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"Making Waves with Durable, Resilient Concrete Pavements"

BOOK OF ABSTRACTS

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Session 1: Airfield Pavements

Sensitivity Analysis of FAARFIELD Rigid Airport Pavement Thickness Determination

Greg White, Mitch Sterling, Matt Duggan, Jordan Sterling

FAARFIELD is a common mechanistic-empirical software that uses a combination of layered elastic and finite element methods for the determination of rigid aircraft pavement thickness. The primary input parameters are the aircraft type, mass and departures, concrete flexural strength, sub-base material and thickness, as well as subgrade support characteristic. A parametric sensitivity analysis, including three common commercial aircraft and four subgrade conditions, determined that concrete thickness was most sensitive to concrete strength and aircraft mass. The concrete thickness was least sensitive to the sub-base material and thickness and was moderately sensitive to the subgrade condition and aircraft departures. These relative sensitivities were consistent when the results were analysed based on average percentage change in concrete thickness, the average slope of lines of best fit for normalised parameters values and the coefficients of a numeric linear regression for concrete thickness. It is recommended that designers focus their attention on accurately estimating realistic concrete strength and aircraft mass values, as these parameters had the greatest influence on concrete thickness.

Investigating Alternates to Flexural Beams for Airport Concrete Strength Compliance

Greg White, Matthew Johnson

Concrete for airport rigid pavement construction is generally specified to achieve a minimum characteristic flexural strength of 4.5 MPa and acceptance testing during construction aims to verify this key design assumption. The large flexural beam specimens are cumbersome and the testing is expensive. Consequently, industry desires a more convenient test and a laboratory-based conversion to an estimated flexural strength for acceptance testing during production. This research developed and trialed a protocol for the conversion of indirect tensile strength and compressive strength to estimated flexural strength. The laboratory correlation was encouraging. However, when trialed on a real construction project, the conversions significantly underestimated the measured flexural strength and the risk of rejecting compliant batches of concrete was significantly higher. Further research is required to understand why the reliable

conversions developed in the laboratory failed in the field. This may be related to the effect of ambient temperature on 28 day flexural strength, despite the constant curing condition.

Concrete Pavement Strength And Fatigue Investigations At The FAA National Airport Pavement Test Facility

Mesbah Ahmed, Hao Yin, David Brill

The Federal Aviation Administration (FAA) is conducting a full-scale rigid pavement test using simulated aircraft gear loads at the National Airport Pavement Test Facility (NAPTF) as part of NAPTF Construction Cycle 8 (CC8). The objective of this test is to determine the cracking strength and fatigue life of concrete slabs designed and built to FAA standards, hence it is designated the Strength/Fatigue (S/F) test. The experiment considered various combinations of concrete flexural strength (650 vs. 900 psi), slab thickness (9 vs. 12 in), and subgrade strength (CBR 3-4 vs. 7-8).

Cracking strengths of some slabs were determined by a series of static load tests using the single-wheel module on the National Airport Pavement Test Vehicle (NAPTV). For all the cracked slabs, the load-related stress was 45-75% of the flexural strength obtained from field-cured beams. These lower-than-expected cracking loads are tentatively attributed to the presence of non load-related (built-in) stresses in the slab. Rolling load tests used a single wheel load (SWL) set to 80% of the estimated bottom-up cracking load and no wander, intended to propagate the crack from the bottom of the slab to the surface. Initial observations suggest that the crack initiation stage is controlled more by slab thickness than by concrete strength, but that the reverse is true for crack propagation once the initial bottom-up crack is formed. Initial analysis also suggests that the FAARFIELD rigid failure model underestimates damage accumulation from crack initiation up to the appearance of the full-depth crack on the surface. However, model predictions were conservative on the terminal deterioration phase during which the surface crack extends to full length, regardless of slab thickness and concrete strength.

Evaluation Of Concrete Pavement Joint Performance At The FAA National Airport Pavement Test Facility

Mesbah Ahmed, Carlos Cary, Hao Yin, David Brill

On November 08, 2018, the Federal Aviation Administration (FAA) National Airport

Pavement Testing Facility (NAPTF) completed a full-scale test on concrete airport pavements comparing joint types, as part of NAPTF Construction Cycle 8 (CC8). The objective of this experiment was twofold: (a) compare the performance of a new type of sinusoidal keyway joint with standard doweled longitudinal construction joints; and (b) compare the performance of doweled versus undoweled transverse contraction joints. The indoor test pavement consisted of twelve slabs divided into four groups according to the joint types. All four groups received traffic from a full-scale dual-wheel landing gear configuration using the FAA National Airport Pavement Test Vehicle (NAPTV). All test items were trafficked to failure. Performance of the joints was analyzed using data from heavy-weight deflectometer (HWD) tests and from embedded strain gages to determine load transfer values.

For equal traffic, the sinusoidal design of keyway joints demonstrated performance at least equivalent to standard doweled joints. As expected, doweled transverse contraction joints maintained high load transfer throughout the traffic test and were much less sensitive to temperature variations than the undoweled joints. For both types of longitudinal construction joints and for doweled contraction joints, stress-based load transfer values across the joint exceeding 30% were observed. This is significant because the FAA's FAARFIELD design procedure assumes 25% load stress transfer for rigid pavement design.

Session 2: Moisture Effects

Consideration of the Hygrothermal Actions in Concrete Pavement Design Procedures: Do we Follow the Right Approach?

