribute to the fire.

One of the factors that modifies the behavior of fires inside tunnels is the type of road pavement. A recent study of the Spanish Technical Association of Firefighters shows that concrete pavements are inert elements and their interaction with fire is limited to the absorption of part of the heat generated. On the other hand, asphalt pavements are active elements that burn, releasing fumes and heat. This material can modify the spread behavior of the fire, worsening evacuation conditions and complicating the work of firemen.

In some extreme cases, the use of concrete pavements may be the key factor that permits keeping the amount of heat and gases under the design limits, so that the extraction system continues working until the situation is under control. Evacuation procedures and the action of emergency teams will never be affected in this case. On the contrary, asphalt surfaces could complicate the situation.

Safety contribution of concrete pavements during fires in road tunnels is widely justified by professional fire brigades and, therefore, they strongly recommend the use of concrete pavements in any road tunnel independently from their length.

The paper explains the special characteristics of fires inside tunnels and the advantages of concrete pavements in comparison with asphalt pavements in this kind of situations.

KEYWORDS

CONCRETE PAVEMENT / ASPHALT PAVEMENT/ FIRE / TUNNEL / SAFETY

**INNOVATIVE CONCEPTS FOR CONCRETE ROADS
FURTHER DEVELOPMENT OF THE CONSTRUCTION
(ID 13)**

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Our modern world is characterised by traffic, the traffic of goods and/or information. Both will increase in the near future. Further there will be a strong increase in communication technology which will influence the individual traffic as well. At the same time all kinds of emissions caused either by the construction of the roads (as CO₂ emissions) or by the traffic (as noise) have permanently to be decreased. There are some developments concerning noise reducing pavements but actual with a too short service life time. Therefore it will be necessary to divide the future road construction into two parts, one load bearing layer and one top layer. Next to a huge research program from the German government concerning the vision for the German roads in the 21st century, CEMEX started programs for the further development of new road models, with a load bearing layer and a top layer. Further the new road concept works with concrete which causes less CO₂-emissions during erection of the road compared to concretes based on CEM I which are usual used for road constructions.

KEYWORDS

CONCRETE ROADS / FUNCTIONAL ROAD/ CO₂-REDUCED CONCRETE /

SLAB CURLING AND ROLLING RESISTANCE (ID 19)

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In a life cycle analysis a higher investment cost is justified by lower maintenance costs, less and fewer traffic flow intrusions, and a longer technical life. All these factors contribute to a reduction of the carbon footprint. To further improve the sustainability of PCC pavements the rolling resistance should be lower on stiff and elastic materials. To prove this thesis, studies of fuel consumption have been made where a truck is driven over different pavement types. However, it is difficult to precisely access how much can be attributed to the pavement internal structure. Many factors affect the rolling resistance, such as roughness, texture, air flow et cetera. The present paper presents a different approach analyzing data from a falling weight deflectometer, (FWD). Pavement hysteresis is assessed by evaluating time histories. Thus, energy losses due to the properties of the pavement structure can be estimated. For plain jointed concrete pavements, the energy used is higher near the edge of the slab. The present paper investigates the effect of upward curling on the rolling resistance.

KEYWORDS

PLAIN JOINTED CONCRETE ROADS / SLAB CURLING / PAVEMENT ROLLING RESISTANCE

OPTIMIZATION OF THE RECYCLING OF CONCRETE IN CONCRETE: APPLICATION TO AN AIRPORT SLAB (ID 37)

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The use of demolished concrete as recycled aggregate in new concrete is a promising solution within the context of sustainable development. However, this application is still limited in the construction sector due to the lack of knowledge. In that context, Ifsttar (France) and the French industry's major players have finished in 2012 a 3 year collaborative research to provide a better comprehension of the influence of such recycled concrete aggregates on the properties of concrete.

The paper first describes the context and the issues of the research. In the second part, the methodology used is presented. It mainly consisted in producing a first generation of different concrete mixes with natural aggregates. They were then crushed and recycled in a second generation of mixes. The cycle was repeated a last time to produce a third generation of concrete mixes. Concrete production and crushing were conducted in semi-industrial conditions, but under a strict control, in order to guaranty the quality and the traceability of the different materials thus produced.

Concrete performances as well as recycled aggregates properties were investigated for each generation. These data represented a rich experimental basis which was analyzed and used to develop a set of semi-empirical models, linking the properties of concrete with those of recycled aggregates they are made of, but also the properties of recycled aggregates to those concrete which they are produced. The paper makes a focus on a specific concrete property to demonstrate how these models can be used to elaborate (multi)recycling scenarii.

The last part of this paper is dedicated to a real case of recycling, consisting in renewing an airport area by a slab containing only aggregates recycled from old slabs.

The paper concludes on the next collaborative research engaged in France research on this subject within the scope of the national Project „Recybéton“.

KEYWORDS

RECYCLED AGGREGATE CONCRETE / AIRPORT SLAB / RECYCLING

INFLUENCE OF RECYCLED CONCRETE AGGREGATES ON STRENGTH PROPERTIES OF CONCRETE (ID 47)

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The demand to use recycled aggregates in concrete is getting more important. However, to obtain a sustainable road, it is necessary to construct durable pavements and therefore to use concrete of good and reliable quality. The use of recycled aggregates will give environmental advantages but could lead to excessive shrinkage and lower strength and durability.

This paper investigates a new approach towards the use of recycled concrete aggregates, in which the mortar phase present in the recycled aggregates is taken into account. The study, carried out in the framework of a master thesis at Ghent University, comprises the comparison of concrete properties for different concrete mixes with recycled concrete aggregates (RCA) using the equivalent mortar volume method (EMV method) and the more conventional method. The concrete mix design that was used is typical for the Belgian road construction. Several mixes were tested in the laboratory for mechanical and physical characteristics. In order to compare the different methods, three types of concrete mixes were prepared:

- with only natural aggregates,
- with use of RCA in a traditional design,
- with use of RCA using the EMV method.

In this study the concrete properties were evaluated by performing pressure tests, bending tests and splitting tests on lab made specimens. Also the modulus of elasticity and the shrinkage properties were measured. First conclusions indicate a severe loss of strength but also a decreased shrinkage. This paper will not only focus on the comparison between the conventional method and the EMV method, but will also point out some interesting characteristics of the use of recycled aggregates by analysing some international research publications.

KEYWORDS

RECYCLED CONCRETE AGGREGATES (RCA) / RECYCLED AGGREGATE CONCRETE (RAC) / RMC-TEST / EMV-METHOD.

SESSION 4

PHOTOCATALYTIC AIR PURIFYING PAVEMENTS IN BELGIUM: WHERE ARE WE? (ID 53)

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The construction and rehabilitation of roads are more and more linked to the environmental impact of this road. Durability, noise and air quality become more and more important as design criteria. The choice of materials can influence the environmental impact of traffic and road infrastructure. In this respect, photocatalytic concrete constitutes a promising technique to reduce a number of air contaminants such as NO_x and VOC's. Ideally, the photocatalytic material, titanium dioxide, is introduced in the top layer of the concrete pavement for best results. In addition, the combination of TiO₂ with cement-based products offers some synergetic advantages, as the reaction products can be adsorbed at the surface and subsequently be washed away by the rain.

A first application has been studied by the Belgian Road Research Centre (BRRC) on the side roads of a main entrance axis in Antwerp with the installation of 10.000 m² of photocatalytic concrete paving blocks. Although measurements on site did not give the expected results due to the configuration of the road surface, the laboratory results indicated a good efficiency towards NO and NO₂ abatement as well as a good durability of this air cleaning characteristic. Special attention is given to the nitrogen oxides content in the air, since they are for almost 50% caused by the exhaust of traffic and are at the base of smog, secondary ozone and acid rain formation.

For now, the translation of laboratory testing towards results in situ remains critical to demonstrate the effectiveness in large scale applications. Moreover, the durability of the air cleaning characteristic with time remains challenging for the application in concrete roads. In this perspective, several new trial applications have been initiated in Belgium in recent years to assess the “real life” behavior.

A field site was set up in the Leopold II tunnel of Brussels in the framework of the European Life+ project *PhotoPAQ*. This major environmental project aims at demonstrating the effectiveness of photocatalytic materials on a realistic scale. To this purpose, photocatalytic materials have been applied on the walls and roof of the tunnel. Furthermore, in 2010 the INTERREG project *ECO₂PROFIT* started in cooperation with the regional development agency POM Antwerp. Here, a photocatalytic concrete with TiO₂ in the top layer was applied for the construction of new pavements on industrial zones in Wijnegem and Lier (province of Antwerp).

This paper first gives a short overview of the photocatalytic principle applied in concrete, to continue with some main results of the laboratory research recognizing the important parameters that come into play. In addition, some of the methods and results, obtained during the investigation of the existing application in Antwerp (2005) and during the implementation of the new realizations in Wijnegem and Lier, (2010-2012) and in Brussels (2012-2013), will be presented to provide an overview of the current status of understanding of photocatalytic materials and future perspectives.

KEYWORDS

CONCRETE PAVEMENTS / PHOTOCATALYSIS / AIR PURIFICATION / TITANIUM DIOXIDE /
DOUBLE LAYERED CONCRETE

DURABLE AND SUSTAINABLE CONCRETE PAVEMENTS ON PUBLIC PRIVATE PARTNERSHIP (PPP) PROJECTS (ID 65)

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Due to its central location in Europe Germany is a typical transit country, where traffic load by heavy traffic increases annually. Highways are especially affected, with freight traffic not only increasing in number but also showing a trend of 5-axle vehicles with larger utilization of the allowed axle loads at the same time.

In Germany a service life period of at least 30 years is assumed when designing new road constructions and complete renovations. Under normal circumstances the road will outlast this time in economically acceptable conditions before it must be replaced again.

Despite the enormously increasing load specifications have remained the same in large parts so that the question arises whether they can meet the already increased requirements.

An alternative solution for this issue can be public private partnership (PPP) models, in which the contractor not only will build the road, but also operates and maintains it over a 30 year period.

The contracting entity in this way encourages new and even innovative solutions. The contractor has to find new and different approaches in order to submit a financial offer. Strategies are needed that ensure higher quality construction performance within the period of use that will result in low maintenance costs and make the use of concrete in paving projects economically sound. Availability of the road plays a crucial part in paving maintenance, and these strategies must also allow for minimal closures.

To ensure the necessary useful service life and to minimize risks the vast majority of all PPP-models in the last few years were executed with concrete pavements.

In the example of the highway A5, Malsch-Offenburg, the presentation shows the special efforts in preparation and construction of the road. New approaches such as the analytic design, special initial testing of concrete, and specific criteria for installation by a quality assurance system are shown, laying the foundations for economic success.

KEYWORDS

CONCRETE ROADS / SUSTAINABLE PAVEMENTS / PRIVATE PARTNERSHIP PROJECTS / ANALYTIC DESIGN / QUALITY ASSURANCE SYSTEM

**PROBABILISTIC LIFE-CYCLE COST OF PAVEMENTS: CHARACTERIZATION AND
APPLICATION OF PARAMETER INPUT VARIATION FOR SCENARIOS
(ID 85)**

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Life Cycle Cost Analysis (LCCA) evaluates the economic performance of alternative pavement investments. Currently, practitioners treat input parameters as static, deterministic values, which although computationally simpler, will hide the implicit uncertainty underlying the analysis. Over the past decade, an emphasis has been placed upon accounting for uncertainty by treating input parameters as probabilistic, rather than deterministic, values. This research builds upon existing pavement LCCA work by probabilistically characterizing several sources of uncertainty, including unit-cost of construction activities, pavement deterioration, and forecasting of future material prices. The probabilistically characterized input parameters have subsequently been implemented in three concrete pavement case studies which vary in terms of analysis period. For each case study, uncertainty has been propagated to characterize the difference in life-cycle costs and has been used to elicit which input parameters are significant contributors to the overall life-cycle cost uncertainty in each scenario. From the analysis, uncertainty surrounding unit-cost is the dominant driver of variation across all scenarios, significantly outweighing the impact of the many other input parameters considered; this suggests practitioners should focus their efforts on deriving statistical characterization methods to reduce its variation, if possible, rather than focusing their efforts on more trivial uncertain parameters

KEYWORDS

CONCRETE PAVEMENTS / LIFE CYCLE COST ANALYSIS / RISK ANALYSIS / SCENARIO ANALYSIS / STATISTICAL CHARACTERIZATION / UNCERTAINTY PROPOGATION

SUSTAINABLE CONCRETE PAVEMENT DESIGN SOLUTIONS APPLIED ON THE LARGEST PPP MOTORWAY CONSTRUCTION PROJECT IN EUROPE (ID 88)

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The authors present the sustainable pavement design solutions applied on 106 km long section of A2 toll motorway in Poland. For this largest infrastructure project, realized in the frame of Public-Private Partnerships (PPP), the concession model, where the concessionaire has to be paid by public part for the accessibility of the pavement during concession period of 30 years, was applied. The maximum pavement availability to traffic and so minimum maintenance actions were required by Public part. The pavement had to be designed so that after this period all traffic lanes will be handed over to public partner still at the highest technical conditions, class A, specified by Polish Law. Thus the pavement of the concession motorway had to be designed practically for more than 30 years. All the maintenance actions had to be predicted at the design stage, in order to minimize concessioner risk, paid for availability. This led finally to the decision to choose the rigid pavement with exposed aggregate concrete, applied for the first time in Poland on this Project. The two-layers jointed plain concrete slabs with dowels and tie bars were applied. Two existing sub-sections were constructed once with continuously reinforced concrete and once with doweled slabs.

KEYWORDS

PAVEMENT DESIGN / PPP PROJECT / EXPOSED AGGREGATE CONCRETE / CONTINUOUS REINFORCEMENT / WHITETOPPING / SKID RESISTANCE

NOISE EMISSION OF CONCRETE PAVEMENT SURFACES PRODUCED BY DIAMOND GRINDING (ID 95)

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In Germany, diamond grinding is frequently used to improve the evenness and skid resistance of concrete pavement surfaces. Since diamond grinding has been observed to affect tyre / pavement noise emission favourably, the relationship between surface texture, concrete composition and noise emission of concrete pavement surfaces has been systematically investigated. The simulation program SPERoN was used in a parameter study to investigate the main factors which affect noise emission. Based on the results of the simulations, textured concrete surfaces were produced using a laboratory grinding machine. As well as the composition of the concrete, the thickness and spacing of the diamond blades were varied. The ability of the textured surfaces to reduce noise emission was assessed from the texture characteristics and the air flow resistance of textured surfaces measured in the laboratory. It was found that concrete composition and, in particular, the spacing of the blades affected the reduction in noise emission considerably. The noise emission behaviour of numerous road sections was also considered in field investigations. The pavement surfaces had been textured by diamond grinding during the last years or decades. The results show that diamond grinding is able to provide good, durable noise-reducing properties. Several new pavement sections were investigated using thicknesses and spacings of the blades similar to those used in the laboratory to optimize noise emission reduction. It is concluded that diamond grinding is a good alternative to exposed aggregate concrete for the production of low-noise pavement surfaces.

KEYWORDS

CONCRETE / PAVEMENT / GRINDING / QUIET / TEXTURE

SESSION 9

ENVIRONMENTAL PRODUCT DECLARATION OF CZECH CEMENT (ID 120)

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This paper explains the basic concepts, history of studies and the results of the Life Cycle Assessment (LCA) of the Czech Cement and Environmental Product Declaration (EPD) of the Czech Cement. The Environmental Product Declaration is based on the method of life cycle assessment, which generally evaluates the impact on the environment from the mining of raw materials to the final disposal of waste, in the case of cement only to the factory gate. LCA is prepared according to the Product Category Rules (PCR).

The first sector environmental product declaration in the Czech Republic for construction materials was created for “Czech Cement”. The Czech Cement Association, which represents all cement producers in the Czech Republic, decided in 2010 year to create the first LCA study as a basis for the cement sector EPD. The EPD of cement was verified by an independent certification body and published in the EPD database of the Czech Republic. The EPD of cement can be needed for establishing EPD of concrete. EPD of Czech Cement was created with the intention to show the possibilities of cement LCA and EPD to Czech manufacturers and to stimulate their interest in creating their own EPDs for their own products.

KEYWORDS

CZECH CEMENT / ENVIRONMENTAL PRODUCT DECLARATION / LIFE CYCLE ASSESSMENT /
PRODUCT CATEGORY RULES

**CONCRETE ROADS IN POLAND:
THE CASE FOR SELLING NON-MAINSTREAM INFRASTRUCTURE TECHNOLOGIES
(ID 127)**

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The paper illustrates, on the grounds of Poland's case, the concrete roads network development in a jurisdiction dominated by asphalt roads. The author reviews typical drawbacks apparent when promoting concrete roads, and identifies several most arresting phenomena that have led to the current technological stalemate. The goal of the paper is not to replicate the common and yet well-known argumentation in favor of concrete roads, but rather to deal with the investors' typical opposition to this argumentation, find out how to bypass these concerns, and finally help facilitate a major systemic shift. This paper's contribution is the attempt to universalize Polish experience, making it relevant and helpful for concrete promoters in other countries. Such a knowledge-sharing exercise should increase the success rate of salesmen based in regions overwhelmed by asphalt tradition, and let them best leverage on the available resources. This is also a source of bibliography for sales teams that plan to take off with concrete roads promotion in their countries.

KEYWORDS

CONCRETE PAVEMENTS / CONCRETE INFRASTRUCTURE / SALES MANAGEMENT /
BUSINESS-TO-GOVERNMENT SALES / PUBLIC PROCUREMENT / INFRASTRUCTURAL
INVESTMENTS

**CONCRETE PAVEMENTS IN THE CZECH REPUBLIC
(ID 132)**

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The paper resumes the development of the concrete roads in Czechoslovakia, resp. in the Czech Republic over the span of time between two major specialized events held in Prague, in particular the XIVth World Road Congress 1971 and the 12th International Symposium on Concrete Roads in 2014. The concrete pavements are realized to motorways, high-speed roads, hardstandings and airfields. Some sections of the roadways are given as examples, illustrating the development the construction technologies underwent, including the structure of roadways and their surfacing. Special road cement is mentioned and testing methods is discussed with respect to the alkali-silica reaction in concrete and freeze-thaw resistance of concrete with the occurrence of anti-freeze salts.