Angel Mateos, Miguel Millan, John Harvey

Concrete moisture-related and thermal (hygrothermal) actions are known to have a large impact on the performance of concrete pavements. Despite that, current mechanistic-empirical design procedures oversimplify the prediction of these actions and their effects on the structure of the pavement. This paper evaluates the most common simplifications adopted by current mechanistic-empirical design procedures. The evaluation is based on the experimental data collected from fifteen thin bonded concrete overlay of asphalt pavements that were instrumented with sensors to measure the structural and hygrothermal response. The experimental data included the response of the slabs under the ambient environment, measured during fifteen months, and the response measured under the wheel of the Heavy Vehicle Simulator. The analysis of the experimental data shows that some simplifications adopted by current mechanistic-empirical design procedures lead to a considerable underestimation of the effects of thermal and moisture-related actions. The study emphasizes the need for a better understanding of a number of phenomena before a fully realistic modeling of the hygrothermal actions in concrete pavements can be achieved. Among those phenomena are concrete tensile creep, slab-base interaction, and concrete moisture content effect on the coefficient of thermal expansion.

Pore Water Potential Development in Cement-Based Materials

Payam Vosoughi, Peter Taylor, Robert Horton

Consumption of water during hydration reactions and surface water evaporation result in the development of negative pressure in capillary pores of concrete at early ages. Capillary pore water potential (PWP) creates early-age shrinkage strain and increases the chance of early-age cracking. The aim of this study was to investigate the effects of internal curing (IC) and water-to-cementitious materials ratio (W/CMs) on the hydration reactions and PWP development in cement-based materials. For this purpose, 11 mortar mixtures with different W/CMs (0.3, 0.375, 0.45 and 0.525) and lightweight fine aggregate (LWFA) substitutions (10, 20, 30 and 50%), as well as, 9 concrete mixtures with different W/CMs (0.35, 0.42 and 0.5) and LWFA substitutions (10, 20, 30 and 40%) were made and evaluated through isothermal calorimetry and pore water

potential tests. The results demonstrate that IC is efficient in both promoting hydration kinetics and suppressing capillary PWP development, especially for the mixtures with low W/CMs.

Application of Internal Curing in Slab Replacement using Rapid Strength Concrete

Parvini Mehdi

The California Department of Transportation (Caltrans) uses rapid strength concrete (also known as high early strength concrete) to repair or rehabilitate concrete pavements. Failed concrete slabs are removed and replaced with rapid strength concrete (RSC) that is often volumetrically proportioned in the field. Both Type III Portland cement concrete and specialty cements are used to prepare RSC. The performance of slab replacement strategy using RSC has been questionable based on past experience. A study was conducted to evaluate and compare the performance of RSC made with the two different cement types. Due to relatively short performance data and variability of the influencing performance factors, no definite conclusions were derived from this study. One consideration in potential short service life of slabs constructed with RSC is the limitation of proper concrete curing. Internal Curing (IC) with lightweight aggregate is employed to compensate for the lack of external/surface curing of the concrete. A pilot slab replacement project on route 680 in Bay Area was identified and slabs were placed side by side with and without lightweight aggregate to monitor and compare the performance of the RSC using internal curing (RSC-IC). The steps that are taken to initiate, design and construct this pilot project is discussed in this paper. Caltrans plans to monitor, test and report the expected improvement in the performance of internal Cured rapid strength concrete in the future.

Application of a Poromechanistic-Empirical Drying Shrinkage Modeling Approach to Structural Design of Concrete Pavements

Milena Rangelov, Somayeh Nassiri

Top-down drying in concrete pavement slabs causes differential drying shrinkage strains (μ_{sh}), which may warp the slab and lead to cracking. Warping is typically represented by an equivalent temperature difference (ETD_{sh}) that will cause the same slab curvature as μ_{sh}. However, the current ETD_{sh} computation procedures are empirical and simplified. In this study, a poromechanistic-empirical (PME) procedure is proposed to compute time-dependent ETD_{sh} for concrete pavements. The PME procedure integrates a

diffusion model to predict the internal relative humidity with a poromechanistic model to calculate μ_{sh}-profiles. Both models are calibrated based on differential drying experiments conducted on mortar prisms from seven mixture designs. After applying an empirical correction for coarse aggregate volume, the developed μ_{sh}-profiles are used to calculate ETD_{sh} for an instrumented pavement section in Pennsylvania for validation. Higher sensitivity of the PME procedure compared to the current pavement design guide, AASHTOWare PavementME, to both mixture design and climate is demonstrated for four pavement sections. The largest difference in ETD_{sh} among the climates is 33°C based on the PME procedure, as opposed to only 2°C by PavementME. PME ETD_{sh} also shows the benefits of fly ash and low w/cm to mitigate warping, especially in dry non-freeze climates.

Session 3: Life-Cycle Cost Analysis

A Comparison of Contemporary Life Cycle Costs of Heavy Duty Road Pavements in Australia: Asphaltic Concrete vs Portland Cement Concrete

Justin Moss, Nicole Liang

Life cycle cost analyses (LCC/A) have not typically been used for pavement optioneering for nearly 30 years in Australia, nor are they generally required in detailed design. To date, asphalt pavements were assumed to have lower construction costs but acknowledged as requiring regular maintenance (every 5 to 10 years),whereas concrete is well known to require less maintenance (typically at intervals of 10 to 20 years). Concrete is therefore characterised as being lower cost only in terms of its life cycle and consequently overlooked where construction costs are the focus of pavement options evaluation. However, with significant recent changes in road construction materials and processes, preconceptions around life cycle costs of asphalt and concrete pavements around the world should be reviewed. This paper reports on the findings of a study conducted by Arcadis which compared the life cycle costs of highway low-noise high-speed pavements-plain concrete (PCP), full depth asphalt (FDA) and asphalt over heavily bound (ACH). The study compared LCC of these pavements across a range of project-specific scenarios (resource availability, site complexity and traffic constraints) in addition to the impact of adopting international discount rates. With a new generation of pavement renewal now commencing in Australia (45 years after the first), this work also examined the viability of prolonging the service life of pavements in relation to its impact on life cycle costs, closures and environmental impact. This paper ultimately concludes best value of the various pavement scenario combinations by ranking and comparing all pavements options, and makes recommendations for future life cycle assessments.