KEYWORDS

CONCRETE ROADS / SKID RESISTANCE / EXPOSED AGGREGATE CONCRETE /
ALKALI-SILICA REACTION / FREEZE-THAW RESISTANCE

AN INDUSTRY PERSPECTIVE TO IMPROVE THE LIFE CYCLE COST ANALYSIS PROCEDURE USED FOR PAVEMENT TYPE SELECTION: A CASE STUDY FOR ALABAMA (ID 137)

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At the request of the cement and concrete industry, in 2012 the Alabama Department of Transportation (ALDOT) funded Auburn University and the University of Alabama to recommend updates to ALDOT's Life Cycle Cost Analysis (LCCA) methods for comparing asphalt and concrete paving alternatives. Auburn was asked to address LCCA from the point of view of the asphalt paving industry, and the University of Alabama was asked to address LCCA from the point of view of the concrete paving industry.

While the mechanics of performing a life cycle cost analysis are not complicated, there are many aspects dealing with the assumptions used in the LCCA procedures that can have a dramatic impact on the LCCA results. This paper presents the information and the recommendations made by the concrete industry for improving ALDOT's LCCA procedures, as well as comparisons to the asphalt industry recommendations in the following areas. These areas were considered to have strong effects on the risk, costs, and performance of competing asphalt and concrete pavement alternatives:

- Trigger value for doing a LCCA
- Analysis periods
- Performance periods / Rehabilitation selection timing
- Discount rate
- Accounting for Price Adjustment Clauses (PACs) for initial construction costs
- Accounting for Material Specific Inflation Rates (aka "real price changes") in future rehabilitation costs
- Salvage value

KEYWORDS

LIFE CYCLE COST ANALYSIS / REHABILITATION SELECTION / REAL PRICE CHANGES

**MULTI-FUNCTIONAL NOISE REDUCING PAVEMENTS MADE OF UHPC – MATERIALS;
DESIGN AND CONSTRUCTION TECHNOLOGY****(ID 147)**

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The constantly rising traffic volume is leading to high mechanical stress of the pavements. As a result, the requirements of maintenance, refurbishment and renewal are increasing. In contrast to this, financial resources are decreasing constantly. Moreover, the increasing traffic noise emissions are experienced as growing stress. New, highly sustainable and at once silent multifunctional concrete pavements made of ultra-high performance concrete are a solution for this set of problems. UHPC reinforced with steel bars and/or fibers, allows considerably thinner layers. It is practically impenetrable by chlorides and alkali which means that the steel reinforcement will not corrode and there will not be any alkali-silica reaction. Onto the load-bearing concrete a thin layer of a special, also ultra-high performance mortar can be applied wet-on-wet. A special texture will be imprinted into the fresh mortar which enables a noise reduction of 5 dB(A). Due to its high surface strength this texture will remain intact continuously during the useful life of the concrete road. In the paper we will report about the results of two extensive research projects that are nearly completed, in which new construction methods have been developed, one for the installation with common road pavers, the other as a construction method with precast parts for the quick road repair or construction. Industrial enterprises and Joint Research Centers are involved in both projects. A first trial section has successfully been constructed.

KEYWORDSWHITETOPPING / PRECAST ELEMENTS / ROAD CONSTRUCTION / ULTRA HIGH
PERFORMANCE CONCRETE / NOISE REDUCTION

**TEXTURE AND NOISE CHARACTERISTICS
OF EXPOSED AGGREGATE CONCRETE ROAD SURFACES
(ID 149)**

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Exposed aggregate cement concrete (EACC) road pavements are used on a large portion of the Austrian federal motorway network due to their durability and reduced noise emission. The standardized types with 8 and 11 mm chipping sizes have been characterized due to their noise emission and are subject to approval testing after construction. Nevertheless there are variations in the noise performance of specific EACC road sections which may be linked differences in the realized texture. This paper reports on the results of a pilot study based on simultaneous measurements of noise emission and texture with a mobile device according to ISO/CD 11819-2. These results should give a first insight into the possible causes and serve as preparation for a larger investigation starting in 2014 within the Austrian national research project OSILAWA.

KEYWORDS

TEXTURE / NOISE EMISSION / EXPOSED AGGREGATE CONCRETE / LOW NOISE PAVEMENT

SESSION 15

UNCERTAINTY MANAGEMENT IN COMPARATIVE LIFE-CYCLE ASSESSMENT OF PAVEMENTS (ID 154)

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There is significant uncertainty and variation in the environmental life cycle assessment of pavements. Uncertainty and scenario variation should be sufficiently accounted in the comparative life cycle assessment in order to increase the confidence on decisions regarding the environmental implications of alternative pavement systems. In this paper we first present a probabilistic approach for conducting comparative environmental life cycle analysis of pavements under uncertainty and variation. Making use of this model, we then examine the effect of variation in design life and analysis period on the results of comparative life cycle global warming potential of pavements. Two types of pavement alternatives under four different scenarios are compared. These scenarios are defined by prescribing different sets of values for the design life and analysis period. This information is used to quantify the degree by which the conclusion regarding the environmental superiority of the pavement choices under study is influenced by the variation in the design life and the analysis period. The results indicate that for the presented case study the variation in the design life and the analysis period does not lead to a different decision regarding the environmental advantage of these two pavement types.

KEYWORDS

PAVEMENTS / LIFE CYCLE ASSESSMENT / ENVIRONMENTAL IMPACTS / UNCERTAINTY

**SKID RESISTANCE OF CONCRETE PAVEMENTS AND THEIR DURABILITY
(ID 157)**

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The article states that a relative traffic accident risk depends on the values of skid resistance and its durability, which are both influenced by the texturing of Concrete pavements (CP). From the very beginning of the CP construction in the Czech Republic, transverse tining was used for surface texturing. The surface retains its acceptable skid resistance even after 40 years of traffic. Since 1993 a texturing with burlap dragging technique was introduced. Use of this surface treatment results in the reduction of megatexture and macrotexture, i.e. the reduction of unevenness and noise emissions of pavement surface, but simultaneously it reduces its skid resistance. New transverse tining with negative macrotexture and exposed aggregate technology has been tested. The maintenance technology used for the texturing of slip surfaces is milling and by high pressure water texturing. Measured results of surface skid resistance of all surfaces are documented by measurements of TRT measuring device according to ČSN P CEN/TS 15901-4 and emission of noise according to CPX method in accordance with ISO/CD 11819-2. The durability of surface is evaluated by Wehner/Schulze accelerated polishing method according to prEN 12697-49. Exposed aggregate technology respecting the results of the Wehner/Schulze test can bring the durability of skid resistance and noise emission.

KEYWORDS

CONCRETE PAVEMENTS / SURFACE TEXTURING / FRICTION COEFFICIENT / TRANSVERSE TINING / BURLAP DRAG / EXPOSED AGGREGATE / SURFACE MILLING / NOISE EMISSION / AGGREGATE POLISHING

**ROAD AND RAILWAY TUNNELS
THE CONCRETE, SOLUTION FOR IMPROVING PASSENGER SAFETY AND EMERGENCY
RESPONSE
(ID 158)**

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Road tunnels and railway tunnels generally, located in sensitive sites, must not be considered simply as an extension of standard open-air sections. For the road tunnels, the thickness of the structure, its future maintenance and the consequences on traffic, as also the effect on lighting of pavement lightness have to be examined closely right from the project phase. In the case of railways tunnels, the long-term criteria (durability of the structure especially) and the access for fire services as quickly as possible mean that technical solutions (cement concrete track bed for example) enabling them to enter using their emergency vehicles and to drive on the track should be preferred

KEYWORDS

CONCRETE ROADS / RAILWAY / TUNNEL / DESIGN / SUSTAINABLE DEVELOPMENT / SAFETY / FIRE

RE-USE OF MARGINAL AGGREGATES IN CEMENT BOUND MIXTURES FOR PAVEMENT FOUNDATIONS
(ID 166)

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The paper reports the results of an experimental study aimed at designing cement bound granular mixtures for pavement foundations, made exclusively with marginal materials, namely electric arc furnace steel slags, ladle furnace slags, waste foundry sands, glass wastes and coal ashes, used with different proportions.

The laboratory investigation has been divided in a preliminary study of physical-geotechnical properties of the by-products, and in the following mechanical characterization of the cement bound mixtures. The formulation of the mixes has been developed in terms of Proctor, compression and indirect tensile strength tests. At the end of the study, the elastic modulus of the mixtures has been determined by means of ultrasonic tests, at different curing periods.

The satisfactory results (compression and indirect tensile strength at 7 days up to 7.33 MPa and 0.74 MPa respectively, depending on the mixtures type), have met the main Italian Contract Specifications, so demonstrating the possibility of using industrial by-products as integral substitutes of the natural aggregates in the production of cement bound granular materials for pavement foundations.

KEYWORDS

PAVEMENTS FOUNDATION / CEMENT BOUND MIXTURES / MARGINAL AGGREGATES / BY-PRODUCTS

**OPTIMAL PORE DISTRIBUTION OF POROUS CONCRETE PAVERS AGGREGATE
(ID 174)**

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Concrete pavers are often used for construction of urban area roads as they offer both easy and fast construction as well as high aesthetical value. Although noise reduction is also very important in urban areas, research focusing on low noise concrete pavers is still rare. This paper illustrates a study for optimizing aggregates pore distribution for porous concrete pavers in view of noise reduction. As a first step packing density and void ratio of typical granulometric fractions and mixes of these were experimentally determined. The results showed good correlation to analytical calculated packing densities. Afterwards sound absorption curves were determined for each mix by means of an impedance tube. Among others, the test results demonstrated an increasing sound absorption coefficient by increasing void ratio. Probably particle shape had influence on packing density and sound absorption of the mixes. For studying the effect of void ratio and fineness of voids on sound absorption this influence had to be eliminated. Therefore packing density and sound absorption of spherical glass beads were analyzed. Mixes of single grain sizes and mixes of two grain sizes were analyzed. The results showed that for mixes of single grain sizes the fineness of the voids of the mix affects significantly the acoustical properties of the mix. In mixes of two grain sizes the voids fineness have bigger effect than the void ratio on acoustical properties. These findings were then transferred to mixes of closely sieved aggregates following previous tests. Concluding results could be corroborated on porous concrete mixes with different grain-size distribution curves. The results of this study enable the design of porous concrete mixes ensuring good sound absorption so the design can focus also on other concrete properties like strength and durability.

KEYWORDS

CONCRETE PAVERS / PAVING STONES / POROUS CONCRETE / LOW NOISE PAVEMENT / QUIET PAVEMENT / ACOUSTICS / POROSITY

THEME 2 – SOLUTIONS FOR URBAN AREAS SESSION 2

GUIDELINES FOR BUS STOPS IN CONCRETE IN THE NETHERLANDS (ID 9)

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New legislation for improving accessibility to buses by people and especially disabled people led to the modification of bus platforms and particularly the kerbs at these platforms. Buses should be able to approach quite close to these platforms. This depends on the design of the bus stop area. The dimensions of the bus stop must match the length of the different type of buses and the line in which the bus approaches the platform. Based on these requirements bus stops have been designed with concrete pavements. Solutions in doweled concrete, reinforced concrete and fibremix concrete have been designed. This includes details such as joints, sealing products, water evacuation, surface characteristics and connections to other types of pavements.

KEYWORDS

CONCRETE ROADS / PUBLIC TRANSPORT / BUS STOPS / FIBRE CONCRETE /
BUSSTATION/

EXPERIMENTAL SHORT CONTINUOUSLY REINFORCED CONCRETE PAVEMENT: CRACK PATTERN AND LOAD TRANSFER EFFICIENCY ACROSS CRACKS (ID 16)

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As a proposed long-term pavement solution for bus stops and corridors in highly urbanized areas, four experimental short continuously reinforced concrete pavement (CRCP) sections with different percentages of longitudinal steel were built in São Paulo, Brazil. The pavement sections are only 50 meters long each, a short constructive length in comparison to traditional CRCP normally built as long as the concreting process allows. Technical literature indicates that CRCP performance depends mostly on its crack pattern. Usually, narrow crack spacing and large crack width are regarded as non-desirable. A two-year crack survey showed that the shorter length, and the consequential lack of anchorage, makes the experimental short CRCP crack pattern to be unlike the traditional CRCP one; section 1 did not present any cracks yet. The up to date crack mapping is presented in order to compare the crack spacing trough time with traditional CRCP crack spacing. Additionally, deflection tests were performed using a falling weight deflectometer (FWD) to measure the load transfer efficiency (LTE) across all cracks. The results show that the LTE values are adequate (above 90%) in all sections, despite its distinct crack pattern; and that steel percentage does not influence LTE.

KEYWORDS

CONTINUOUSLY REINFORCED CONCRETE PAVEMENT / CRACKING / SPACING / WIDTH / LOAD TRANSFER EFFICIENCY

**THE VECU PROCESS FOR ROADWAYS, PUBLIC SPACES, AND URBAN DEVELOPMENT
PROJECTS A NEW APPROACH FOR CONSOLIDATING THE STATE OF THE ART
(ID 26)**

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Urban roadways and public spaces are major fields of application for road concrete in France. Specialised contracting firms have gradually refined the finishes, skills and techniques to provide an extensive range of decorative concrete models. A collaborative process known as VECU (French acronym for roadways, public spaces and urban development projects) has assessed the state of the art through an inventory of over 50 finishes favouring such notions as beauty, sensitivity, personalisation and integration, all of which are embodied in the creative talents of designers, architects, landscapers, and prime project consultants. The new concepts of URBA-Béton, ECO-Béton and INNO-Béton offer a new look on the contribution of concrete to urban development and to the enhancement of regional infrastructures.

KEYWORDS

URBANITY / PUBLIC SPACE / INNOVATION / URBA-BÉTON / ECO-BÉTON / INNO-BÉTON

HEATED TRANSPORTATION INFRASTRUCTURE SYSTEMS: EXISTING AND EMERGING TECHNOLOGIES

(ID 170)

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Ice and snow on pavement surfaces cost the U.S. national economy in snow removal, damaged pavement and lost man-hours due to travel delay. Common practices for removing ice and snow from pavement surfaces include spraying anti-ice chemicals on the ground and deploying snowplowing vehicles. These methods are labor-intensive, occasionally ineffective at extremely low temperatures and have associated environmental concerns with possible contamination of nearby water bodies. Heated pavement systems (i.e., the concept of supplying heat to the pavement through an external or internal source) melt snow and ice without the need for anti-ice chemicals and snowplowing vehicles. A vast majority of the existing heated pavement systems utilize electrical or geothermal (hydronic) heating technologies. The use of anti-icing coatings and mix designs to deter ice formation is a closely related, but distinct concept. The objective of this paper is to provide a comprehensive review of the current state of practice and research of existing heated transportation infrastructure systems (highway pavement, bridges and airport pavement) as well as provide an overview of the emerging technologies.

KEYWORDS

HEATED PAVEMENTS / ICY ROADS / HYDRONIC / CONDUCTIVE CONCRETE /
SUPERHYDROPHOBIC / PHASE CHANGE MATERIALS

EVALUATION OF EXCAVATABLE CEMENT TREATED MATERIALS FOR URBAN AREAS (ID 31)

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For networks owners, like the French national gas utility, it is essential to ensure a rapid access to their installations, even with a simple pick, for normal or emergency maintenance matters. Modular concrete pavements were developed during the last years for that purpose. In order to keep their stability, the concrete elements are laid on a base made of cement treated material. With this concept, the pieces on the surface are designed to be easily removed but the base material must be excavated with light equipment as well.

On the other hand, and whatever the base layer is made of, self-compacting materials with low cement content could be used more widely for back-filling of urban trenches because they don't need mechanical compaction and so require less wide trenches. But as for the first case, the dissemination of the so called Controlled Low Strength Materials is hampered by the need to ensure their excavability for further maintenance.

Yet, current available classification systems or empirical criteria appear to be inefficient to estimate accurately if a cement treated material can be easily excavated. In this context, Ifsttar and the French national gas company, are developing a new approach based on an original laboratory punching test validated on field excavation tests.

The paper first presents the context and the issues of the research. Then it describes the new tools developed and a large experimental campaign comparing laboratory data and in-situ test results. Finally, a model based on the punching penetration test which allows the prediction of excavated volumes for a given energy is presented and applied to the results. The paper concludes on the relevance of the developed method and on the interest of the punching test to characterize excavability.

KEYWORDS

CONTROLLED LOW-STRENGTH MATERIALS/REMOVABLE CONCRETE PAVEMENT / CEMENT
BASED MATERIALS/EXCAVABILITY / PICK / PUNCHING TEST / TRENCH

**PRECAST ELECTRIFIED ROADWAY PAVEMENT SYSTEMS USING ENGINEERED
CEMENTITIOUS COMPOSITES
(ID 62)**

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The adoption of electric vehicles (EVs) remains low mainly because of its battery related problems, which include high cost, range limitation and weight. Electrified roadways, which allow EVs to charge while they are in operation (motion or stationary) by using Inductive Power Transfer, is a very innovative technology to overcome all of battery related issues. Implementing these electrified roadways into pavement management systems needs a cost effective and applicable pavement system. Precast concrete pavement systems (PCPs) are suitable pavement systems to fulfil electrified roadway requirements. However, due to their nature of construction, PCPs typically need two layers of steel reinforcement, which can influence the electromagnetic field as well as arrangements of electrical components. These two factors affect the overall performance of wireless energy transfer. Engineered Cementitious Composite (ECC), which has tensile strain hardening behaviour similar to ductile metal, has the potential to be a good material for precast electrified roadway pavement. Therefore, the main aim of this paper is to investigate whether ECC is a suitable material for precast electrified roadway pavement in terms of handling during the construction phase and pavement structural performance using finite element models (FEMs). The research results indicate that durable ECC can not only help precast electrified roadway pavement to withstand critical loadings during construction but also greatly strengthen the pavement service life.