Enhancement Of Sustainable Road Design Towards Compatibility Between Pavement Materials

Larissa Strömberg, Lev Khazanovich, Staffan Hintze

The need for correctly made comparisons of different pavement materials, regarding cost-efficiency to reduce the climate impact, is increasing, especially in connection with new types of climate-neutral materials, so that sub-optimizations and oblique competition do not arise. Both the Swedish and USA's authorities are beginning to demand

the Environmental Product Declaration (EPDs) as a certificate of the pavements' environmental performances from the contractors. There are some methodological difficulties to use the EPDs for comparison of the environmental impacts between different asphalt mixes or between the asphalt- and concrete pavements. This paper has analyzed two new standards which propose to extend the declaration to several aspects of sustainability: technical, environmental and economic performance. In this article, we have investigated if these standards can be used to form a framework to create an extended sustainability declaration of road pavements allowed a multidisciplinary comparison of different materials based on technical performance, Life Cycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA).

Cost-Effectiveness Analysis For Concrete Pavement Preservation Strategy Selection And Resource Allocation

Mark Snyder, Prashant Ram, Tom Van Dam, Kurt Smith

There are usually many preservation and rehabilitation strategy options for any pavement section at any point in time. Each project-level strategy has associated costs, which are typically evaluated using life-cycle cost analyses (LCCA). Limitations to these analyses include: inability to accurately predict the actual timing and costs of future rehabilitation work; use of an appropriate discount rate; the assumption of equal benefits and service among competing alternatives; and treatment of end-of-life values (service life and salvage material). Each preservation option also impacts pavement service quality and service life, and the value of service on any pavement section depends on the volume and composition of traffic using the facility. Typical preservation strategy selection strategies do not adequately consider these factors in a quantifiable way. This paper presents and demonstrates the use of cost-effectiveness analysis in pavement preservation strategy selection to account for the different levels of service associated with different preservation strategies applied at different times. It also demonstrates concepts for using cost-effectiveness analyses in the allocation of network funds, considering both the quality of service provided and the number and type of users that use different pavement sections in the network. The analysis and strategy selection/optimization techniques presented herein are intended for use as tools to aid in decision-making, recognizing that there are likely additional factors that impact the decision processes that are not represented by these techniques.

The Benefits of Industry Competition in the Pavement Market: And How Agencies Can Use it to Lower their Pavement Cost

James Mack

In 2016, the U.S. spent an estimated $175 billion on its highways and roadways, with the vast majority of funding coming from state and local governments ($128B from states and local governments vs $47B from the Federal Government). (Urban Institute, n.d.) Despite this enormous outlay of funds, the U.S. highway infrastructure needs are at an all-time high. The road system earned a D grade from the American Society of Civil Engineers (ASCE) on their 2017 report card, which was the same grade received on the 2013 Report card. Nearly one-fourth of U.S. roadways are in a poor/deficient condition and there is about a $420 billion backlog of highway repair projects. In addition, more than two out of every five miles of America's urban interstates are congested, with traffic delays costing the country an additional $160 billion in wasted time and fuel. (ASCE, 2017)

Improvement of the system is needed and the primary approach to address this challenge to date has been to increase funding. While more funding is needed, agencies also need to find ways to be more efficient within their constrained budgets in order to get more out of their roadway and pavement investments. This paper will show how competition in the pavement bidding process and across paving industries can bring value to Transportation Agencies by lowering pavement unit costs.

Session 4: Overlays, Part 1

Quantifying the Impact of Structural Fibers on the Performance of Concrete Overlays on Asphalt

Thomas Burnham, Michael Wallace, Manik Barman

Concrete overlays on asphalt pavement, also known as whitetopping, are growing in popularity as an option for the rehabilitation of distressed asphalt pavements. The performance of whitetoppings over the past several decades has shown that under heavy and frequent traffic loads, they can be susceptible to panel migration and faulting due to the lack of tie bars and dowel bars within the thin cross sections. One mitigation method to reduce panel migration and faulting is the inclusion of structural fibers into the concrete mix. While structural fibers have anecdotally been shown to contribute toward better performance in whitetoppings, few studies have quantified the benefits provided by the typical dosage of fibers used in recent specifications. Two sets of similarly designed experimental test sections constructed at the MnROAD test facility in 2004 and 2013, have provided the opportunity to evaluate and quantify the impact of structural fibers on whitetopping performance. This comparison of the performance between plain concrete and fiber-reinforced concrete overlay test sections includes analysis of material properties of the mixes, the difference in response to environmental and traffic loads,typical distresses, and ride quality. Based on the results of the analysis, recommendations were made with regards to whether the types and dosages of structural fibers used in the test sections made a sufficient impact on performance.