KEYWORDS

ELECTROMOBILITY / ELECTRIFIED ROADWAY / PRECAST ELECTRIFIED ROADWAY
PAVEMENT / ENGINEERED CEMENTIOUS COMPOSITE / FINITE ELEMENT MODEL

MODULAR SECURITY BARRIERS FOR URBAN DEMANDS CURRENT AND DEMANDS STATE OF THE ART SOLUTIONS (ID 163)

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Using appropriate security barriers for directing the traffic in urban areas, close to downtown, shopping centers, protecting working zones in urban areas in general, and separating traffic, is essential for the safety of different traffic users. The traffic flow at industrial, commercial and public areas is easily managed by using precast modular security barriers.

The market offers a wide range of products for separating pedestrians and cyclists from heavy traffic in order to avoid direct contact and injuries.

Security barriers are used if the European Norm for road restraint systems, EN 1317, is not any more required because of reduced speed of traffic users. In the most EU countries security barriers need to have a national approval from the relevant authority with typical national requirements. Modern security barriers for urban demand are developed based of experience and with the know-how of crash tested EN 1317 restraint systems and similar characteristic.

In the field of security barriers you can find numerous solutions produced in different materials. The main request from the user of security barriers is to protect and separate and keep flexibility in moving the barrier. Slim barriers, with rubber pads on the bottom and modular connection are the best choice in separating and secure different road users in order of space-saving.

KEYWORDS

FLEXIBLE PRECAST SECURITY BARRIER SYSTEMS / MODULAR PRECAST SECURITY BARRIER SYSTEM / SAFETY FOR ROAD-WORKERS AND ALL URBAN TRAFFIC USERS / URBAN, SECONDARY, OR NARROW ROADS / COST EFFICIENT TRAFFIC REGULATION

SESSION 12

TOWARDS A STANDARDIZED DESIGN STRUCTURE FOR CONCRETE TRAMWAYS IN FLANDERS (ID 73)

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For more than ten years tramway structures in Flanders have been built in concrete, particularly those which are subject to traffic loading by trams and city buses. As there has never been a standardized design, a wide range of different solutions have been tried, either in jointed concrete slabs with or without additional steel reinforcement, or in continuously reinforced concrete (CRC). Some of the solutions were successful; others failed.

The central engineering department of the Flemish public transport company “De Lijn” has taken the initiative to evaluate the different solutions and to move towards one or more standardized design structures. One of the difficulties is that different solutions for the positioning of the rails need to be considered - according to different commercial suppliers -, and this has an impact on the structural solution for the concrete layers.

In general, the structure consists of a base layer and two layers of concrete. The bottom layer, mostly in conventional concrete C30/37, is the bearing structure for the rails. The top layer, normally in pavement quality concrete, is the running surface for buses.

Typical technical details to be dealt with are the spacing of joints in the narrow concrete slabs, the reinforcement in the top or bottom part of the concrete top layer, the bond or separation between the two concrete layers, and the layout of steel reinforcement and anchoring abutments in case of CRC.

KEYWORDS:

CONCRETE ROADS / BUS LANES / TRAMWAYS / FLANDERS / DE LIJN

A CONCRETE CYCLE TRACK IN THE VELODROME OF SAN VICENTE DEL RASPEIG (ALICANTE, SPAIN) (ID 92)

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A concrete cycle track was built in the velodrome of San Vicente del Raspeig, a town close to the Mediterranean Sea in the province of Alicante, in the South East part of Spain. This sport facility was opened in 2013.

The cycle track is 7 m wide and 250 m long. The straights are banked 11 degrees, while in the turns banking increases gradually up to 37 degrees.

A concrete pavement was chosen for the cycle track since it is placed in the open air and then subjected to weather conditions. The pavement, 20 cm thick, is jointed reinforced. It is placed on a vibrated lean concrete base, 10 cm thick, and a crushed granular subbase. A characteristic compressive strength of 20 MPa at 28 days was specified for concrete.

A longitudinal joint was placed in the centeline of the pavement, while transverse joints are spaced 4 m at most. In addition, expansion joints are placed in the ends and the middle of the turns.

Reinforcing consists of a steel mesh, placed at mid depth and interrupted at all transverse joints.

The pavement was finished by hand polishing, trying to obtain a texture which not damage cyclists in the event of falls but at the same time not compromising safety in wet conditions.

KEYWORDS

CONCRETE CYCLE TRACK / VELODROME / JOINTED REINFORCED CONCRETE

THINKING OUTSIDE THE BOX WITH ROLLER COMPACTED CONCRETE PAVEMENT (ID 106)

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Roller compacted concrete (RCC) pavement has been used for decades in situations where repetitive heavy loads are applied and for large paved areas. These applications have included logging yards, ports, automobile manufacturing plants, and warehouse districts among other places. While these are appropriate applications for RCC pavement, there are many other uses for this versatile paving material. Alternative applications for RCC pavement include light industry, municipal airports, local streets, low volume roadways, highway shoulders, middle turn lanes, lane widening, alleys, and may also be used as a rigid base for portland cement concrete or asphaltic concrete surface courses. When utilizing RCC pavement in these alternative settings, it is important to design the RCC mixture and place the pavement using methods that are applicable to these areas. Additionally, production of RCC mixtures utilizing ready mix operations may also be considered as a more economical alternative when paving RCC for low volume roadway applications like residential streets and other urban applications.

KEYWORDS

ROLLER COMPACTED CONCRETE PAVEMENT / ZERO SLUMP CONCRETE / LOW VOLUME ROADWAYS / STREETS AND LOCAL ROADS

GUIDELINES FOR CONCRETE ROUNDABOUTS IN THE NETHERLANDS (ID 107)

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Due to the durability advantages of concrete pavements, the application of concrete for roundabouts is gaining more and more popularity among commissioning authorities. In the Netherlands it is estimated that there are over 3,000 roundabouts. The market share of concrete is still growing. Concrete roundabouts can only be durable when attention has been devoted to design and execution and the right choices are made for the right situation.

For that reason a guideline for concrete roundabouts has been drawn up: 'Concrete Roundabouts – just a bit different'.

This paper will deal with the design aspect of different types of roundabouts and explain the points of attention for execution in doweled concrete, fibremix concrete and continuously reinforced concrete (CRCP) with special attention for optimisation of crack width control. Furthermore, the ways of execution will be explained, including kerbs, etc.

KEYWORDS

CONCRETE ROUNDABOUTS/ FIBREMIX CONCRETE/ CRCP/ CRACK WIDTH CONTROL

RECENT ADVANCES AND USES OF ROLLER COMPACTED CONCRETE PAVEMENTS IN THE UNITED STATES (ID 128)

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Roller Compacted Concrete (RCC) is a no slump concrete that is placed by an asphalt paver and compacted with vibratory rollers similar to asphalt pavement construction. RCC has long history of good performance as a pavement for ports, container yards, and manufacturing plants. This paper will summarize a recent survey of uses of RCC, types of paving equipment and final surface since 2011 in the United States as well as provide a few case studies on local roads, hike and bike trails, and industrial projects. The paper documents many of the benefits of using RCC on these types of projects such as speed of installation and traffic opening. Recent advances in mix design with admixtures, aggregate selection, as well as utilization of diamond grinding for a smoother finish are also documented.

KEYWORDS

ROLLER COMPACTED CONCRETE / HIGH DENSITY ASPHALT PAVING MACHINE / PAVEMENT / CONSTRUCTION / ADMIXTURES / DIAMOND GRINDING

ACCELERATED FULL SCALE TEST ON PREFABRICATED CONCRETE SLAB PAVEMENT FOR ELECTRICAL SUPPLY BY INDUCTION OF URBAN TRANSPORT SYSTEMS (ID 151)

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Innovative solutions for transport infrastructure are needed to meet future mobility needs, especially in urban areas. Recently, Bombardier Transportation has developed a new system for supply by induction of electrical public transportation vehicles. It consists in integrating electrical supply cables in a prefabricated concrete slab implemented in the road. These cables create an electromagnetic induction field, used for charging of electrical vehicles. A key aspect of the project is the design and durability of the prefabricated slab pavement under heavy traffic. For this purpose, it was decided to carry out a full scale test on the accelerated pavement testing facility of IFSTTAR in Nantes. Five different prototype slabs are tested, differing by the width of the slab, and the thickness of the concrete cover above the supply cables. The experiment consists in applying one million passes with a dual wheel load of 65 kN and monitoring the mechanical behaviour of the slab pavement by measuring displacements and strains at chosen points. The paper presents the design of the prefabricated concrete slab pavement, the results after the first half of the current full scale test (after 500 000 loads), and the perspectives, in terms of deployment of this technology for urban transport infrastructure.

KEYWORDS

PREFABRICATED CONCRETE SLAB / ACCELERATED FULL SCALE TEST / ELECTRIC VEHICLE SUPPLY / INDUCTION / URBAN TRANSPORT SYSTEM

CONCRETE PAVEMENTS AND STRUCTURES FOR DEDICATED PUBLIC TRANSPORT LANES (ID 27)

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Bordeaux, Clermont-Ferrand, Caen, Grenoble, Lille, Lyon, Marseille, Montpellier, Nancy, Nantes, Nice, Orléans, Rouen, Saint-Étienne, Strasbourg, Paris... Which city hasn't developed – or is about to develop – its own network of public transport on dedicated lanes? Users warmly welcome this mode of public transport, typical of urban renewal projects for local authorities wishing to move beyond the car era, once the hassle of the construction period is over. The present communication will present the context and the main issues for engineering stakeholders, and explain how the good use of concrete in various forms and finishes can enhance the performance expected from these mobility spaces, that have become emblematic places within cities.

It will also highlight the increasing importance of Bus Rapid Transit systems (BRT, or BHNS in French), which are alternative or complementary solutions to trams.

Going beyond a true operational reality, the present communication will thoroughly explain why and how this field must be a major area for research and innovation. It will present the latest advances, and the promising results obtained by breaking barriers between professions and building new partnerships. These results can also be explained by the growing use of precast pavements, composite pavements, and by the number of innovations designed to meet the growing interest in sustainable greenways, in particular.

KEYWORDS

TRAMWAY / BUS RAPID TRANSIT SYSTEMS BRT/BRTS / SURFACE PUBLIC TRANSPORT / PUBLIC TRANSPORT ON DEDICATED LANES / CONCRETE STRUCTURES / CONCRETE PAVEMENT / GREENWAY

THEME 3 – DESIGN AND CONSTRUCTION SESSION 3

IMPACTS OF THE LONGITUDINAL JOINT LOCATION ON SLAB STRESSES (ID 35)

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Longitudinal joints in concrete pavements historically have been located along the edges of lane lines, a condition that results in applied loads being located at the most critical points (e.g., edges and corners of slabs). With increasing use of light-colored silicone sealants that contrast less with the concrete surface color, the innovation of thinner sawcut blades that also make the joints less visually prominent, and a realization that joints in the middle of a driving lane are not problematic (through the adoption of thin concrete overlays with shorter joint spacings and other short-slab design methodologies), locating longitudinal joints at the edges of lane lines might lead to an underoptimized design. For example, a typical geometric design of a 2-lane roadway with 12 ft (3.7 m) wide lanes and 6 ft (1.8 m) shoulders on either side could be designed such that only two longitudinal joints are used, evenly spaced at 12 ft (3.7 m), rather than the conventional three longitudinal joints. Such an arrangement reduces stresses and deflection under the same applied loads because edge loads are turned into interior loads. Other benefits, such as easier access to longitudinal joints for future maintenance, also exist. This paper presents finite element analysis to support this concept and examples of the application of mid-lane alternate longitudinal joint layouts in the USA and Australia.

KEYWORDS

JOINTED PLAIN CONCRETE PAVEMENT (JPCP) / EVERFE / LONGITUDINAL JOINT / THICKNESS OPTIMIZATION / EDGE STRESS / AASHTOWARE PAVEMENT ME

**THE NEW BALLASTLESS TRACK PROJECT (NBT): FROM IDEA TO 1KM PROTOTYPE
(ID 38)**

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Within the frame of a French collaborative research program started in 2007, private companies, a public research laboratory and a rail network owner have jointly developed a new ballastless track structure (NBT) based on independent concrete slabs. This structure is dedicated to both very high speed operations and mixed passenger/freight operations and has a design life of 100 years. The present paper describes the different steps of the project: the conceptual design, a 10 million loading cycle test made on a real scale mock-up up in laboratory and finally the construction of a 1km long demonstration track on the French railways network, in 2013. The paper concludes by highlighting the particular advantages expected from this solution compared to ballasted track when life cycle is analysed.

KEYWORDS

CONCRETE SLABS / RAILWAY INFRASTRUCTURE / LIFE CYCLE COST / THERMAL GRADIENT

RECYCLABLE HIGH VOLUME FLY ASH (HVFA) PAVEMENT CONCRETE USING LIMESTONE AGGREGATE (ID 42)

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Fly-ash is a pozzolanic material, so it can contribute to various properties, such as strength development at mature age. The strength development at early age, however, is significantly slow and may negatively affect traffic service. Early strength may be improved when limestone filler is mixed in fly-ash concrete. In addition, the fly-ash concrete made with limestone aggregate may be recyclable as raw material for cement production. The foci of the present study are to achieve high early strength development of HVFA concrete and to develop a recyclable concrete pavement. The paper describes the flexural strength properties of pavement concrete made with 40% of cement replaced by fly ash. The test result indicates higher flexural strength development and adequate fatigue strength for pavement concrete. In addition, the study examines abrasion and skid resistances of the concrete to discuss the practical application for road pavement. The test results confirm that the HVFA concrete has almost equal performance to conventional concrete pavement.

KEYWORDS

FLY ASH / HVFA CONCRETE / RECYCABILITY / LIMESTONE AGGREGATE / FLEXURAL STRENGTH / FATIGUE

RECENT DEVELOPMENTS IN THE DESIGN AND CONSTRUCTION OF CRCP TOWARDS A MORE DURABLE CONCEPT (ID 61)

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The technique of continuously reinforced concrete for pavement construction is being applied in Belgium since the 1960s. The original design underwent several changes over time, sometimes for economic reasons but mostly in order to improve the long term behaviour of the pavements. Today there are still possibilities for further optimisation, mainly aiming at an improved cracking pattern. Studies on the influence of different parameters on the crack pattern and field measurements will be presented together with the results of an ME-PDG analysis. Discussion will concern the choice of steel reinforcement rate and lay-out and other possible measures for the optimisation of the crack pattern and CRCP performance, in particular the technique of active crack initiation. Other fields of progress are the surface and texture characteristics of exposed aggregate concrete, both in single layer and double layer constructions. Modifications in the concept of double layered CRCP will be presented. These theoretical studies, trial sections and the monitoring of real worksites remain important in order to evaluate the performances of the different concepts and to come to the right choice.

KEYWORDS

CRCP / CONCRETE ROADS / CRACK PATTERN / REINFORCEMENT / DOUBLE LAYERED CONCRETE / TWO LIFT PAVEMENT / ACTIVE CRACK INITIATION

**THE ROLE OF QUALITY ASSURANCE IN DELIVERING LONG-LIFE CONCRETE PAVEMENTS
(ID 46)**

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The fundamental goal behind any pavement design and construction project is to provide a system that will survive the predicted traffic and environment for the selected lifetime. Considerable effort is paid to the structural design of a pavement in order to reach that goal. On the other hand, the concrete mixture and construction practices are generally assumed to be acceptable, yet the properties that most affect pavement life are not tested or not tested in real time when corrections can be accomplished. This paper will provide an overview of the two sides of quality assurance (QA) (quality control and agency acceptance) and the role each plays in ensuring that the pavement both meets specifications and provides a long service life. The roles of both the agency and contractor must be clearly understood. New technologies are available for both quality control and agency assurance that could significantly improve pavement quality and contractor profitability.

KEYWORDS

CONCRETE PAVEMENTS / QUALITY CONTROL / QUALITY ASSURANCE / MIXTURE DESIGN / CONCRETE TESTING

IMPORTANCE OF CORRECT DOWEL POSITIONS IN TRANSVERSAL JOINTS OF RIGID PAVEMENTS (ID 51)

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Positions of dowels and tie bars in jointed unreinforced concrete pavements and the importance of their correct placement on pavement behaviour and lifespan was studied as a part of R&D project of Technology Agency of the Czech Republic No. TA02031195 and TE01020168. Laboratory concrete beams with in-built dowels in different positions and strain gauges were prepared and exposed to cyclic loading. Another method concerned the modelling of stress state in the vicinity of in-built dowels by the FEM method in ANSYS software. The paper presents the results of modelling and performed experiments and makes conclusions which are important for practical usage.

KEYWORDS

CONCRETE PAVEMENT / DOWEL / FEM / LABORATORY TEST / FIELD TESTS

CONTINUOUSLY REINFORCED CONCRETE PAVEMENT WITH ASPHALT TOP LAYER OR SURFACE TEXTURE FROM DIAMOND GRINDING – THE TRIAL SITE ON MOTORWAY A94 (ID 29)

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For many years, the traffic volumes and percentage of heavy traffic on German roads and motorways have steadily increased and this trend is expected to continue in the future. To guarantee mobility in the future, road construction with a maximum service life and a minimum of necessary maintenance are needed. In Germany, concrete pavements are traditionally built with Jointed Plain Concrete (JPC), designed for a service life of 30 years. However, it is well known that the transverse joints in JPC pavements are the weakest aspect of this method. There is another way to build concrete pavement: Continuously Reinforced Concrete Pavement (CRCP). This type of construction is, for example, standard in Belgium and in some states in the USA. With CRCP, cracking freely occurs, and because of the reinforcement, smaller “slabs” occur. Load transfer is provided through aggregate interlock that is facilitated by the continuous longitudinal reinforcement. Experience so far has shown that CRCP achieves a longer service life, has better ride quality, and that less maintenance is needed compared to JPC pavements. Both unreinforced and continuously reinforced concrete pavements can be covered with an asphalt top layer. In this way, the surface requirements for skid resistance and noise are provided by the asphalt, and the structural capacity by the concrete below. CRCP is especially suitable for this purpose because there are no discontinuities in the form of transverse joints. This Composite Pavements have the potential for a service life of 50 years, and the life cycle costs will be lower than the current standard. To raise awareness of the potential benefits of this pavement, test sections along motorway A94 near Forstinning in Bavaria were constructed in 2011. This trial consisted of three parts: CRCP with a thin hot-mix asphalt top layer, jointed plain concrete with a thin hot-mix asphalt top layer, and jointed plain concrete with surface texture from diamond grinding. Under the framework of the Research Association for Roads and Traffic (FGSV), Working Group 8.3.4 was created. This group, together with the Building Department of Bavaria and the Federal Highway Research Institute (BAST), created a concept and then implemented it by starting a research program. The first results from this research are with respect to cracking of the CRCP, movement at the end anchors, and adhesion between asphalt and concrete.