Optimized Joint Spacing for Concrete Overlays with and without Structural Fiber Reinforcement

Dan King, Jerod Gross, Halil Ceylan, Yu-An Chen, Peter Taylor

In thin concrete overlays (10 to 15 cm, 4 to 6 in), field observations have sometimes shown that not all contraction joints activate initially and, in some cases, do not activate until many years after construction. Contraction joints that do not activate may be considered an inefficient design that can lead to unnecessary maintenance efforts, unnecessary costs, and negative impacts on concrete overlay performance. Optimum joint spacing design for concrete overlays may need to be determined based on factors different from those that are currently considered. This study included an analysis for recommended joint spacing using pavement design software, as well as a

field review of joint activation in existing concrete overlays using non-destructive testing. Test sections were also constructed in conjunction with new concrete overlay projects to analyze a wider range of variables and study early-age joint activation behavior. The data showed that joint spacing was the most significant factor affecting joint activation in thin concrete overlays. The addition of 2.4 kg/m^3 (4 lb/cy) structural synthetic macro-fibers did not affect the rate of initial joint activation compared to overlays without fibers. A design parameter, slab length over the radius of relative stiffness (L/ℓ), was identified to correlate with joint activation rate and timing. Designing joint spacing to achieve L/ℓ between 4 and 7 may provide the desired balance between maximum, timely joint activation and good overlay performance.

An Innovative Method to Minimize the Joint Sealant Requirement in BCOA Pavements

Venkata Joga Rao Bulusu, Kusam Sudhakar Reddy, Muppireddy Amarnatha Reddy

The small paneled bonded concrete overlay on asphalt (BCOA) pavement is considered to be a very durable and maintenance free rehabilitation technique. These pavements have lower thickness requirement of cement concrete layer. However, the number of joints is high as the panel size is small and hence there is a huge requirement of joint sealant. In this work, an attempt was made to minimize the joint sealant requirement by changing the joint sawing pattern. Test section was constructed for the study and square panels of 1 m, 1.5 m size are adopted. The joint sawing was divided into two stages. In the first stage the panels were sawn into 3 m X 3 m size and after one day they are further sawed into 1 m X 1m or 1.5 m X 1.5 m sizes. It is often observed that this pattern of joint sawing results in the formation of full depth joints at a spacing of 3 m. Even in the full depth joints at 3 m interval, every third joint has a crack width of nearly 0.6 mm and other two joints have a crack width less than 0.3 mm. So, if these full depth joints only are sealed then the cost of sealant will be less and purpose of sealant will be fully served. This will save the sealant cost by 85% for 1 m panels and by 70% for 1.5 m panels. The crack width measurements and the frequency of full depth cracks are discussed.

Session 5: Built and Novel Environment

Cool Pavements for Sustainable Urban Development

Sushobhan Sen, Jeffery Roesler, Benjamin Ruddell, Ariane Middel

Around the world, urban development and densification leads to the Urban Heat Islands (UHI) effect, in which cities are warmer than adjoining rural areas. Cool pavements have been recommended as a mitigating strategy for the UHI effect. However, the spatial extent over which cool pavements need to be applied to achieve widespread mitigation has received little attention. A previously developed urban microclimatic model for the Power Ranch community in suburban Phoenix, Arizona, was used to investigate this question. The microclimatic model is used to investigate the effects of urban densification for the meteorological conditions at 5:00 PM on August 13, 2015. In the modeled scenario, the heights of the buildings were increased from 5 m to 10 m,a large, central park was redeveloped as a parking lot,and a reflective pavement was implemented in the parking lot.Both localized and downwind air temperature effects at 2m of this further densification were quantified in the modelling effort. For the lower building height, using typical concrete to redevelop the parkas a parking lot increased the 2m air temperature directly over and downstream by about 0.20°C. When a reflective concrete parking lot was used instead,the 2m air temperature decreased by 0.20°C over and downstream. At 10m building heights, the reflective parking lot decreased the 2m air temperature by 0.20°C, however, its effect was more localized with less benefit for downstream areas. Thus, urban form with taller buildings affects the airflow, which requires a more distributed application of reflective surfaces to mitigate UHI.

Impacts Of Flooding On Concrete Pavement

Remi Oyediji, Susan Tighe

With shifting paradigms in usual climatic events and increased occurrence of flood hazards, vulnerability assessment and adaptation of road infrastructure is essential. Road pavements are critical in sustaining socio-economic activities and their vulnerability to flood hazards could have serious cost consequences. Therefore, a conscientious decision to consider pavement materials, designs and alternatives that are resilient to recurring flood events is desired. Based on previous investigations into how pavements types, classes and configuration respond to extreme events, concrete pavements are reported as better flood-resilient systems in countries that have experienced intense

flooding and inundation. Although Canada has experienced some of the worst flood incidences in history and owns a number of concrete pavement infrastructure, no study has been conducted to better understand its performance under extreme conditions. To provide insight on concrete pavement flood response, the use of the state of the art AASHTOWare Pavement ME Design (PMED) program is employed to model various flood scenarios on concrete pavement types and configurations common to two Canadian provinces, Ontario and Manitoba. The performance of the various pavement classes in terms of flood resilience, service life and cost feasibility is analyzed and results provide insight on the resilience and adaptive capacity of rigid pavements to flood hazards in Canada.

Investigation Of TiO_2 Photocatalytic Properties Of Concrete Samples With Dielectric Constant Applications

Alireza Joshaghani, Dan Zollinger

There is a going interest to reduce emission and improve air quality of the environment through the use of titanium dioxide (TiO_2) topical treatments. TiO_2 is regarded as one of the most efficient and environment-friendly ultraviolet light-sensitive materials for the photocatalytic degradation of various pollutants. The effort to reduce nitrogen dioxides in the ambient air is proposed to be implemented on the surfaces of streets and sidewalks. Two methods are used to quantify photocatalytic performance: direct and the indirect. The direct method measures the difference of NO concentrations before and after surface treatment, but this method may be highly inaccurate due to the influence of various parameters, time, and costs. The indirect method, on the other hand, quantifies the photocatalysis performance by using the measured surface dielectric to estimate the amount of oxidized NOx byproducts that have accumulated on the surface. This approach is entirely non-destructive and constitutes a new protocol to assess the field-effectiveness of photocatalytic topical treatments based on reproducible and logical monitoring procedures. Finally, mass balance computation was used to validate the effectiveness of this protocol and check the accuracy of the proposed method.

Use Of Alternative Aggregates In Pavement Concrete: Research And Practice In Belgium

Elia Boonen, Sylvie Smets, Audrey Van der Wielen

Alternative aggregates, including recycled (concrete) aggregates as well as artificial

aggregates (such as crushed stainless steel slag), are being increasingly used in road construction in the context of a more circular economy, e.g. in base and subbase layers. As these materials are applied higher up in the structure (surface and binder courses), stricter requirements are made to allow for higher loads and the stronger influence of the environment, and the application of these aggregates becomes less straightforward. The Belgian standard specifications, for instance, allow incorporation of recycled concrete aggregates in concrete pavements or linear elements in concrete, but only if certain stringent requirements are met and only up to certain percentages of substitution of the natural coarse aggregates. Furthermore, artificial aggregates originating from stainless steel slag are not even allowed for the time being in pavement quality concrete, although a Belgian standardization working group has recently been installed to investigate this matter in more detail. This paper presents an overview of laboratory research conducted in Belgium to characterize several types of alternative aggregates and concrete mixtures incorporating them, while focusing on practical execution as well as on the durability of pavement concrete. In addition, several concomitant pilot applications in Belgium are discussed in view of future perspectives for the application of alternative (recycled and/or artificial) aggregates in road construction.

Session 6: Geotechnical Aspects

Numerical Simulation on the Life-Cycle Assessment of Concrete Pavement - Diverse Soil's Density Coupled to Moving and Fixed-Point Pulsating Loads

Nguyen Huu Quoc Hung, Koichi Maekawa

The compaction of the soil foundation and effects of the load levels is known as one of the key factors to the life-cycle evaluation of concrete pavement. This paper presents the three-dimensional modeling under a range of the soil's density and the load magnitudes in both cases of the moving and fixed-point pulsating loads. The high-cycle fatigue constitutive laws are incorporated in the coupled code of the soil and concrete slab interaction. It is found that the soil's density has a great influence on fatigue life due to nonlinear behaviors. The results are emphasized on the significant decrease of fatigue life under the moving loads compared to the fixed-point pulsating ones. This reduction in life is discussed in the views of the computed S-N diagrams to show the distributed damage of concrete slabs and soil over a large number of moving-wheel passages, opposite to the localized deterioration of the fixed-point pulsating loads. This paper also addresses the specific fatigue failures of concrete pavement, which happen to either soil or concrete slabs as well as both depending on the load levels and the soil's compactness. The impacts of the relative density of soil from the loose to the dense foundations and the distinctive load levels applied on the top surface of concrete slabs are investigated as the sensitivity factors of modeling, respectively.

Causes Of Distress In Cement Concrete Pavement On Black Cotton Soil And Remedy

R K Jain, P.L Bongirwar, U. V. Kulkarni, G. V. M. Kiran Babu, and Raman Kumar

Black Cotton (BC) soil is present in large parts of India. This soil absorbs lot of water while getting wet and swells even more than 50% which is called Free Swelling Index (FSI). If swelling is prevented, it exerts lot of pressure on the pavement and causes all types of cracks. The CBR of this soil is between 2% to 3.5%. Indian design guidelines provide for Cement Concrete Pavement (CCP), a minimum of 8% CBR for subgrade. While constructing CCP on BC soils special precautions are needed, otherwise distresses will develop. If the new pavement is to be constructed, the remedy lies in removal of the BC soil up to a depth of about 2m from Natural Ground Level (NGL), and treating the underlying soil in construction prism with lime and cement

ensuring 12% CBR and 98% compaction. In this case study a 10m wide CCP was built on existing 7m wide flexible pavement by removing the bituminous layer overlaid with Granular Sub-base and Roller Compacted Concrete. Fresh shoulders 1.5m wide on each side were added. The road failed prematurely. Study involved investigation of reasons for the failure of CCP on a highway. The distress is found to be in the form of wide and long longitudinal cracks with faulting at a few places, as well as transverse cracks, multiple cracks and corner breaks in some panels. In-situ stabilisation of Black Cotton Soil is suggested as an effective remedy to mitigate the problem to a large extent.