KEYWORDS

CONCRETE PAVEMENT / CONTINUOUSLY REINFORCED CONCRETE PAVEMENT / ASPHALT TOP LAYER / DIAMOND GRINDING / TRIAL SITE / GERMAN MANUAL CRCP

SESSION 5

FIBREMIX CONCRETE FOR PAVEMENTS; EXPERIMENTAL SEARCH FOR MAXIMUM CRACK-FREE SLAB LENGTH (ID 10)

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Road constructions with fibremix concrete allow longer distances between joints, compared to unreinforced concrete pavements. In the absence of a dedicated design tool for fibremix concrete pavements, the search for a maximum crack-free slab length took place in several projects. Fibremix concrete has been used in parking areas near motorways, roundabouts, road crossing, bicycle paths and regional roads with slab lengths up to 80 m.

The knowledge gained from these projects is related to the variation in day and night temperature during execution of the pavement. Pavements constructed in October and November, with less variation in temperature, still have crack-free joint distances of 80m.

This paper describes the experiences with the several projects and recommends joint distances for different weather conditions and type of constructions.

KEYWORDS

CONCRETE ROADS / FIBREMIX CONCRETE / CRACK WIDTH / SLAB LENGTH / STEEL FIBRE
REINFORCED CONCRETE

**AIR VOID FORMATION IN THE LABORATORY AND IN PRACTICE
(ID 15)**

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As a result of a short mixing time excess air-entraining agent (AEA) is added during the production of air-entrained concrete to achieve the required air content. In this case, the fresh concrete contains AEA that has not been fully activated. If there is a subsequent input of mixing energy, the air content of the concrete can rise. The extent of the rise (the re-activation potential) is substantially affected by the active substance of the AEA. Any increase can be avoided if the AEA is fully activated due to a sufficient mixing time. The knowledge of the air void formation in relation to the mixing time is precondition for the production of air-entrained concrete conforming to the requirements. The functioning of an AEA can be characterized in the laboratory during extended initial testing. However, the air void formation is also influenced by the mixer type, quantity of mixture and mixing intensity. The extent to which laboratory results can be applied to practical construction conditions has not yet been clarified. In a research project the air void formation in fresh and hardened concrete in relation to the mixing time was therefore determined in the laboratory and in a ready-mixed concrete plant. Comparison of the test series shows that the results of laboratory trials can be applied to practical conditions.

KEYWORDS

CONCRETE ROADS / AIR-ENTRAINED CONCRETE / AIR-ENTRAINING AGENT

**FRANCE: FIFTEEN YEARS REVIEW ON THE BEHAVIOUR OF COMPOSITES PAVEMENTS
(CONCRETE ON ASPHALT MIX)
(ID 18)**

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On the initiative of concrete road professionals on the one hand – the French cement industry represented by its trade association CIMBETON and concrete pavement construction companies represented by the trade association SPECBEA – and the French road administration represented by SÉTRA on the other hand, a new concrete pavement structure was developed in France around 1995. This new structure is composed of Continuously Reinforced Concrete Pavement (CRCP) placed, not conventionally on a lean concrete subbase, but on a subbase made of asphalt material, more precisely on improved asphalt bound material. The purpose is to take advantage of the bonding, even temporary, of the two layers to have the subbase play a true part in the design of the pavement. The objective is to achieve a structure with long lasting of life at a lower cost, by reducing thicknesses.

Based on this concept, two experimental projects were carried out on the national road network. The first project was accomplished in 1998, a 3 km pavement on the RN141, near Angoulême in Charente (south-west of France). The second project, a 2x3 km pavement, was carried out in 2001 on the RN4, between Nancy and Strasbourg in Moselle (north-east of France) where the climate is more rigorous and more continental. In order to accelerate reports on structural behaviour, “fuse” reference sections were built, specifically with 10 cm of CRCP on 8 cm of class 3 asphalt-bound material. To this day, these test sections, which have been carrying very heavy traffic (approx. 2000 heavy goods vehicles/day and per direction) for 15 years, have exceeded the theoretical service life for which they were calculated. The last series of tests were carried out during the summer of 2013. The present article provides a review of these tests, showing promising results that exceed designers’ expectations for this structure and validate the design hypotheses considered.

KEYWORDS

CONCRETE PAVEMENT/ COMPOSITE PAVEMENT/ CONTINUOUSLY REINFORCED
CONCRETE PAVEMENT/ LONG LASTING OF LIFE STRUCTURE

A 32-YEAR-OLD CRCP, ONLY WITH A NEW POROUS ASPHALT TOP LAYER, STILL FIT FOR THE FUTURE (ID 104)

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The A76 is the corridor between the Ruhr area (Germany) and Antwerp (Belgium) in the southern part of the Netherlands. It was built in 1985. Because the asphalt pavement failed as a result of a geological fault in the subsurface, a CRCP with a toplayer of porous asphalt was chosen. During the winter period 2012-2013 the porous asphalt was damaged and the asphalt layer had to be milled off for safety reasons. The traffic drove on the milled concrete surface for several weeks. After the cracks and the surface had been inspected, it was decided to renew the porous asphalt layer. The results of the measurements and the expected remaining lifetime are presented in this paper.

KEYWORDS

CONCRETE ROADS / CONTINUOUSLY REINFORCED CONCRETE / LONG LIFETIME / LOW NOISE PAVEMENT / MILLING

**PERFORMANCE ENGINEERED MIXTURES FOR CONCRETE PAVEMENTS IN THE US
(ID 28)**

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Many concrete pavement mixtures in the US are proportioned based on recipes that have been used before, or on prescriptive specifications. As budgets grow tighter and increasing attention is being paid to sustainability metrics, greater attention is beginning to be focused on making mixtures that are more efficient in their usage of materials, yet do not compromise engineering performance. While the technology is largely available in the concrete industry, a number of challenges are slowing the development of more performance-based specifications and mixtures in the US market. These include resistance to change from familiar to less known, resistance to any change in the distribution of risk, and a lack of good performance tests.

This paper addresses these factors by clearly laying out the barriers to adoption of more performance-based specifications for mixtures, along with identifying the research that is needed to address them. Suggestions are made on the steps that can be taken to move the process forward. The paper also discusses work recently conducted to investigate an alternative approach to mix proportioning that is better able to deliver designed performance requirements for local materials.

KEYWORDS

CONCRETE PAVEMENTS / PERFORMANCE-BASED SPECIFICATIONS / PASTE-TO-VOIDS
VOLUME RATIO / MIX PROPORTIONING / MIX OPTIMIZATION

SESSION 7

RECENT RESEARCH ON PCC PAVEMENTS ON BRIDGES IN CZECH REPUBLIC (ID 52)

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Skanska a.s. is one of the leading construction companies, who successfully execute concrete pavement projects in Czech Republic, Slovakia, Poland mostly on motorways and airports. To achieve the best quality, durability and cost-efficiency, it is needed to put an effort to research and development. Recently experts from Skanska are leading and/or are involved in several R&D project together with Technical Universities and other Research institutions. The results of the R&D projects give participants an overview about the most frequent issues connected with concrete pavements and their solutions within Czech Republic's technical and environmental conditions. The three major projects are:

- Concrete pavement surface characteristics as the main component for traffic safety,
- Dowel bars positioning in joints of JPCP,
- Concrete pavements on bridges – safer, efficient and more durable alternative to asphalt pavement, when the adjacent road is in concrete.

KEYWORDS

CONCRETE ROADS / BRIDGES / SURFACE / SKID RESISTANCE / DOWEL BARS /
TEMPERATURE / PRE-STRESSED CONCRETE PAVEMENT

CRCP WITH GROUND TEXTURE – EXPERIENCES AND RESULTS OF THE “GESEKE ACCESS ROAD” PILOT PROJECT (ID 54)

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In 2009, an innovative road pavement “Continuous Reinforced Concrete Pavement with Ground Texture” was successfully realised by HeidelbergCement AG with the pilot project, “Geseke access road”. In an extensive measurement programme, long-term measurements are being made over a period of 5 years to investigate the behaviour of the carriageway under traffic, as well as the evolution of surface characteristics of the ground textures, e.g. noise reduction and skid resistance under high heavy traffic load. The scientific backing and measurements are being carried out by the Ruhr University Bochum (RUB) and the German Federal Highway Research Institute (BAST). The aim is to create a lifespan and economic efficiency forecast for the CRCP with ground texture based on these measurement values.

For the dimensioning of the CRCP, the road concrete class StC 35/45 - 4.0 according to AL-Sp Beton 06 [1] has been taken as a basis. The road is driven on daily by approximately 500 clinker and limestone transport lorries with a total weight of 40 t.

The approximately 1 km-long and 7.50 m-wide road was built with a longitudinal and transverse reinforcement made from steel bars (0.75 % reinforcement). The concrete (strength class C35/45 - XF4, XM2 according to DIN EN 206-1) [4] with a thickness of 22 cm was installed using a slipform paver onto a 10 cm thick asphalt base layer.

The texturing of the surface with a grinding process used for the first time in this new construction has shown that an extremely quiet and high-grip surface texture can be produced with this type of surface finishing. Through the grinding or profiling of the surface, all the irregularities created during the construction of the concrete were eliminated, therefore enabling the construction of an absolutely flat surface with extremely high driving comfort and outstanding driving dynamic properties. By means of a longitudinally aligned texture geometry with a defined grinding depth and groove and gap width, the drainage of the surface water is influenced positively, which leads to a reduction in spray generation and the risk of aquaplaning, and therefore leads to a substantial improvement in road safety.

Two different groove spacings were implemented on the test section (blade distance 2 mm and 3 mm / blade width 3.2 mm / grinding depth 3 mm). Very good results were measured with the Close Proximity Method (CPX) as well as with the Lateral Force Measurement method (SKM) with regard to noise reduction and grip in 2010 and 2013 (e.g. grinding 2 mm: $CPX_{P,80 \text{ km/h}}$ 94.9 / 95.2 dB(A) and $\mu_{SKM,60 \text{ km/h}}$ 0.84 / 0.81).

The HeidelbergCement AG “Geseke access road” pilot project proved impressively that all the requirements of a modern, quiet, roadworthy and low-maintenance construction are safely and sustainably fulfilled through a jointless CRCP with ground texture.

KEYWORDS

CONCRETE ROADS / LOW NOISE PAVEMENT / GRINDING / GROUND TEXTURE

FAILURES OF CONCRETE SLIT DRAINS, CAUSED BY NEGATIVE EFFECT OF THEIR ERRONEOUS INTEGRATION INTO SURROUNDING MULTI-LAYER ROAD SYSTEMS (ID56)

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Concrete slit drains (also known as slot drains – see fig. 1,2) are being used for the draining of highways and roads, as well as for large handling and parking areas. Recently, this system of drainage has become increasingly applied, which does, however, bring with it an increased incidence of failures.

The study concentrates on the failures of concrete slit drains, caused by the negative effect of their erroneous integration into surrounding multi-layer road systems. It starts with a theoretical analysis of the problem, i.e. the negative influence of thermal expansivity of surrounding concrete slabs on slit drains, the impact of their shrinkage, and the co-action of these factors. In addition, it presents a computer numerical analysis of a concrete slit drain loaded by the pressure of adjacent concrete slabs exposed to temperature effects and shrinkage. The most frequent stresses are modelled and the relevant results introduced. Furthermore, the authors introduce a real case from construction practice illustrating extensive damage to concrete slit drains, followed by the relevant computer simulation.

From the computer simulation and lab tests it follows that the failures of concrete slit drains can be easily caused by deformations of the concrete slabs constituting the surrounding multi-layer road system. Thermally-induced expansions and contractions, as well as concrete shrinkage, produce, in non-dilating connection, stress in the link between the multi-layer road system and the lateral walls of the slit drains. The slit drains are highly sensitive even to a very small malfunction of the expansion joints (e.g. clogging of the slit by solid materials), or their bad installation. It is apparent that failures (cracks) in the slits arise even by the slight compression of a slit drain (to the order of tenths of a millimetre). The analysis presented shows the necessity for a careful installation of expansion joints during the placement of the slit drains into the surrounding multi-layer system, which could otherwise induce horizontal pressures on the drains. The study is concluded by recommendations for designers.

KEYWORDS

CONCRETE ROADS / SLIT DRAINS / SHRINKAGE / TEMPERATURE

**CONCRETE PAVEMENTS IN MOTORWAY SERVICE AREAS
(ID 57)**

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Even if the forecasts for the development of goods traffic are more cautious than they were just a few years ago, growth remains strong in Europe. Most goods will continue to be transported by road in the future. Not everywhere, however, has the expansion of motorway rest and service areas been able to keep up with the enormous growth in goods traffic. In Germany, bottlenecks in the number of available parking spaces for heavy vehicles in the evening and night-time hours are the result. The reduction of this deficit through the needs-driven expansion of motorway rest and service areas thus remains an important project within the field of transportation infrastructures. Heavy vehicle parking spaces at rest and service areas are subject to high structural loads. Due to tight radii and heavy vehicles moving at slow speeds or standing stationary, the entry slip roads, through lanes, drive aisles, and exit slip roads are also subject to strong loading forces. Constructed in concrete, these pavements are durable and show a great resistance to deformation even at higher temperatures. As it is not always possible to avoid irregular slab geometries in concrete road pavements at rest and service areas, working out a joint layout plan that is optimised to the local conditions is of fundamental importance. Considerable potential for increasing durability can also be found in the construction of parking area islands and kerbside gutters.

KEYWORDS

CONCRETE PAVEMENTS / SLAB GEOMETRY / JOINT LAYOUT / DOWEL ALIGNMENT
ADHESIVE KERBS / MONOLITHIC KERBS

QUALITY AND OPTIMAL GRADING OF SAND FOR OPTIMAL PERFORMANCES OF CONCRETE PAVEMENTS (ID 59)

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The quality of sand influences in every way the quality of concrete and affects, among others, the workability, the durability as well as the mechanical strength of concrete. It is acknowledged that a sand of good quality to be used in concrete pavements must contain few fine grains and be rich in medium size grains. In addition, all grains should be as round as possible, which means non-crushed sand is an advantage. Today, natural rounded coarse sand is getting rare and is more and more replaced by crushed sand of size 0/4. Knowing that the angularity of the grains affects negatively the workability of concrete, this phenomenon is worth to look at. This article treats in particular sand grading and its influence on water demand in the case of concrete pavements. Based on the analysis of different cases, an optimal grain size is suggested and is then compared to the requirements of the applicable European standard specifications.

KEYWORDS

CONCRETE ROADS / SAND / WATER DEMAND / OPTIMAL GRADING

**BELGIAN SPECIFICATIONS FOR FREEZE-THAW-RESISTANT PAVEMENT CONCRETE
(ID 60)**

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The Belgian standard specifications contain a number of clear requirements for the composition of concrete mixtures and the properties of fresh and hardened concrete. It is generally known that water and air content have a substantial impact on the frost susceptibility of a concrete surface – the former in a negative and the latter in a positive way. The water absorption test by immersion is a quite simple and rapid test; the result of which is a good indication for water-accessible pores and hence, to a certain extent, for durability. However, in some circumstances the test does lead to erroneous results. To have a better indication of the durability of concrete, scaling of the surface under freeze-thaw cycles in the presence of de-icing salts is tested.

This paper describes the relationship between the different parameters of the concrete, i.e. water content, water absorption, air content and resistance to scaling, in more detail. It also explains the influence of the choice of materials and concrete composition on resistance to scaling. The findings are illustrated by a number of examples of concrete mixtures.

KEYWORDS

CONCRETE COMPOSITION / DE-ICING SALTS / FREEZE-THAW RESISTANCE

SESSION 11

PAVEMENT TYPE SELECTION: WHAT IS THE IDEAL PROCESS? (ID 138)

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Pavement type selection is often one of the more challenging and controversial decisions highway administrators face. The process involves weighing engineering factors such as materials, structural, and even long term performance against initial and life-cycle costs to help agencies decide between various pavement alternatives. Given the expenditure of significant public monies invested in pavement construction and rehabilitation, concerns have arisen recently about the equity and effectiveness of the pavement type selection process, particularly in light of ever-increasing needs, construction inflation, and dwindling resources to address the needs of the nation's highways. In the United States, pavement type selection has been the subject of numerous publications over the last 50 years. This paper explores the history of pavement type selection in the U.S.; the guidance behind these practices; and a proposed pavement type selection process that attempts to include all possible and proper measures to ensure the taxpaying public receives full value of every highway dollar spent. This process considers pavement design equivalence, life cycle cost analysis, transparency, and most notably, the benefits that healthy competition between paving industries can provide.

KEYWORDS

CONCRETE PAVEMENTS / CONCRETE ROADS / COMPETITION / PAVEMENT TYPE SELECTION / LIFE CYCLE COST ANALYSIS

**ACOUSTICAL ASSESSMENT OF EXPOSED AGGREGATE CONCRETE ROADS
(ID 64)**

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Exposed aggregate concrete is appreciated in road construction for its durability and its skid resistance - and it is the only standardized method in Germany for the construction of low noise concrete roads. Both skid resistance and noise reduction are mainly determined by the surface texture of the concrete road.

Recent investigations have found, that exposed aggregate concrete road surfaces show a considerable spread in acoustic performance. To get a deeper understanding of the underlying mechanisms comprehensive investigations on the acoustical behaviour of exposed aggregate road surfaces have been performed. These investigations have been done in 3 project-phases.

In phase I existing exposed aggregate concrete road surfaces have been investigated with regard to relations between concrete composition, texture properties, skid resistance and noise emission. Phase II was a parameter study, where parameters such as maximum aggregate size, grading curve and profile characteristics have been investigated considering their potential influence on rolling noise and skid resistance. In phase III test surfaces were built in the laboratory for selected sets of the above-mentioned parameters. On these test surfaces on site measurements of surface texture, air flow resistance and skid resistance were performed. The measurement results were used to calculate the expected pass-by levels with the tyre-road noise prediction model SPERoN. From the results comprehensive conclusions were drawn with respect to the maximum noise reduction potential of exposed aggregate concrete roads, keeping the needs for dry and wet grip in mind.