Analysis and Evaluation of the Development of Various k-Values for Use in Design

Robert Rodden, Eric Ferrebee

Inconsistency exists between common conversions from soil index properties (e.g., CBR) to a design k-value and a widespread nomograph that has become the definitive industry reference on the topic in the United States. Propagation of these inconsistencies into guidance from groups like the American Concrete Pavement Association (ACPA) and American Concrete Institute (ACI) Committees 330 and 360 has contributed to confusion in the industry. Advancements between the pavement and slab-on-ground communities have occurred in parallel but are inconsistent with each other, thus adding more confusion. ACPA developed a conversion set to better align the industry on a static k-value for design. While the ACPA model is included in StreetPave, PavementDesigner.org, and the ACPA App Library, outdated conversion equations are frequently used due to familiarity and lack of understanding of the underlying principles. This paper presents a summary of the industry's prior practices and recommendations, a detailing of the approach proposed by ACPA, and guidance on which k-value is recommended for design of concrete pavements and slabs-on-ground.

Ready-Mixed Foamed Cellular Concrete as Engineered Backfill Material

Roberto Montemayor, Jeffery Roesler, David Lange

Backfill materials can be excavated soils, granular materials, or cementitious flowable materials. Depending on the application, backfill materials require specific properties such as workability for placement, resistant to settlement, minimum strength, and durability. Backfill materials must distribute loads to reduce vertical and lateral

pressures on adjacent or underlying infrastructure components as well as existing materials. Historically, backfill materials are susceptible to poor quality control, high material heterogeneity and segregation, erosion, and sometimes excessive strength. Foamed cellular concrete (FCC) offers an alternative engineered material that can achieve a specified density and compressive strength while still providing superior placement efficiency and durability relative to traditional backfill materials. The density of FCC ranges from 300 to 1800 kg/m^3 and is achieved by the incorporating a high volume but stable air system inside the cementitious paste. Likewise, the compressive strength of FCC can be tailored from 10 to 130 kg/cm^2. FCC can be batched using traditional ready-mix equipment and only requires cement, water, and a foaming agent. Admixtures are beneficial to improve workability and paste stability properties while maintaining a reasonable cost. Other benefits of FCC for backfill applications are self-compacting and self-leveling, lightweight for reducing overburden, pumpability, erosion resistant, and thermal insulating, which makes it attractive for utility and drainage trenches, void filling, support layer for pavement patching, and for filling abandoned conduits.

Session 7: Overlays, Part 2

Thin Concrete Overlays with Carbon Reinforcement

Julia Neumann, Kristina Farwig, Rolf Breitenbücher, Manfred Curbach

In many countries like Germany, concrete pavements are normally built as Jointed Plain Concrete Pavements (JPCP). Due to a lack of alternatives, maintenance of concrete pavements usually requires a replacement of the whole pavement structure, which is labour- and resource-intensive. Therefore, new techniques like the application of thin concrete overlays as a partial repair of deteriorated concrete pavements have been developed. As a major disadvantage of such overlays, the existing joints in the retained concrete bottom-layer have to be transferred in the overlay in order to avoid reflection cracking. When using non-corrosive carbon-textile reinforcement in such concrete overlays, cracks might be distributed more finely, enabling jointless repairs while keeping a thin repair layer. In addition, the bond behaviour between the retained concrete and the applied concrete overlay as well as between the concrete overlay and the textile reinforcement is crucial for a successful repair. In this paper, the basic principles and feasibility of such a repair method are examined. On the one hand, the decisive influencing variables and parameters such as bond behaviour between the concrete layers and the cracking behaviour of the overlay are pointed out and discussed. On the other hand, the evaluated laboratory tests carried out are presented. These include large-scale beams built with an overlay on top of a retained concrete layer, which were subjected to cyclic flexural stress and to a subsequent detailed investigation of the bond behaviour and durability. Furthermore, the crack formation in the overlay was determined by means of tensile and flexural tensile strength tests

10+ Years of Experience in Concrete Slabs with Optimized Geometry

Juan Pablo Covarrubias V., Pelayo Del Rio B., Carlos Binder E.

In 2005, a new concept in concrete pavements was developed, Concrete Slabs with Optimized Geometry. This technology is based on designing the concrete slabs so that no more than one wheel or set of wheels will be loading the same slab at any time. This causes the slabs to work in a different way than usual, decreasing stresses and allowing a reduction in thickness, when compared to a traditional concrete pavement design. All without reducing its lifespan and increasing its fatigue resistance.

Since 2005 there have been important developments of this technology. With more than 129 million square feet (12 million square meters) in application, 200 projects across 10 countries, the technology has been used in many different climates and loading conditions. All this information has helped to calibrate and understand the behavior of this new system. This paper shows the most important things we have learned in the last 10+ years, also explanation of the development and protection for the technology.

Effects of Interlayer Properties on the Performance of Unbonded Concrete Overlays

Julie Vandenbossche, John DeSantis

Unbonded concrete overlays (UBOL) consist of a new Portland cement concrete (PCC) layer placed on an existing PCC pavement. The new concrete layer is separated from the existing pavement by an interlayer system, allowing these overlays to be placed on distressed PCC pavements. The interlayer system usually consists of a thin open graded or dense graded hot mix asphalt (HMA) layer or a non-woven geotextile fabric. In an effort to develop a mechanistic-empirical design procedure for UBOLs, the effects of the interlayer properties on the performance of the overlay must first be established. There are many variables to consider when selecting an interlayer for UBOLs such as, drainability, frictional restraint, prevention of reflective cracking, and stability of a mixture to prevent erosion or consolidation/ rutting. Performance data from in-service pavements at the Minnesota Road Research Facility (MnROAD), Michigan, Missouri, and Pennsylvania, as well as data in the Long-Term Pavement Performance (LTPP) database is examined to establish the influence of interlayer characteristics on overlay performance. . Many of the distresses are at least partially caused by breakdown of the interlayer. Longitudinal cracking develops in the wheelpath due to erosion or consolidation of an asphalt interlayer, while transverse cracking can occur due to reflective cracking, reflective distress, or erosion along the transverse joint. The characteristics of the interlayer also play a role in the rate of the development of faulting. Based on this evaluation, factors that should be considered for optimizing the performance of the interlayer are defined.