KEYWORDS

CONCRETE ROADS / EXPOSED AGGREGATE CONCRETE / LOW NOISE PAVEMENT /
TYRE-ROAD NOISE

PRECAST & IN SITU CONCRETE BARRIERS – THE COMPLETE SAFETY SOLUTION FOR ROADSIDES (ID 164)

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The technology of in-situ concrete safety barriers has not really changed in the last two centuries. After an extensive development and crash-test program a new generation was created recently. This is a technical report on the right way to use in-situ concrete at today's level of technology. In the central reservation on motorways in most European countries mainly in-situ concrete safety barriers are built. These are considered to be particularly effective, because they need little maintenance, they are cost-effective and can be built quite fast. The working width, respectively the displacement of the in-situ concrete barrier in case of an impact naturally is very low and is therefore extremely advantageous. Because the in-situ concrete safety barrier is very massive and rigid, the impact severity and passenger protection in light vehicles are in a critical range and an intensively discussed issue European wide. However this disadvantage seems to be accepted due to the cost pressure in road construction and missing alternatives.

KEYWORDS

IN-SITU CONCRETE SAFETY BARRIERS / STEP PROFILE / PRODUCT LIFETIME /
CONSTRUCTION JOINTS / CORROSION PROTECTION / REPAIR METHOD / CRASH TEST /
EN 1317 / PRECAST CONCRETE SAFETY BARRIERS

IN SITU MEASUREMENT OF THE CAPILLARY PRESSURE IN CONCRETE ROAD CONSTRUCTION (ID 70)

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Concrete pavements are vulnerable to cracking already in the plastic material stage, i.e., before the concrete has reached a significant strength. Due to the evaporation of water at fresh concrete surfaces, a capillary pressure is built up in the pore system of the material. This underpressure leads to the so-called capillary or plastic shrinkage and possibly to cracking. Since the capillary pressure provides direct information on the response of the concrete to the water loss by evaporation, it may be used to estimate the cracking risk in situ and to control curing procedures. At the examples of an on-site measurement, the applicability of capillary pressure sensors is demonstrated and discussed.

KEYWORDS

CONCRETE ROADS / PLASTIC SHRINKAGE / EVAPORATION / CURING / CAPILLARY PRESSURE

**PROMISING PROJECT - CONCRETE ROADS
(ID 44)**

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Countries that have little experience in concrete pavement design, application and operation, like Turkey, may face many difficulties while planning of concrete pavement construction (life-cycle, design, cost, technology and equipments etc.). We want to share as follows; managing the project, road map, learning phase, experiences, difficulties, mistakes and best practices about concrete roads in Eskisehir. The important point is the ground type of Eskisehir: high plasticity, clay with silt layers and its groundwater level is between 0, 5 to 1 meter from the surface.

KEYWORDS

CONCRETE ROAD

OPERATION EXPERIENCES ON CONCRETE PAVEMENTS DURING THE LAST 10 YEARS IN HUNGARY (ID 76)

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Since the middle of 90s in Hungary the permanent deformations of semi-rigid asphalt pavements have become a major problem due to increasing traffic and changing climate conditions. It has been a particular challenge concerning the M0 motorway around Budapest exposed to the most serious heavy vehicle traffic. The preceding test sections provided the base to update regulations and realisation of the first motorway built with cement concrete pavement. The building and operating experiences of the following motorway sections led to continuous modifications and feedback in regulations.

Sections put into operation until 2010 have been constructed as single layer doweled concrete pavement. Since 2009 the M0 Southern section has been built as a two layer doweled concrete pavement with exposed aggregate.

Operator claimed for cement concrete pavement also on the bridges which required special solution. Up to now the operation and maintenance yielded experiences mostly with one-course surfaces, mainly slab edge and corner breakings, joint sealing turns, cracks and slab peelings. So far, the applied repair methods, mostly resin-bound surface dressings have not given satisfactory solution due to significantly shorter durability. Experiments are in progress to test application of the possible repair materials.

KEYWORDS

CEMENT CONCRETE PAVEMENT / WARRANTY / TRANSVERSAL AND LONGITUDINAL
CRACKS / JOINTS / REPAIR TECHNOLOGIES

**RESTRAINED SHRINKAGE CRACKING OF CONTINUOUSLY REINFORCED
SELF-CONSOLIDATING CONCRETE ROADS
(ID 77)**

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Continuously Reinforced Concrete Pavements (CRCP) are designed in such a way that the longitudinal reinforcement limits the widths of the transverse cracks in the pavement in order to prevent the water, chemicals and deicing salts from penetrating into the pavement. Self-Consolidating Concrete (SCC) is a new and innovative concrete type, which has been increasingly used in heavily-reinforced concrete members in the last decades due to its several superiorities, including the lack of the need for the mechanical vibration. The use of SCC in concrete pavements was proposed and tested in recent studies to increase the speed of the pavement construction and decrease its cost and labour. One of the major drawbacks of this new type of concrete is its higher amount and rate of shrinkage compared to Conventionally Vibrated Concrete (CVC). The use of SCC in rigid pavements causes the pavements to be prone to possess wider cracks with the problem being more emphasized in CRCP." In the present study, the restraint stresses that develop in a model CRCP cast with SCC were investigated and compared to the limit stresses given in the design guidelines. The results indicated the need for the additional amounts of longitudinal reinforcement to withstand these stresses.

KEYWORDS

CONCRETE ROADS / SELF-CONSOLIDATING CONCRETE / RESTRAIN STRESS / SHRINKAGE CRACKING

SESSION 13

SPLITTING TENSILE STRENGTH OF CONCRETE ROAD SLABS – A KEY PROPERTY FOR LOAD CAPACITY AND DURABILITY

(ID 66)

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Concrete pavements are continually subject to the effects of weather and traffic. These may cause tensile stresses at the top and bottom of the concrete road slabs. The resistance of the concrete slab to such effects depends on a large number of factors. In particular, the concrete tensile strength and the thickness of the concrete slab are key factors in dimensioning.

In principle, it is possible to determine the concrete tensile strength directly or indirectly. For experimental reasons, the indirect determination of the tensile strength is the most frequently used method in practice. In this manner, the generally applicable splitting tensile strength testing method for simple and effective concrete tensile strength testing was further developed and modified for road construction 10 years ago. Here the upper and lower discs of a test cylinder or drill core are tested. The evaluation ensued statistically at the lower 5% quantile. This method and the testing device are precisely described in a national test specification.

Initial applications of this testing method were undertaken in recent years as part of major projects (PPP models), in which the splitting tensile strength thus determined represents the standard input value for the computational dimensioning. Experience to date reveals that the test statistical spreading of the splitting tensile strength and compressive strength tests exhibits approximately the same order of magnitude.

In order to determine the precision of the testing method in a sound manner, a round robin test with 13 testing laboratories and 8 test lots was performed in Germany and statistically evaluated. In addition, the development of the compressive strength and splitting tensile strength was ascertained over time in a further research project. Fatigue tests were also performed here to take account of the fatigue behaviour, in order to establish a correlation to the statistical splitting tensile strengths.

The aforementioned research project was first and foremost aimed at verifying the goal, precision and practical suitability of the testing method. This is particularly important because the statistical determination of the splitting tensile strength represents a simple testing method in practice. Basically, it is also envisaged to make use of the mechanical splitting tensile strength parameter as a test quantity for conventional construction projects in the future.

KEYWORDS

CONCRETE ROAD PAVING / DIMENSIONING / SPLITTING TENSILE STRENGTH / TESTING METHOD

COMPARISON OF TWO REHABILITATION WORKSITES OF MOTORWAYS: SINGLE VERSUS DOUBLE LAYERED CRCP (ID 153)

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The technique of continuously reinforced concrete is used in Belgium for the construction or rehabilitation of heavily trafficked motorway sections. Since a few years, double layered CRCP is being considered in order to improve the rolling noise characteristics of the surface. In this paper, two worksites where CRCP was used, will be compared, one with a single layer design, the other one with the double layer concept.

The first one is the renewal of a part of motorway E17 south of the city of Ghent, built in 2011; the second worksite is located on the motorway from the east of Belgium towards Antwerp, construction took place in 2012.

Attention will be paid to the benefits and challenges of both techniques in terms of design (thickness, position of the steel reinforcement, base layers), concrete mixes (specifications and results for the single layer concrete, for the bottom and the top layer of the double layer concrete) and construction aspects (concrete plants, supply, compaction).

Finally the surface characteristics of both new motorway sections will be compared and the choice for one or the other technique will be evaluated.

KEYWORDS:

CONCRETE PAVEMENT / CRCP / DOUBLE LAYERED/ TWO-LIFT

**NEW DEVELOPMENTS OF „POROUS CONCRETE“ AND FIRST EXPERIENCES IN GERMANY
(ID 72)**

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Porous surfaces of cement concrete (OPB) or asphalt concrete (OPA) have a permanent transfer of rainwater and additionally noise reduction potential compared to the dense microstructure with exposed aggregates concrete.

Pervious concrete test sections in the field of heavy-duty highways previously reported, however, do not have sufficient durability. Causes of damage have included grain outbreaks in porous concrete and a lack of bond between concrete and base layer. In addition, the grip was reduced by the traffic load.

Porous concrete for noise-reducing pavements is composed only with chips grain-size 5/8 mm and a cavity of 15 to 20 Vol.-%. To ensure adequate freeze-thaw resistance a polymer dispersion is added to the cement-paste.

In order to avoid the existing drawbacks newly special polymer dispersion has been developed which has sufficient durability, even at low temperatures and high dynamic loads.

The focus of the test track in April 2013 in Mainz-Amoeneburg was on gaining experience about the material's workability and processing technology using a modified asphalt paver. To improve the durability and increase the flexural strength a section with standard cement CEM III/A 42.5 N and a further with high-performance cement CEM II/B-S 52.5 R was carried out.

The roadway also serves as a reference for the forthcoming German FGSV- standard „Guidelines on Permeable Traffic Areas“. The choice of the layer structure was performed according to the guidelines described in this leaflet.

KEYWORDSCEMENT CONCRETE ROADS / POROUS CONCRETE / TEST TRACK / LOW NOISE
PAVEMENT / DURABILITY

**DATA ANALYSIS AND SIMULATION OF RIGID PAVEMENT TEST ITEM AT THE NATIONAL
AIRPORT PAVEMENT TEST FACILITY
(ID 173)**

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The Federal Aviation Administration's (FAA) National Airport Pavement Test Facility (NAPTF) conducts accelerated full-scale testing of airport pavements under controlled conditions. Construction Cycle 6 (CC6) was aimed at evaluating the effects of concrete strength and subbase materials. Two types of isolation joints were also tested for comparison.

Data from embedded strain gages and deflection sensors were acquired and analyzed along with the observed performance data. The wander pattern for the traffic test consisted of nine discrete tracks. All sensor data were collected for each track and stored in a database. Traffic tests were simulated using the finite element method in three dimensions and compared with sensor readings. The effects of equivalent temperature gradient and interface contact were evaluated. It was found that the friction coefficients can greatly influence the difference in stress magnitude between the slab top and bottom. Therefore, this parameter needs to be carefully considered when attempting to match the observed sensor data.

The CC6 test data show that strains under wheel loads were unsymmetrical with respect to the concrete slab neutral axis. It was found that the magnitude of strain at the slab top is greater than at the slab bottom for the same horizontal location. This was observed for two cases: (a) where the maximum tensile stress was at the slab bottom due to wheel loading directly over the gage, and (b) where the peak tensile stress occurs at the top of the slab, i.e., where the gage of interest is located on the neighbor of the slab receiving the principal loading.

KEYWORDS

CONCRETE PAVEMENT / FULL-SCALE TESTING / FINITE ELEMENT METHOD / NAPTF

**URBAN CONCRETE PAVEMENTS – HISTORY AND CURRENT TECHNOLOGY
(ID 176)**

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SUMMARY

This paper aims to outline briefly the history of the first concrete pavements in Europe and in the United States. The authors will present examples of concrete pavements built in Tarnów, a relatively large city (115,000 inhabitants) in southern Poland. They will show technological and structural solutions for using concrete pavements in urban environment: city roads, footpaths for pedestrians and cycling paths.

KEYWORDS

CONCRETE PAVEMENT / CONCRETE ROADS / ROAD CONSTRUCTION / STAMPED
CONCRETE

HOW TO BUILD SMOOTH CONCRETE ROADS AND MEASURE SUCCESS THE MOMENT YOU PAVE (ID 123)

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The Strategic Highway Research Program 2 (SHRP 2) recently completed a study entitled, "Real-Time Smoothness Measurements on Portland Cement Concrete Pavements during Construction". As part of this project, the feasibility of this technology was explored. There was both an evaluation and demonstration of emerging and proven technologies. Model specifications and construction guidance were also developed to construct smoother concrete pavements and expedite the implementation of these innovative technologies. Seven potential measurement devices were identified and studied, with two of them warranting subsequent evaluation and demonstration. Concrete paving projects throughout the USA including the States of Georgia, Alabama, Texas, Michigan, and New York were visited, and observations made about the potential of these devices. The resulting guidance has proven beneficial in improving the quality of pavement construction through improved smoothness (evenness).

KEYWORDS

SMOOTHNESS / IRI / CONCRETE PAVING / INTELLIGENT CONSTRUCTION SYSTEMS

SESSION 14

EARLY AND LATE AGE SHRINKAGE OF CONCRETE IN INDUSTRIAL FLOORS DESIGN (ID 80)

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For proper joint design, slabs size and slab thickness of concrete industrial floors, as well as other structures, it is necessary not only to know the final shrinkage of the concrete, but also the evolution over time for both long term and early shrinkage, and the relationship between these properties and the various proportioning parameters and curing of the concrete mix involved. Moreover, as in some other projects apart from concrete flooring, the concrete shrinkage value is limited to a maximum value, the influence of various types specific chemical admixtures to control this property, at different doses, is also studied. This work is concluded by correlating the long term and early age shrinkage with basic concrete composition parameters, curing conditions, presence of specific additives for this purpose and other properties which are easier to determine. Finally, in this paper, it is shown that knowledge of some other concrete properties is relevant for concrete floor designs, apart from specified 28 days compressive strength and slump. In addition, this work provides information about the possible solutions, from the concrete technology point of view, if final shrinkage value or its evolution over time are specified for a concrete mix.

KEYWORDS

DRYING SHRINKAGE OF CONCRETE / DRYING SHRINKAGE OF CEMENT PASTES /
AGGREGATES PACKING / CRACKING OF CONCRETE / AUTOGENOUS SHRINKAGE

**ADVANCING THE USE OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENT
IN THE USA
(ID 90)**

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The use of continuously reinforced concrete pavement (CRCP) is enjoying a renaissance in the United States (USA). CRCP has the potential to provide a long-term, “zero-maintenance,” service life under heavy traffic loadings and challenging environmental conditions, provided proper design and quality construction practices are utilized. In the USA, the Federal Highway Administration (FHWA) has worked cooperatively with state highway agencies, academia, and industry to implement improved best practices design and construction procedures and to document the satisfactory long-term performance of CRCP projects. Technical guidance has been developed based on considerable knowledge that has been accumulated over many decades of CRCP use in a number of US States, through the US Long-Term Concrete Performance Program, and through experience in other countries. This guidance is now readily available in the form of technical briefs, design software, and a manual on design, construction, repair and rehabilitation. This paper provides a summary of this guidance, along with online links for downloading key documents and for accessing the proprietary design software.

KEYWORDS

CONCRETE / CONCRETE PAVEMENTS / CONTINUOUSLY REINFORCED CONCRETE PAVEMENT

STRUCTURAL, FUNCTIONAL AND ECONOMIC ANALYSIS OF JOINTED PLAIN CONCRETE PAVEMENTS (ID 20)

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This paper presents a structural, functional and economic evaluation model for Jointed Plain Concrete Pavement (JPCP). The model was implemented by using a computer program developed by the authors at the Department of Civil, Building and Environmental Engineering of University of Rome “La Sapienza”.

This paper will describe this versatile, simple and user friendly tool for concrete pavement analysis: this tool allows the study of stresses and strains under thermal and traffic load, the estimation of construction and maintenance costs, in order to get a feasibility study and economic sustainability analysis of concrete pavements. This software has two functions related to life cycle analysis of JPCP: it examines the effects of subgrade soil, climate, materials, traffic distribution and geometric characteristics on stress-strain state of concrete slabs and it estimates cumulative life-cycle construction and maintenance costs. Pavement performance during service life is estimated by fatigue damage, International Roughness Index and transversal cracking. Construction and maintenance preventive and/or corrective works will contribute to the total cost to be supported by the community.

This new approach to JPCP design allows comparing rigid pavements through a synthetic economic indicator: the Present Value, calculated using the annual discount rate and the annual inflation rate.

KEYWORDS

JOINTED PLAIN CONCRETE PAVEMENTS / SUSTAINABILITY / DESIGN / MAINTENANCE / PRESENT VALUE

DESIGN & CONSTRUCTION OF AN EXPERIMENTAL TWO LAYER CONCRETE PAVEMENT MOTORWAY SECTION IN SPAIN (ID 116)

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In June 2006, GISA a Public Company, within the Department of Planning and Public Works of the Catalanian Regional Government, awarded CEDINSA the concession for the project of constructing and operating the projects of converting into a dual carriageway the stretch Vic-Ripoll of the C-17 highway. As a participant in the UTE (Joint Venture) designated to carry out the project and with the aim of deepening the knowledge in new technologies for rigid pavements, FCC proposed to the Catalanian Regional Government to take the opportunity to build an experimental section, using a new technology for concrete pavement. The demonstration stretch is located between stations 8430 and 9350 of the design document.

This technology consists of placing two layers of concrete of dry consistence made up of different components. Spreading of both layers is done almost simultaneously in such a way that they work jointly when in service. In addition, surface mortar is removed, in order to obtain a negative roughness improving both the traffic comfort and noise-related effects, which are more satisfactory than traditional concrete paving technologies. The upper layer is made up of concrete with a cement content of 460 kg per cubic meter; it has a water/cement ratio of 0.4, an 11 mm maximum siliceous aggregate size and a splitting strength at 28 days over 4.2 MPa. Concrete for the lower layer has a cement content of 390 kg per cubic meter, a water-cement ratio of 0.44 and a required splitting strength of 3.5 MPa at 28 days (i.e, lower than that specified for the upper layer), with a maximum aggregate size of 25 mm.

The texture is obtained through the use of a surface retarder followed by a sweeping of the paving's surface to enable the elimination of a thin layer of unset mortar, resulting in a negative roughness. Once the approval of the *Direcció General de Carreteres de la Generalitat de Catalunya* (the Regional Government's Roads Department) was obtained, and under the supervision of technicians from GISA (*Gestió d'Infraestructures, S.A.U.*, the company cited above in charge of the management of infrastructures), the project was carried out in the designated area between March 15th and 18th, 2010, by pouring the lower layer of 21 cm and the upper layer of 4 cm both of concrete. A team from Alpine, an Austrian company subsidiary of FCC, highly experienced in this type of solution, moved special equipment and skilled labor to Spain to execute the experimental section.

KEYWORDS

TWO-LAYER CONCRETE PAVEMENT / SURFACE RETARDER / EXPOSED AGGREGATE / LOW NOISE PAVEMENT/

**IN-SITU ARCHITECTURAL CONCRETE AND PRE-DOSED MICRO-CONCRETE FOR WEAR THIN LAYER PAVEMENTS IN URBAN AREAS. "DIOGO MENEZES SQUARE" AS AN EXAMPLE OF ENVIRONMENTAL RENOVATION
(ID 118)**

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In this communication the development of non traditional-solutions for pavement surfaces will be assessed, by the use of colored pre-dosed micro-concrete or *in situ* concrete in thin layers of high performance architectural applications for urban, pedestrian, cycling and roads.

This assessment will be focused on frequently technical constructive barriers inherent to the pavement prescription of these solutions, on their performance and on their social, economic and environmental added value, when comparing with traditional and conventional solutions.

At the end, a detailed example of a work where such solutions were applied will be described - "Diogo Menezes Square" at Cascais Citadel, Lisbon, Portugal, outlining the architectural purposes and demands in terms of durability and environmental context, and all the inherent laboratory work and project specifications that were prescribed and executed.

KEYWORDS:

DURABILITY / VERSATILITY / COMFORT / AESTHETIC / FUNCTIONALITY

THEME 4 – MAINTENANCE AND REHABILITATION SESSION 6

CONCRETE PAVEMENT PRESERVATION INTEGRATING ENGINEERING, APPLICATION AND THE ENVIRONMENT (ID 1)

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Concrete Pavement Preservation (CPP) is a series of engineered techniques developed over the past 40 years to manage the rate of pavement deterioration in concrete streets, highways and airports. CPP is a non-overlay option used to repair areas of distress in concrete pavement without changing its grade. This rational, preventive procedure restores the pavement to a condition close to or better than original and reduces the need for major and more costly repairs later. Due to the growing popularity of CPP, an increasing number of research projects focused on the application and benefits of CPP have been initiated and completed during the past decade. The focus of this paper is engineering application related to CPP with an emphasis on dowel bar retrofit and diamond grinding. The paper is presented in three sections. The first outlines the available treatments used for concrete pavement preservation. The second section is focused on current research related to these treatments and highlights the benefits and lessons learned while applying these treatments over the past 40 years. The final section discusses the environmental benefits of CPP and its role in today's environmentally responsible and sustainable transportation marketplace.

KEYWORDS

CONCRETE PAVEMENT PRESERVATION (CPP) / DOWEL BAR RETROFIT / DIAMOND GRINDING

DETERMINATION OF THE BEHAVIOR OF ON SITE PAVEMENT RECYCLING WITH CEMENT (ID 5)

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On site pavement recycling with cement is the most sustainable restoration technique, by means of which a degraded pavement is transformed into a consistent and more homogeneous structure, using the road as a source of aggregates. Both bearing capacity and homogeneity are therefore considerably improved.

Due to the absence of research information, this paper characterizes the structural recycled material and determines its laws of behavior. To do this, one Spanish road was selected and recycled. The material was transported to the laboratory and underwent testing over a period of three years (more than 350 strength tests, many of these have dynamic variables) in order to obtain the following:

- Correlations between compressive strength at 7 day intervals, which is the usual control parameter on the work site, and long-term tensile and flexural strength.
- Fatigue characterization of recycled materials with cement.

These results have been used to develop performance models, optimizing the structural design of pavements with cement-recycled layers. Using performance and behavior models, a catalogue of structural sections has been proposed.

KEYWORDS:

RECYCLING / CEMENT-RECYCLED LAYERS / COMPRESIVE STRENGTH / FLEXURAL STRENGTH / FATIGUE EQUATION / CATALOGUE OF RECYCLED SECTIONS.

THE USE OF “FAST-SETTING CONCRETES” FOR AIRPORT REPAIRS (ID 33)

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A frequently noted disadvantage of cement concrete pavements is repair time. For further application of this technology, it was necessary to eliminate this disadvantage and significantly reduce repair time. Therefore, Skanska developed the “Fast-setting concrete technology”.

In-house development commenced in 2005. MC Bauchemie, design engineers and investor representatives also participated. Work began in the laboratory followed by tests in simulated construction site conditions and completed with the first repair of a highway concrete pavement.

Verified on highways, the technology was tested on runway junction RWY 06-24 - RWY 13-31 at Prague Ruzyně Airport. The repair necessitated limiting operation of the entire airport (both runways).

The repair of this critical location necessitated cooperation between the investor, design engineer and Skanska as the contractor and know-how holder.

The task was the repair of a cement concrete apron on RWY 06-24 at junction TWY D, the most burdened part of the airport in terms of aircraft traffic. The area designated for replacement covered 1,135 m² with a concrete thickness of 250 mm. The time limit for the repair was 72 hours.

KEYWORDS

AIRPORT / SPEED OF REPAIR / CONCRETE ROADS / “FAST-SETTING CONCRETES” / REPAIRS OF CEMENT CONCRETE PAVEMENTS

**FIRST EXPERIENCE OF DIAMOND GRINDING CONCRETE IN MEXICO
(ID 41)**

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The surface condition of a pavement is a factor that may vary due to the influence of traffic and construction methods, and is a functional characteristic that impacts the road user considerably. For concrete pavements in good structural condition, diamond grinding can be a highly effective and economical choice for rehabilitation. Diamond grinding is the removal of a thin layer of concrete (generally about 6 mm [0.25 in.]) from the surface of the pavement. This is accomplished using special equipment fitted with a series of closely-spaced diamond saw blades. Major applications for diamond grinding are to remove surface irregularities, to restore a smooth riding surface, to increase pavement surface friction, and to reduce pavement noise. Diamond grinding produces smoothness values approaching (and in some cases exceeding) those typically obtained for new pavement construction, and also provides an immediate improvement in the surface friction of the pavement. The aim of this paper is characterize and analyze the behavior of the first diamond-ground road in Mexico, namely the 057D, one of Mexico's main highway corridors with an AADT of 43 626 vehicles, consisting primarily of heavy vehicles.

KEYWORDS

DIAMOND GRINDING / CONCRETE PAVEMENT / SURFACE CONDITIONS AND REHABILITATION

SURFACE GRINDING CONCRETE PAVEMENTS (ID 172)

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The report outlines some of the perceptions and issues associated with Concrete roads, and asks if the process of Diamond Grinding is a viable solution to the refurbishment of worn concrete pavements. The paper outlines the process of Diamond Grinding for reconditioning structurally sound but worn concrete surfaces. Gives a description of the process and the types of machinery required. Describes the benefits relating to improved low speed skid resistance and reduced noise levels with test data recorded over a 36 month cycle on a number of test sections on 30 year old UK concrete pavements. These projects and results are supported by experience from the US including profiling with reference to a study by Wisconsin Department of Transport comparing accident rates on ground and unground surfaces over a 6 year period showing considerable reductions in accidents levels. The benefits are summarized and also give comment to further action and testing.

KEYWORDS

CONCRETE ROADS / GRINDING / NOISE REDUCTION / SKID RESISTANCE

SUPER FAST CONCRETE REPAIR SYSTEM FOR ROADS, AIRFIELDS AND RAILWAYS, BASED ON A SPECIAL CEMENT FOR INFRASTRUCTURE PROJECTS (ID 55)

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From both an environmental and economic point of view, the availability and performance capability of infrastructure traffic areas today and in the future is of the highest priority. This applies to both public and private roads and air traffic areas, as well as for busy parking and logistics areas and railways.

Normally, only short shut-off periods are available for the maintenance and repair of heavily frequented traffic areas, and for this reason, extremely quick and safely functioning quick-repair systems are necessary today. Special cements in combination with special high-performance superplasticizers form the basis for manufacturing such high-performance rapid-hardening concretes.

HeidelbergCement has developed a special Portland cement in strength class CEM I 52.5 R according to DIN EN 197-1 [1] for these application cases. Regarding the alkali content (Na_2O equivalent), this special cement also meets the requirements for road paving cement according to TL Beton-StB [8].

This quick-repair system can be extremely flexibly planned regarding its concrete composition, so as to enable an individual performance for the concrete manufacturer and contractor which is attuned to the respective purpose. For example, different parameters can be varied, such as types of aggregate, maximum aggregate size, grading curve, w/c ratio, consistency, fresh concrete temperature, processability time, strength development etc. As a result, it is also possible to manufacture a rapid-hardening concrete with an exposed aggregate surface texture for the repair of concrete carriageways.

Up until now, numerous repairs have been successfully carried out on motorways, air traffic surfaces, logistics areas and railways.

KEYWORDS

CONCRETE ROADS / STRUCTURAL MAINTENANCE / RAPID-HARDENING CONCRETE

SESSION 8

SKID RESISTANCE PROPERTIES OF CONCRETE PAVEMENT SURFACES IN TUNNELS (ID 84)

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Skid resistance properties of concrete pavement surfaces in tunnels are measured with the dynamic measuring device TRT on a regular basis in the Czech Republic. Measurements are usually carried out before and after putting the tunnel into operation and then approximately once a year; the skid resistance is also measured after each maintenance of the pavement surface. With the regular measurement of the friction coefficient F_p it was found out that depending on the traffic intensity, the quality of skid resistance deteriorates quickly. As a part of research and development projects, causes of this rapid decrease of skid resistance of concrete pavement surfaces in tunnels were investigated. It was found out that apart from rapid abrasion of concrete pavement which is textured with burlap drag during placement, the dangerous slipperiness is caused by pollution of the surface by greasy dirt coming from exhaust fumes of the passing vehicles. While outside tunnels, the greasy residues are dusted off during rain and carried away from the road with the water spray, in tunnels they cling to the walls and pavement surface and on the polished surface, they cause slipperiness dangerous for road traffic.

The article introduces examples of skid resistance measurements where the decrease of the friction coefficient F_p depending on traffic intensity in time is shown. Furthermore, results of research of concrete pavement pollution by greasy residues are stated, which affect the skid resistance to the highest degree, and also influence of the protective steam-tight coating on wax basis which is applied to fresh concrete is described. In conclusion, maintenance technologies that re-establish skid resistance are introduced which were tested in tunnels.

KEYWORDS

CONCRETE ROADS / SKID RESISTANCE / GREASY DIRT / PROTECTIVE STEAM-TIGHT COATING / MAINTENANCE TECHNOLOGIES

**PRECAST CONCRETE PAVEMENT INNOVATIONS, PERFORMANCE AND BEST PRACTICES
(ID 96)**

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The precast concrete pavement (PCP) technology is gaining wider acceptance in the US for rapid repair and rehabilitation of concrete pavements as well as for heavily trafficked asphalt concrete intersections. Although the US PCP technology is of recent origin, with projects less than about 12 years old, many projects have been constructed and many advances have been made and continue to be made in the design, panel fabrication, and panel installation aspects of the technology. In the US, the PCP technology is being used for intermittent repairs (full-depth or full panel replacement) and for continuous applications (longer length/wider area rehabilitation) with service life expectations of at least 20 years for repairs and at least 40 years for continuous applications, without significant future corrective treatment. Recent activities in the US have resulted in comprehensive guidance on the selection, design, fabrication, and installation of PCP systems. In addition, the construction and precasting industries continue to innovate to achieve economical PCP designs and to improve panel fabrication and panel installation processes. The field evaluation of PCP projects (jointed and posttensioned systems) constructed to date indicate that most projects are performing well. This paper summarizes recent innovations in the PCP technology in the US

KEYWORDS

CONCRETE / CONCRETE PAVEMENTS / PRECAST CONCRETE PAVEMENT / PRESTRESSED CONCRETE PAVEMENT

IMPROVING THE REHABILITATION TIMING AND SELECTION IN A PAVEMENT LIFE CYCLE COST ANALYSIS (ID 162)

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Life Cycle Cost Analysis (LCCA) is an economic procedure used to compare competing pavement designs, over a defined analysis period, considering all significant costs expressed in equivalent present value dollars. Currently, most agencies apply a standard, policy set, rehabilitation schedule to all pavements based on “historical” performance. However, this can mean that the assumed performance used in the analysis will not be representative for the design due to the fact that historical data is often based on old pavement designs; designs with different features; or is from “non-like roadways” (e.g. using high volume road data for low volume road applications).

This paper will look at two process that can be used to develop a project specific rehabilitation schedule for any given pavement design in order to have a more a realistic LCCA. These processes answer the following questions:

1. When are rehabilitation activities required (eg timing)?
2. What rehabilitation activities are done (eg selection)?

The timing aspect will be addressed using the American Association of Highway and Transportation Officials Pavement-ME Design Procedure, which predicts performance for different pavement designs. The selection of activities will be addressed using a decision tree analysis to look at multiple rehabilitation activities. These two processes allow the analyst to develop more robust and reliable LCCA's in order to better determine the cost effectiveness of competing designs and to make better decisions about the final pavement selection.

KEYWORDS

LIFE CYCLE COST ANALYSIS / REHABILITATION SELECTION / REHABILITATION TIMING / PAVEMENT DESIGN

EXTENDING THE SERVICE LIFE OF STRUCTURALLY SOUND CONCRETE ROADS IN ENGLAND (ID 103)

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A number of concrete surfaced roads in the UK have been in service for over 30 years. In some cases, the original surface laitance applied to these carriageways is becoming worn, leading to reductions in texture and skid resistance, a combination that has been shown to have a negative effect on road user safety. Where the original pavement is structurally sound, a surface re-texturing treatment (such as longitudinal diamond grinding, transverse grinding, bush hammering, shot blasting, or fine milling

This paper describes several re-texturing treatments and discusses the results of texture depth and skid resistance monitoring on trial sections over several years, which has led to the development of new policy for the management and rehabilitation of concrete roads. The expected service life of the re-texturing treatments has been estimated, together with the environmental effects resulting from both the treatment process and for the treated in-service road.

KEYWORDS

CONCRETE ROADS / RE-TEXTURING / SKID RESISTANCE / SURFACE NOISE / LOW NOISE PAVEMENT / GRINDING

**RELEVANT INTERACTIONS FOR ALKALI-SILICA-REACTIONS IN CONCRETE PAVEMENTS
(ID 108)**

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In the last few years cracking in concrete pavements often is attributed to alkali-silica-reaction (ASR). Although this is a very important aspect other impacts such as traffic loads and restraint stresses due to thermal and hygral effects may not be neglected. In many cases interactions between various causes can become relevant and a superposition of different mechanisms will be responsible for the final cracking. In opposite to common structures the external supply of alkalis by deicing agents plays an important role in the ASR-development in concrete pavements. The ingress of those alkalis is intensified by microcracking, which is the result of millions of load cycles, affecting the microstructure. The relationship between microcracking, external alkali ingress, ASR and final cracking was studied in extensive investigations in situ and in the laboratory.

KEYWORDS

CONCRETE PAVEMENTS / ALKALI-SILICA-REACTION / CRACKING / CYCLIC TRAFFIC LOADS
/ CASTING TEMPERATURE

**THE REHABILITATION OF THE UNDERPASS “BLEICHERWEG” IN ZÜRICH
(ID 117)**

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In Zurich the underpass Bleicherweg had to be maintained. An important part of the job was the pavement. The civil engineering department of the city of Zurich decided that the original asphalt pavement had to be replaced with a concrete pavement. The base of this decision, minimize possible water vapor pressure from groundwater, will be described in the paper. To this also the special measures to prevent problems with the interaction between old and new concrete, cracking and a steep incline as well as the results of preliminary test will be discussed. The concrete is tailor made for this project and will give information for future projects.

KEYWORDS

CONCRETE ROADS / BOND / REDUCTION OF SHRINKAGE / FIBERS

SESSION 16

IMPACT OF JOINT-FILLING MATERIALS ON CRACKING IN CONCRETE GUTTERS AT LARGE AIRFIELDS (ID 122)

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In the last few years at several airports cracking in the internals of concrete gutters has been detected. This was mainly observed, where large airfields (about 60 to 100 m in length) are located next to these drainage lines. In order to reveal the influences on this cracking both laboratory investigations as well as numerical analyses referring the expansion joints and the gutters were performed. Due to seasonal variations in temperature concrete pavements casted in wintertime tend to expand by higher temperatures in summer, whereas the deformations of the free edges can amount up to 5 to 10 mm. Such deformations should be met without any restraint. If this cannot be ensured, horizontal stresses up to 5 to 10 MPa are activated. However, the concrete gutters are normally not designed and constructed for such horizontal loads. The result is an extensive cracking in the interior of the gutters and finally their complete destruction. In adequate laboratory tests the stress-strain-relations for various materials was determined. For the mostly used bituminous soft board a comparatively stiff behaviour was proved. Besides this optimization of the filling materials methods for refitting of such expansion joints in already existing airfields were developed.