Adaptation and Calibration of the Faulting Model for Thin Concrete Pavements

Carlos Binder, Juan Pablo Covarrubias Vidal

Joint faulting is a pavement distress that affects the comfort level of jointed plain concrete pavements. The appearance of joint faulting usually occurs in areas of high traffic of trucks at high speed. Variables such as level of rainfall and the erodibility of the subbase increases the magnitude of this phenomenon. To predict joint faulting in Thin Concrete Pavements, the design software OptiPave2 ®, launched in 2012, used the same model developed for the Mechanistic Empirical Pavement Design Guide (MEPDG), which uses an energy differential model. After 6 years of the release of the software and after 10 years since the construction of some thin concrete pavement projects, there are pavements with clear signs of joint faulting and others without. For this reason, the OptiPave2 model was reviewed and compared with field data, concluding that the faulting model needed to be adjusted This new model was calibrated with the data from existing concrete pavement projects.

Session 8: Long Life Pavements

New Long-Life Concrete Pavements in the Czech Republic

Bohuslav Slánský, Vit Šmilauer, Jiří Hlavatý, Richard Dvořák

A jointed plain concrete pavement represents a reliable, historically proven technical solution for highly loaded roads, highways, airports and other industrial surfaces. Excellent resistance to permanent deformations (rutting) and also durability and maintenance costs play key roles in assessing the economic benefits, rehabilitation plans, traffic closures, consumption and recycling of materials. In the history of concrete pavement construction, slow-to-normal hardening Portland cement was used in Czechoslovakia during the 1970s-1980s. The pavements are being replaced after 40-50 years of service, mostly due to vertical slab displacements due to missing dowel bars. However, pavements built after 1996 used rapid hardening cements, resulting in long-term surface cracking and decreased durability. In order to build durable concrete pavements, slower hardening slag-blended binders were designed and tested in the restrained ring shrinkage test and in isothermal calorimetry. Corresponding concretes were tested mainly for the compressive/tensile strength evolution and deicing salt-frost scaling to meet current specifications. The pilot project was executed on a 14 km highway, where a unique temperature-strain monitoring system was installed to provide long-term data from the concrete pavement. A thermo-mechanical coupled model served for data validation, showing a beneficial role of slower hydration kinetics. Continuous monitoring interim results at 24 months have revealed small curling induced by drying and the overall small differential shrinkage of the slab.

Long-Life Pavement for Users of an International Roadway in New Mexico

Sam Tyson, Shiraz Tayabji

A 36-lane-mile (60 lane-km) international roadway was rehabilitated in the United States of America (USA) during 2018 by the New Mexico Department of Transportation (NMDOT) to provide uninterrupted long-life pavement performance for commercial users of the roadway. The southern border of the USA with the country of Mexico marks the starting point of New Mexico State Road 136 (NM 136), a four-lane divided roadway that carries heavily-loaded trucks associated with the United States–Mexico–Canada Agreement (USMCA), formerly the North American Free Trade Agreement (NAFTA). Truck traffic in the dual north- and south- bound lanes of this roadway is especially

high on the 9-mile (15-km) section of NM 136 between the international border and an intermodal railway facility located in the USA state of New Mexico. Prior to this rehabilitation project, the structural cross-section of NM 136 consisted of 4.5 to 6.0 inches (110 to 150 mm) of asphalt on 5.0 to 6.0 inches (130 to 150 mm) of coarse-grained soils. Prior to this project on NM 136, NMDOT had very little experience with concrete pavements and none with continuously reinforced concrete pavements (CRCPs). The structural design for this rehabilitation project utilized the existing asphalt pavement as a satisfactory base for the CRCP by milling 1.5 inches (40 mm) of the existing asphalt concrete (AC) pavement and applying a 1.5-inch (40-mm) AC levelling course followed by the CRCP. This paper presents the design and construction related details of the NM 136 CRCP project.

Successful ASR prevention in Germany: Influencing Factors and Adequate Measures

Robin Przondziono, Rolf Breitenbücher

Alkali-Silica Reaction (ASR) in concrete pavements has become a real problem in Germany in the end of the 1990s / beginning of the 2000s. In an extensive research project, the background for such ASR-damaging has been examined intensively at the Ruhr University Bochum. ASR in concrete pavements is not only influenced by the reactivity of the aggregate, but rather by a superposition of different influencing factors. For concrete pavements for example, there are specific conditions that increase an ASR significantly. On the one hand, concrete pavements are microstructurally damaged by the superposition of cyclic stresses induced by traffic and climate changes, and on the other hand they are exposed to alkaline de-icing agents during the wintertime. Thereby, an ASR-promoting external alkali supply is given. Three absolute preconditions are necessary for an ASR to occur: potentially reactive aggregates, sufficient supply of alkalis and an adequate degree of moisture. In Germany, there have been numerous measures taken in the last 10 to 15 years in order to prevent ASR-damages in concrete pavements. Already in 2005 the alkali-content (Na2O-Equivalent) allowed in cements for concrete pavements has been limited to 0.8% by mass. Additionally, in each case the aggregates intended to be used must be assessed beforehand in a special procedure. Since these requirements were established by the highway-authorities in 2005 (with modifications in 2013) there have been no new damages related to ASR observed on concrete pavements, which have been constructed in compliance with these guidelines.