KEYWORDS

CONCRETE GUTTER / CONCRETE PAVEMENT / FILLING MATERIAL / CRACKING

A REVIEW OF MECHANISMS ASSOCIATED WITH PREMATURE JOINT DETERIORATION IN CONCRETE PAVEMENTS

(ID 100)

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Premature deterioration of sawn joints has been reported in some cold climate regions in the USA. This paper reviews the multiple mechanisms have been found to contribute to the deterioration. Laboratory and field investigations have shown that freezing and thawing of saturated concrete is a dominant factor. Magnesium and calcium chloride salts used for de-icing also attract water and so increase the degree of saturation at the joint face. Laboratory tests have also demonstrated that where the interfacial transition zone around aggregates is exposed to salt solutions by saw-cutting, the risk of distress increases. This paper is a review of the mechanisms that appear to be contributing to this distress.

KEYWORDS

JOINT DETERIORATION / CONCRETE PAVEMENT / FREEZING AND THAWING / DEICING SALT

ULTRASONIC TOMOGRAPHY AS NON DESTRUCTIVE MEASURING TECHNIQUE FOR CONCRETE PAVEMENT EVALUATION (ID 45)

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Ultrasonic tomography is a non-destructive method to evaluate different characteristics of the pavement such as thickness, position of reinforcement, presence of cracks and impurities, strength evolution. This technique can be used for control and follow-up of new pavements but also for non-destructive analysis of existing pavements in order to determine the cause and extent of distresses on these pavements.

This technique has first been applied on concrete pavements by researchers at the University of Minnesota, USA. With their help, the E34, a Belgian highway constructed with a double layered continuously reinforced concrete pavement, was analysed. This pavement exhibited early punch-out at the surface, due to the existence of horizontal cracks located at the height of the reinforcement and which could be detected by the ultrasonic tomograph. Extreme shrinkage probably laid at the basis of the observed damage.

Since the beginning of 2013 the BRRC has invested in an ultrasonic tomography device. First calibrations have been done on a test slab with various thicknesses and reinforcement bars. Subsequently, measurements on different pavements have shown that ultrasonic tomography is indeed a suitable method for the evaluation of concrete roads.

This paper presents the ultrasonic tomography method and its possible applications. The accuracy of the measuring technique is demonstrated, based on the calibration measurements done in the laboratory and in-situ. The usefulness of this method for pavement management is shown by some particular measuring campaigns carried out in Belgium.

KEYWORDS

ULTRASONIC TOMOGRAPHY / NON DESTRUCTIVE MEASURING TECHNIQUE / THICKNESS
MEASUREMENTS / PAVEMENT EVALUATION

POSTERS SESSION 10

A NEW ROAD WITH A MICROMILLED CONCRETE PAVEMENT AND A BRIDGE OVER THE ESLA RIVER IN LEON (SPAIN) (ID 7)

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The Castilla & Leon Regional Government has built a new road between the towns of Castrofuerte de Campos and Toral de los Guzmanes, located in León Province, in the Northwest part of Spain. It includes a 324m long and 10m wide bridge allowing local traffic to avoid a long detour around the Esla river.

The total length of the road is 3,787m. The pavement is composed of 20 cm of concrete on 15 cm of crushed granular material. A minimum of 28 days flexural strength of 4.0 MPa was required for concrete when tested at 28 days.

Transverse joints were placed at a sequence of distances of 3.4 - 3.6 - 3.8 m, as well as a longitudinal joint between traffic lanes. All of them were sawn and then sealed. Aiming to reduce noise levels, the texture was obtained by micromilling the surface (this was the first Spanish experience). In addition, evenness problems caused by stops of the paver were also corrected. Last but not least, speed of construction was increased with respect to that achieved when an exposed aggregate texture was selected at the beginning of the work, since winter conditions prevailing at the jobsite hindered the removal of unset surface mortar and therefore the cutting of joints. As a result, a silent, high skid-resistant texture was achieved. All things considered, micromilling increases both comfort and safety of drivers.

KEYWORDS

CONCRETE ROAD / MICROMILLING / EXPOSED AGGREGATE TEXTURE / JOINTS / TEXTURE PROBLEMS / IRI

**CONCRETE IN ROUNDABOUT DESIGN
(ID 8)**

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The paper describes the actual possibilities of using concrete pavement in a roundabout. Concrete may be better material for aprons than conventional cobblestones. It can be better for both durability of the road and for road safety. If heavy vehicles often pass through the cobblestone pavement in the apron, the cobbles can eventually move out of their position. These loose cobbles could then become dangerous for traffic and can cause an accident. Concrete is now also recommended instead of asphalt for circulatory roadways because concrete resists better under a high traffic load and the surface does not require frequent repairs. This paper presents the current knowledge of this practice, particularly in the Czech Republic.

KEYWORDS

CONCRETE PAVEMENT / ROUNDABOUT / TRUCK APRON / CIRCULATORY ROADWAY

IMPROVEMENTS TO THE CONSTRUCTION PROCESS FOR SEMI-RIGID PAVEMENT REHABILITATION ON MEXICAN HIGHWAYS (ID 11)

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The Mexican Federal Government has allocated a great deal of investment to the maintenance of pavements across the existing road network (in 2010 and 2011, this investment amounted to €7,860M and €7,894M respectively). During the 1990s, a pavement system was introduced in Mexico involving the incorporation of Portland cement using a mechanical process (grader) in order to improve the mechanical properties of the lower layers (base and subbase), thereby increasing their strength. However, homogenization of the stabilized base has never been achieved using this construction process. Currently, a process is being employed that involves reclaiming part of the existing pavement and incorporating Portland cement directly *in situ* using automated equipment, thereby allowing homogeneous application at the lower layers. The aim of this research is to examine the impact on the performance of the lower layers of semi-rigid pavements as a result of using automated equipment on Mexico's major highways. In order to achieve this goal, comprehensive monitoring and data analysis was performed, based on the falling weight deflectometer (FWD) as a key tool for *in situ* evaluation (mainly in terms of base deflection and moduli).

KEYWORDS

STABILIZED PAVEMENT / HOMOGENIZATION / PORTLAND CEMENT / MAINTENANCE AND REHABILITATION

**“PAVEMENTS AND LIGHT” FOR THE RIGHT LIGHTING: CONTRIBUTION OF
CONCRETE PAVEMENTS
(ID 25)**

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Public lighting contributes to the safety and quality of life in urban areas and, like all services, is confronted with the challenge of “doing better with less.” Closer ties between the trades of the road and lighting offer proven opportunities for significant economic and environmental gains once steps are taken to look at projects in an integrated manner, taking closer into account the photometric properties of pavement surfaces with luminous fluxes. The “Pavements and Light” partnering approach applied in France over the past 5 years is bearing its initial fruit. Pavements in concrete and some other types have been clearing the way towards gains in this area. The first demonstration of a specifically studied concrete roadway at the Cettons II eco-friendly business park showed the feasibility of taking luminance better into account. Rapid technological and organisational progress, like the introduction of energy performance contracts, help to bring to maturity the collaborative work of contracting authorities, engineering firms and contractors handling roadway and lighting projects, thus making it possible to achieve the goal of better lighting at lower cost throughout the service life of the road or street. Continuing progress with decorative concrete reinforces this concept and the vision of a sustainable city in which concrete participates actively in meeting the new demands of city dwellers.

KEYWORDS

PAVEMENT / LIGHT / ENERGY / INNOVATION / PHOTOMETRY / INTEGRATED CONTRACTING
AND STUDIES

**CONCRETE PAVEMENT ON BICYCLE TRAILS
(ID 32)**

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On the beginning of third millennium we, in the Czech Republic, can also notice a big construction boom in the area of bicycle roads and trails. The rehabilitation of existing roads, temporary solutions (e.g. traffic sign placement) overweight the others. Other systematic approaches are also built and they bring a lot of interesting technical solutions. What is an actual development in the Czech Republic? If we compare the Czech Republic with developed European countries, we are certainly not on a leading position.

The purpose of bicycle trails is to provide a safe traffic for cyclists and pedestrians outside the busy roads. Other use can be found in other sport and touristic activities. In the landscape it brings tourists to attractive locations and places. Bicycle trail means, like any other building, intervention in the landscape. Therefore, the local conditions must be obeyed. The bicycle trail is within the transport infrastructure an ecological solution. However, there is not only solution how to design bicycle trails. The main criterion of different technical solutions is the surface of bicycle trail, because in use of existing paths, these can differ from dirty roads to second or third class roads. Gravel surface, asphalt and concrete pavements and concrete paving are mostly met during the new trails design.

**COMPARISON OF ROADWAY JOINTED PLAIN CONCRETE PAVEMENT (JPCP)
THICKNESS DESIGN METHODS COMMON IN THE UNITED STATES (U.S.)
(ID 34)**

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While much research in the United States (U.S.) has focused on the development, enhancement, and sensitivity of the AASHTOWare Pavement ME Design (previously known as MEPDG and DARWin-ME) method, little work has focused on comparing the results from this design method to other design methods already regularly used in practice. This investigation compares required thickness results for new jointed plain concrete pavement (JPCP) obtained from the AASHTOWare Pavement ME Design software, the AASHTO 93 design method via the ACPA WinPAS software, and the ACPA StreetPave software across an array of key design variables such as traffic, concrete flexural strength and modulus of elasticity, reliability, edge support condition, and k-value.

KEYWORDS

JOINTED PLAIN CONCRETE PAVEMENT (JPCP) / THICKNESS DESIGN / AASHTO 93 /
AASHTOWARE PAVEMENT ME DESIGN / STREETPAVE / WINPAS

MEASUREMENTS AND EVALUATION OF THE BEARING CAPACITY OF CEMENT CONCRETE PAVEMENTS (ID 36)

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Concrete pavements dynamic loading tests are one of the diagnostic method to which the goal is to obtain background for evaluation of bearing capacity. In this article are described experimental measurements and results of these measurements on various slab locations, taken from measurements for recognition of connection between slabs and on large areas. Shapes of deflection profiles are the base the measurements analysis and derivation of other characteristics of bearing capacity of pavement structures.

KEYWORDS

CONCRETE ROADS / BEARING CAPACITY OF PAVEMENT / DEFLECTION MEASUREMENTS / LOAD TRANSFER EFFICIENCY

EFFECT OF CURLING BEHAVIOR ON SURFACE SMOOTHNESS OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENT (ID 49)

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The curling behavior of the continuously reinforced concrete pavement (CRCP) under environmental loads was analyzed by measuring vertical displacements at a number of different longitudinal and transverse locations, and the relationship between the surface smoothness and curling behavior was investigated. Two different crack spacings were selected and at each discrete slab formed by the selected crack spacing the gages were installed along the longitudinal and transverse directions to measure the vertical displacement variations under environmental loads. The field experimental analysis results showed that the vertical relative displacements of the CRCP along the transverse direction were very clear especially at the outer edge, and those along the longitudinal direction were affected slightly by the crack spacing. At a designated transverse location, the daily differences in the vertical displacements along the longitudinal direction due to curling tended to increase as the crack spacing became larger. Since the variation of the vertical displacements along the longitudinal direction can affect the ride quality, the Profile Indices were considered depending on the cracking spacing. This study confirmed that the effect of the curling behavior of the CRCP on the surface smoothness was negligible even with large crack spacings.

KEYWORDS

CONTINUOUSLY REINFORCED CONCRETE PAVEMENT / CURLING / CRACK SPACING /
SMOOTHNESS / ENVIRONMENTAL LOAD

MOVEMENT OF UNANCHORED TERMINUS OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENT (ID 50)

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The longitudinal displacements of the terminus of the continuously reinforced concrete pavement (CRCP) without the terminal anchor lug system were measured and analyzed to investigate the maximum terminal joint width and the necessity of the anchor lug system. The terminal movements under environmental loads were measured at the CRCP sections that had different lengths and different bond characteristics between the concrete slab and underlying layers. The measurements were taken for about a year. The results of the study showed that once the CRCP was over a certain length, the movements of the free end termini seemed to converge. This implies that the maximum movement of the terminal joint width is not a function of and independent of the length of the CRCP once the length is over a certain value. The terminal movements per unit temperature change were different depending on the size of the measurement period. The results also showed that the bond characteristics at the interface between the slab and underlying layer affected the terminal movement of the CRCP.

KEYWORDS

CONTINUOUSLY REINFORCED CONCRETE PAVEMENT / TERMINUS / ANCHOR LUG /
EXPANSION JOINT / TEMPERATURE CHANGE

ROLLER COMPACTED CONCRETE PAVEMENTS FOR THE URBAN ENVIRONMENT: TURKISH EXPERIENCE (ID 68)

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Roller compacted concrete has traditionally been used for pavements carrying heavy loads in low speed areas because of its relatively coarse surface texture. However, its use in commercial areas for local streets and highways has been increasing, especially within the United States. Even though Turkey is one of the main cement manufacturer's in the World, the use of concrete pavements in our country is very limited. There have been past efforts, especially by the Turkish Cement Manufacturer's Association to promote the use of concrete pavements within the national highway system. However, concrete pavements have not been the main choice for the Department of Transportation. As the urbanization within cities is in an accelerated growth period, more trucks are entering within the city, thus increasing the damage on the existing flexible pavements. This article will present the application of roller concrete pavements by two municipalities, namely Denizli and Antalya municipalities. With the use of widely available asphalt pavement machinery and the conventional concrete mixing plants, roller compacted concrete pavements seems to be an excellent alternative to traditional flexible pavements especially for the urban environment.

KEYWORDS

CONCRETE ROADS / ROLLER COMPACTED CONCRETE PAVEMENTS / URBAN APPLICATIONS

PROGRESSIVE COMPOSITE BRIDGE CONSTRUCTION WITH CEMENT CONCRETE PAVEMENT (ID 74)

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The project deals with research on effective composite steel and concrete bridge structures, profiting from directly running cement concrete pavements. The aim is an innovative layout solution, technology of construction and maintenance and research of new formulas for concrete parts which will lead to lower collective costs of production and maintenance. The project proposal is focused on research and subsequent practical application of two currently developed contemporary cutting-edge technologies, the combination of which is unique worldwide in terms of the complexity of the solutions and technological development. The technology is being developed for small and medium bridge spans for which standardisation is not a problem. On the contrary their unification is advantageous as regards both production and maintenance.

KEYWORDS

COMPOSITE BRIDGE CONSTRUCTION / CEMENT CONCRETE PAVEMENT / EXPERIMENTAL CONSTRUCTION / LONG-TERM MEASUREMENT / PUMPABLE CONCRETE

SKID RESISTANCE-IMPROVEMENT MEASURES ON CONCRETE ROADS IN AUSTRIAN ROAD TUNNELS (ID 81)

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The results of the investigation concerning the loss of skid resistance on Austrian tunnel roads are presented in this poster as well as the results of trials to improve the skid resistance level in the laboratory. Best results were achieved through cleaning the road surface in the tunnel with tailor made cleaning agents removing the sticky dirt from the surface.

KEYWORDS

TUNNEL CONCRETE ROADS / CLEANING / IMPROVEMENT / SKID RESISTANCE

ROAD SAFETY AND SURFACE DURABILITY ASPECTS ON HUNGARIAN CEMENT CONCRETE PAVEMENTS (ID 87)

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The ratio of cement concrete pavements has increased in the Hungarian motorway network in the last decade, and it has appeared also in the local road network. There are 15 cement concrete pavement sections with different type in Hungary. Maintenance agencies need a simple methodology for calculating surface deterioration of cement concrete pavements. The actual and measured parameters of pavement surface deterioration including the change of roughness are important road asset management inputs. Since the majority of Hungarian road funds have been spent for the construction of major roads (mainly motorways with significant transit traffic) very few attention has been paid for the management of low-volume roads. That is why the general condition of local network including its surface characteristics has become generally very poor. However, some of their road sections and junctions are highly trafficked needing special resistance to load. A possible solution here is the construction of high-quality cement concrete pavements. The road geometric parameters and the “0” measurements values can highlight an additional danger for the eventual quick deterioration of pavements. This risk can be managed more readily by road managers if they have information about the pavement deterioration.

KEYWORDS

CONCRETE ROADS / SKID RESISTANCE/ ACCIDENT / ROUGHNESS / DETERIORATION

A DEDICATED BUS PLATFORM IN CASTELLÓN (SPAIN) (ID 93)

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The metropolitan area of the city of Castellón, situated East of Spain at the Mediterranean coast, has a network of dedicated bus platforms, which was conceived with two main purposes: to enhance public transport and to structure urban development.

As a part of this network, a bus platform, 3.9 km long, was constructed in 2013. It is a section of Line 1, which connects the Port of Castellón to the city center.

Buses are optically guided. Therefore all the vehicles follow the same path. This channelization effect was considered when designing the thickness of the pavement.

The platform is 7 m wide. It has a jointed plain concrete pavement, 25 cm thick, placed on an existing asphalt concrete pavement in service since a number of years. Some centimetres of asphalt concrete were milled to accommodate the thickness of the concrete pavement to the levels of the adjacent areas. A characteristic compressive strength of 4.5 MPa at 28 days was specified for concrete.

Since the pavement was built by half widths, the only longitudinal joint is the construction one between them. It is provided with tie bars to avoid excessive opening. Transverse joints were sawn, at a spacing of 4 m at most.

The pavement was finished with a topping of resin mortar.

KEYWORDS

CONCRETE PAVEMENT / DEDICATED PLATFORM / PUBLIC TRANSPORT / LOW NOISE PAVEMENT

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**DEVELOPMENT OF HIGH PERFORMANCE REPAIR CONCRETE FOR PAVEMENTS
(ID 97)**

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Concrete, used in the production of highways and pavements, may deteriorate after many years of service, due to severe exposure conditions. Due to strategic and economic importance of such infrastructures, swift action for repair works is required. Repairs with conventional concrete may take long time for gaining adequate strength, where rapid strength gaining concrete often presents workability loss problems during application. In this study, a high performance concrete for repair of highways and pavements is developed. Laboratory and field tests are performed to assess workability, slump life and rheological stability. Early age properties are monitored by measuring the development of mechanical strength, fracture energy, hydration heat, thermal expansion coefficient and drying shrinkage. Durability properties, related to exposure conditions, are tested by permeability and salt scaling tests.

During the development of the mix design of the high performance repair concrete, an admixture system, compatible with the cement and aggregates, is proposed. The 4-component admixture system consists of a superplasticizer to assure low water-to-cement ratio, synthetic crystals for achieving faster strength gain, microfibers to enhance early age cracking resistance and an air-entrainer to increase freeze-thaw resistance. The applicability of the proposed design was tested by full scale trial castings on site. Void system, internal stability and homogeneity of in-situ concrete was observed by microstructural examinations.

KEYWORDS

CONCRETE PAVEMENTS / MAINTENANCE / EARLY AGE PROPERTIES / DURABILITY

**BUILDING CONCRETE ROUNDABOUTS IN SWITZERLAND
(ID 102)**

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Since 2003, roundabouts in Switzerland have been built with concrete carriageways. Because space is at a premium due to the population density, the diameter of most roundabouts is less than 30 m. Roundabout carriageways with small diameters are subject to particularly high shear stress levels, which is why the choice of surface depends not only on the road traffic itself but also increasingly on geometrical considerations and/or the roundabout diameter. Consequently, roundabouts in the canton of Zurich with a diameter of less than 28 metres can now only be built with concrete carriageways, irrespective of traffic levels.

In principle, the concrete surfaces of frequently used carriageways are laid on a layer of asphalt in order to avoid subsequent pumping of the flags.

Structurally speaking, the circular carriageway is separated from the approach/exit areas as they demonstrate different movement behaviour. To avoid vertical misalignment in the transition zone, the flags lie on a concrete bedding (bed plate).

The thickness of the concrete surface varies between 26 and 28 cm. Furthermore, it is dependent on the width of the circular carriageway. If the circular carriageway is more than 25 times wider than the thickness, it must be reinforced or a smaller flag size must be favoured by implementing a central longitudinal joint.

To ensure the long-term adherence of concrete carriageways, concrete recipes are increasingly adopted in Switzerland in which the aggregate consists of 60 - 70% crushed stones.

To improve visibility and contribute to road safety in Switzerland, white markings on concrete surfaces are either underlaid in black or the concrete surface itself is coloured black.

An increasing number of traffic islands and inner rings are now made in one piece from concrete with or without pigmentation, as these are the best means of handling high traffic volumes while providing a low-maintenance solution. Concrete constructions are also gaining ground for design-related reasons, with the variable shaping possibilities of concrete and its suitability for pigmentation. Thanks to the very good results displayed by concrete roundabouts, 20 to 25 roundabouts are now built from concrete in Switzerland every year.

THE INFLUENCE OF SAND GRADING ON THE AIR VOID SYSTEM (ID 105)

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In this research the influence of sand grading on the air void system in mortar is determined. Three sand grading types are defined: sand “low”, sand “mean” and sand “high”. The difference is the amount of fines, < 250 µm, (low, mean and high amount of fines) in the sand. The sand grading does have a significant influence on the air void system in the mortar and with sand mean the most small air bubbles (<300 µm), a lower spacing factor, a higher specific surface of the air voids and a higher total air content can be realized. This will lead to a better freeze thaw resistance and workability. Sand low is creating more large air bubbles.

In opposite of what is mentioned in most literature, more and less fines in the sand, without water corrections, results in a lower total air content. Sand mean with the highest void content after vibration has the opportunity to create the highest amount of total air.

If water corrections are made in the mortar to create comparable flow conditions for the three sand types, sand low is improving on the amount of small air voids and sand high is not. The conclusion is still the same: „Sand mean is producing the most small air bubbles in mortar“. It is assumed that the air void grading in mortar tell something about the void sizes in the used sand. It looks like air bubbles are filling the gaps between the ideal mix grading and the used mix grading.

An interesting aspect for concrete pavements and Frost-Thaw resistance.

KEYWORDS

AIR VOID SYSTEM / AIR VOID GRADING / SAND GRADING TYPES / AIR VOID ANALYSER

CLASSIFICATION AND METHODS FOR REHABILITATION OF CONCRETE PAVEMENT; A SPANISH EXAMPLE (ID 115)

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Highways superficial rehabilitation appears nowadays as one environmental friendly option to increase the service life of pavements. The remaining structural section is responsible for providing enough resistance for the ongoing traffic loads.

The basic goal of this kind of treatments is to recover a certain level of comfort and security when driving, mostly measured by the evenness, evaluated by the International Regularity Index (IRI), and the skid resistance, measured by the SCRIM system. These can be achieved through treatments with or without materials addition.

While it is frequent with asphalt mixtures to restore the pavement by adding new asphalt layer (with or without a previous milling) and getting structural and superficial upgrading by this method, in case of concrete pavements is quite different. Inlays and overlays are less used because their usual thickness, choosing usually a complete substitution of the concrete slab.

Consequently several superficial improving techniques, including grooving, grinding and micro-milling, have been developed or updated, suitable either for rehabilitation or even as a constructive technique in new pavements. It must pay special attention to protection of joints during jobs. As an example a 1300 meters long concrete pavement in a tunnel has been micro-milled in its hole length.

KEYWORDS

REHABILITATION / GRINDING / GROOVING / MILLING / UPGRADING

**ENVIRONMENTAL PERFORMANCES OF ROLLER COMPACTED CONCRETE PAVEMENT (RCCP)
(ID 121)**

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The use of RCC is now well established for industrial pavements, and is spreading in North America and recently in Europe for transportation pavement with high mechanical performances requirements such as Tram or Bus platforms. Cost advantage and mechanical performances are two undeniable benefits of this technology. The development of technologies related to usual concrete pavement such as control joints process, curing control, formulation methods, but also the use of high density asphalt pavers make the use of RCC technology realistic for road design. Moreover new tendencies for re-used materials in particular recycled concrete and the potentiality of the RCCP to incorporate such materials combined with the availability of hydraulic binder with low clinker content are considerable aspects to promote this technology in a larger extent, based on low environmental impact. In that context, the present study focuses on RCC designed with very low clinker content (within cement or hydraulic road binder) and 0 to 50% of recycled concrete aggregates. These concretes were optimized using the compressible packing model (accounting for wall and loosening effect). The analysis of the results is based on the ratio between the mechanical performances (modulus and traction strength obtained after experimental test program) and the environmental impact. This impact was assessed using Life Cycle Assessment (LCA) analysis through the Eco-evaluator "ECORCE 2.0" especially developed by LCPC/now IFSTTAR (French Institute of Science and Technology for Transport, Development and Networks) for LCA analysis of road design. Two parameters were observed: greenhouse gas (GHG) emissions and total energy consumption (EC). The good performances of RCCP solutions, in terms of mechanical properties and environmental indicators GHG and EC, are encouraging compared to standard concrete technology (like Concrete with Dowelled Joints), for a given life span.

KEYWORDS

CONCRETE ROADS / ROLLER COMPACTED / RECYCLING / ENVIRONMENT INDICATORS

**RAPID REPAIR OF CONCRETE ROADS USING CALCIUM ALUMINATE CEMENT BASED
MORTAR IN WINTER CONDITIONS****(ID 133)**

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Calcium aluminate based mortars have been widely used for fast setting repair applications. This article will present the laboratory work that was conducted to repair an existing concrete road in Istanbul. The main damage mechanism was both abrasion and frost damage; the maximum time that the road can be closed to traffic is only 6 hours. As the repair was going to be performed in the winter, the desired final compressive strength of the mortar has to be minimum 10 MPa in 4 hours at 5°C. The developed repair mortar consists of calcium aluminate cement, Portland cement and various chemical additives. Lithium carbonate was used as an accelerator and citric acid was used as a plasticiser and set controller. Also a lignosulfonate based superplasticiser was used in order to achieve the desired flowability. Micro silica is added to control the rheology and to prevent the conversion reactions of calcium aluminate cement. First trials performed by CIMSA Cement Research and Application Centre laboratories. After the laboratory trials field application will be performed in İstanbul by İston.

KEYWORDS

CALCIUM ALUMINATE CEMENT / DRY MIX / REPAIR / MORTAR

EXPERIMENTAL STUDY OF PROPERTIES OF PERVIOUS CONCRETE USED FOR BRIDGE SUPERSTRUCTURE (ID 139)

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One of the main advantages of pervious concrete is its ability to drain water easily. Moreover, earlier studies on pervious concrete have shown that it can be designed to perform well in freeze-thaw regions. Bridge superstructures placed in regions where the temperature during winter time varies around freezing point are exposed to a harsh freeze-thaw impact, since bridges are not only cooled from the topside, as a normal road bed, but also from underneath. Hence, the demands to the moisture properties of the superstructure are strict in order to ensure the necessary durability. Pearl-Chain Bridges are a new patented bridge technology consisting of a number of Super-Light Deck elements, which are post-tensioned to create an arch bridge used for example for highways. The present study investigates how pervious concrete can be applied as a stabilizing filling material between the arch substructure and the wearing course. One pervious concrete mixture containing air entrainment is designed and tested. The tests include investigations of compaction methods, compressive strength, stiffness, frost resistance and permeability.

KEYWORDS

PERVIOUS CONCRETE / FILLING MATERIAL / PEARL-CHAIN BRIDGES / DURABILITY / FROST RESISTANCE / PERMEABILITY

FLATNESS AND LEVELNESS OF CONCRETE PAVEMENTS FOR INDUSTRIAL AREAS: REQUIREMENTS AND EVALUATION METHODS (ID 145)

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Among various construction activities, related to concrete pavement technologies, an important role is reserved to industrial floors; these structures, in many cases, present the same technical problems of road pavements. Characteristics, construction techniques, exercise conditions, maintenance and control of industrial pavements, in effect, are very similar to the ones usually defined for road infrastructures; on the other hand, in both cases it is necessary to ensure resistance and stability, durability, reliability and many other requirements. In particular, the flatness is a special requirement that assumes a real significance respect to functional performances, especially when the pavement has to allow the movement of vehicles and goods or the storage in elevated stacks or shelves. The flatness can be defined in different ways, but in every cases it is referred to pavement surface geometry, that has to be even (without superelevated or depressed areas) and level (horizontal, without grades, curvatures and waves). The acceptance limits are defined by some technical standards, in various Countries, together with the suitable methods for measurements and controls. In many cases, however, these methods are considered not really feasible or easy, in particular when a continuous sampling of the pavement, along the selected alignments, is needed. To facilitate the effectiveness of the control methods, it is possible to realize the surveys and the following data processing as in the infrastructure management activities. In particular, the paper describes the operating procedures to calculate indexes F_F and F_L , according to ASTM 1155M standard, starting from data provided by a contact profilometer.

KEYWORDS

CONCRETE PAVEMENTS / INDUSTRIAL FLOORS / SURFACE PROPERTIES / FLATNESS / LEVELNESS / PROFILOMETER / ANALYSIS

**INFLUENCE OF TEST SPECIMEN COMPACTION AND CURING CONDITION
FOR PAVEMENT COLD RECYCLED MIXTURES****(ID 156)**

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Presently in most European countries the quality of cold recycling mixtures in pavement rehabilitation is proven by achieving required strength values (indirect tensile strength or compressive strength) and eventually by values of stiffness modulus (IT-CY test method). This empirical approach of quality assessment is quite simple, relatively fast in performance and set in the long term. On the other hand this kind of assessment is characterized by distinctive weaknesses. Foremost strong dependence of magnitude of received strength values on various factors, whereas one of the most important is the way how test specimens are prepared and compacted. Second important parameter is influence of test specimen curing procedure for given conditions. Technical specifications in various European countries specify specimen preparation by using different laboratory equipment, which compact the test specimen by static pressure, dynamic hits or gyratory motion. In case of gyratory compactor further difference is also in the magnitude of used compaction pressure, number of applied gyrations etc. These parameters influence the resulting mix voids content as well as the resulting strength and stiffness modulus. Curing of test specimens is influenced by used binders (bituminous emulsion, cement, special hydraulic binders, bitumen foam etc.), which have different principles of hardening. Other factors are time and surrounding conditions (temperature, humidity). Presently there are in national specifications different conditions for curing. Usually common is the effort with respect to practical needs and condition to reduce the curing and testing periods by introducing e.g. accelerated curing procedures.

Objective of this paper is to investigate impact of specimen preparation and lastly the curing procedure by using different conditions on the quality characteristics of the cold recycled mixes. This should set necessary fundamentals for unification of technical specifications. Testing was done on specimens prepared by static compacting machine, impact compactor and gyratory compactor

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(following SUPERPAVE standards. Testing was executed on specimens where reclaimed asphalt material has been used in cold recycling technique by applying combined binder of cement and bituminous emulsion or foam bitumen.

KEYWORDS

COLD RECYCLING / SPECIMEN COMPACTION / SPECIMEN CURING / STATIC COMPACTION / GYRATORY COMPACTOR / MARSHALL HAMMER / INDIRECT TENSILE STRENGTH / STIFFNESS MODULUS

**THIN POLYMERIC SURFACE LAYERS ON CONCRETE STRUCTURES:
AN EXPERIMENTAL STUDY
(ID 167)**

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The paper describes a research aimed at analysing the functional and structural properties of trafficable waterproofing for concrete bridge decks. Flexible or rigid pavements are usually laid on bridges and viaducts; they need an underlying waterproofing, have a significant weight and are subject to several types of degradation because of limited durability. For this reason different solutions are now being investigated. A good alternative appears to be the application on bridge decks of surfacing made with resins and aggregate, in a mortar or alternatively a multi-layer form.

Different mixes have been tested, made with a polymeric binder (epoxy resin) and natural or artificial/ industrial aggregate (EAF slag, C&D aggregate, limestone, quartz sand). The mix is suitable for being applied in a single layer, with thickness of 2 to 4 cm over the cement concrete deck: it forms a lightweight pavement surfacing and, at the same time, durable waterproofing.

Several trials have been performed in order to check the structural and functional properties of the mixes: pull-off for adhesion evaluation, wheel-track test for permanent deformation analysis, skid resistance and macro-texture measures, permeability evaluation. The results demonstrate that some of the investigated materials possess functional and mechanical characteristics that make them suitable for use on bridges.

KEYWORDS

WATERPROOFING / BRIDGE DECKS / SURFACING / EPOXY BINDER / SLURRY

A FRAMEWORK FOR A NEW PROTOCOL FOR EVALUATING CONCRETE CURING EFFECTIVENESS (ID 169)

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Excessive early-age concrete surface moisture evaporation can be a source of key issues in the paving of concrete pavement, such as plastic shrinkage cracking and spalling related delamination; the use of liquid membrane-forming curing compounds is one of the most prevalent methods to protect hydrating concrete surfaces. However, the present standard test, ASTM C 156-98, "Standard Test Method of Water Retention by Concrete Curing Materials" has some inherent limitations in assessing curing effectiveness of concrete particularly under field conditions. To better employ curing practices and qualify the use of different curing compounds, a framework for new evaluation protocol is proposed.

The new protocol considers of using a calculated effectiveness index (EI) and measured dielectric constant (DC) curves with the associated α values to represent the effectiveness of a curing compound. As a means of validation, moisture loss and surface abrasion resistance measurements made on prepared concrete specimens were found to have significant correlations with EI, where greater values of EI were associated with less amount of moisture and abrasion weight loss. DC measurements were made and fitted to a modified Weibull distribution function to obtain a regression parameter, α . Lower values of α , which represent a lower rate of reduction in DC measurements were found to be related to less amount of moisture loss of the specimens. A coupled EI - α relationship was also proposed to determine the adequacy of the rate of application of a curing compound used in field conditions.

KEYWORDS

CURING OF CONCRETE / CURING COMPOUNDS / MOISTURE RETENTION CAPABILITY /
CONCRETE SURFACE ABRASION RESISTANCE / DIELECTRIC CONSTANT

**ABRASION RESISTANCE AND TRANSPORT PROPERTIES OF ROAD CONCRETE
(ID 171)**

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Abrasion resistance and impermeability are vital in road concrete. In this experimental study the compressive strength, abrasion resistance and transport properties of the road concrete were investigated. In order to study transport properties, water sorptivity and depth of penetration of water under pressure were taken into consideration. For this purpose, four different concrete mixtures having 28-day compressive strength ranging from 32 to 64 MPa were prepared, using a CEM II B-M (L/W) 42.5 R type portland composite cement, crushed limestone aggregate having a maximum size of 22.4 mm and a superplasticizer admixture (if required). The slump value of the concrete mixtures was kept constant as 75±5 mm. Two series of concrete mixtures were prepared. One of the series was coated with two different types of surface hardener admixtures (SHA). Thus, the effect of w/c ratio and presence or absence of the SHA on the abrasion resistance and transport properties of the road concrete were determined. Test result demonstrated that, compressive strength of the mixture with high w/c ratio increased by using of the SHA. However, application of SHA had not a significant effect on the compressive strength of concrete with low w/c ratio. Expect for the mixture having w/c ratio of 0.63, the control mixture showed better transport property than the counterpart mixtures coated by the SHA. Furthermore, a close relationship was found between the compressive strength and abrasion resistance of the concrete. Besides, the abrasion resistance of the concrete mixtures was found to be improved considerably by applying SHA.

KEYWORDS

ROAD CONCRETE / WATER SORPTIVITY / DEPTH OF PENETRATION OF WATER UNDER PRESSURE / ABRASION RESISTANCE / SURFACE HARDENER ADMIXTURE

MIXTURE QUALITY AND COST-BENEFIT ANALYSIS OF CONCRETE OVERLAY APPLICATION IN LITHUANIA PAVEMENTS (ID 177)

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Heavy vehicles traffic flow and loads are increasing every year and influence faster degradation of asphalt pavement. A lot of money is expended on distressed pavement repair and rehabilitation, so sustainable pavement structure development is one of priority in Lithuania. Flexible (asphalt) pavement design lifetime is 20 years and often the first distresses emerge after the first five years of exploitation. Meanwhile, PIARC Long-life pavement concept defines, that strategic national significance roads and high traffic urban streets pavement lifecycle period should be from 40 to 50 years. Assessing rising oil and bitumen prices and costs for asphalt pavement rehabilitation and maintenance an alternative materials solutions is analyzed. The objective of article is to evaluate suitability of concrete mixture, produced in Lithuania, through compressive strength accordance with requirements. Compare different types of overlays through materials and construction expenses, and to compare traditional asphalt and concrete pavement overlays considering 35 years of exploitation maintenance and repair costs.

KEYWORDS

LONG-LIFE PAVEMENT / RIGID (CONCRETE) PAVEMENT / FLEXIBLE (ASPHALT) PAVEMENT / PAVEMENT STRUCTURE

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