Long-Term Performance of Jointed Plain Concrete Pavement with Rapid Strength Concrete On California Highways

Michael Darter

Rapid Strength Concrete (RSC) slabs on six California jointed plain concrete pavement (JPCP) highway projects were surveyed. These projects had been previously surveyed in 2008 at 3-years of age and by 2018 had reached a service life of 13-years. Of the initial 5430 slabs examined in 2008, a total of 1493 RSC slabs, located on 12 traffic lanes, were observed and distress types recorded again in 2018. These slabs included both CTS and 4x4 RSC located in both inner and outer lanes. Only a small percentage (1.4%) of the 5,430 RSC slabs exhibited any distress in 2008 after 3-years' service and the increases were small over the next 10 years of service with the exception of transverse fatigue cracks. The transverse (top down fatigue) type of cracking had the highest percentage and largest increase of any distress type. The heavy truck outside lanes exhibited 21% transversely cracked RSC slabs and the inner passing lanes 3%. The outer truck lanes carried over 3 times more trucks than inner lanes. The RSC slabs were mostly 200-223 mm thick and thus susceptible to fatigue damage. The overall performance of the RSC slabs (both CTS and 4x4 RSC materials) were similar and considered to be outstanding over 13 years with a large majority expected to survive many more years.

Session 9: Case Studies

Concrete Pavement Preservation: Lessons Learned from 11 Case Studies

Prashant Ram, Jeff Stempihar, Tom Van Dam, Mark Snyder, Kurt Smith, Tom Yu

An ongoing FHWA project is redefining concrete pavement preservation as "preserving the existing concrete pavement structure to extend its service life for as long as possible, by arresting, greatly diminishing, or avoiding the pavement deterioration process." This can be achieved through three fundamental approaches: (a) designing and constructing pavements that remain structurally adequate and relatively distress-free throughout their service lives (i.e., using long-life concrete pavement), (b) using asphalt or concrete overlays as preservation treatments to maintain the functional performance of the pavement, and (c) maintaining the serviceability of the pavement using concrete pavement restoration (CPR) treatments. One of the tasks under the project was to document 11 concrete pavement projects around the U.S. that have successfully demonstrated the application of the three fundamental preservation approaches mentioned above. This includes information on the following: (a) original pavement design, materials, and construction, (b) traffic and service conditions, (c) maintenance and rehabilitation history, (d) present day condition [based on site visits in 2018], and (e) economic analysis. This paper highlights key information for 11 different case study projects and presents a summary of lessons learned from each project. The information gleaned from these success stories are being used in the development of guidelines for long-term concrete pavement preservation strategies.

Effect of Longwall Mining on Pennsylvania I-70

Emily Adelsohn, Anthony Iannacchione, Julie Vandenbossche, Robert Winn, Mingzhou Li,Luis Vallejo, Roy Painter, Joe Szczur, Eric Wanson, Steve Marsinko

A longwall mine was constructed beneath I-70 near the Pennsylvania-West Virginia border between December 2018 and March 2019. This resulted in over a 4-ft drop in the elevation of parts of the roadway. The Pennsylvania Department of Transportation was able to maintain the roadway open to traffic throughout the subsidence period after it was undermined. This paper will describe the steps taken by PennDOT to ensure the roadway could stay in service throughout the subsidence event with minimal traffic disruptions, the subsidence basin that developed as a result of mining, and the distresses that developed within the pavement structures as a result of the subsidence.

Two-Lift Concrete Pavements Constructed Under SHRP2 Project R21 Implementation Effort

Kurt Smith, Prashant Ram, Mark Snyder

Two-lift concrete pavements use two separate lifts of concrete that are placed in a wet-on-wet process to produce a monolithic structure. Although not new, two-lift concrete pavements are an innovative approach to optimizing the characteristics of each layer and, hence, the overall pavement structure. In 2014, the Federal Highway Administration (FHWA), working in collaboration with the American Association of State Highway and Transportation Officials (AASHTO), selected two-lift composite pavements for funding under the SHRP2 Implementation Assistance Program (IAP). Under that initiative, the design and construction of three composite pavement projects featuring two-lift concrete paving were sponsored. This paper summarizes some of the key design and construction details for each of these three projects, and also provides recommendations on the general applicability and selection of two-lift concrete pavements.

Widening Jointed Reinforced Concrete Pavements On The Easing Sydney's Congestion Program

Carlos Solis-Navarro, Anna-Carin Brink

The aim of this paper is to demonstrate how existing jointed reinforced concrete pavements (JRCPs) are incorporated in the design of new and/or widened lanes as part of the Easing Sydney's Congestion (ESC) Program. The ESC Program is one of the Transport for New South Wales' initiatives to meet the increasing demand for infrastructure in the state. At the inception of the Program in 2016, major capital expenditure was set over AU$2.1 billion over five years to 2021. NSW is the State in Australia with the largest number of concrete pavements in the urban road network; mostly JRCPs many of which are now more than 40 years old and surfaced with nominal 50 mm asphalt. As part of the more than 50 projects delivered, the existing concrete pavements required widening to allow for additional lanes and extension of turning lanes. Whilst the pavement designs had to meet minimum engineering standards with a design life of 40 years, they also needed to cater for rapid construction to mitigate disruption to road users in limited construction space. This paper will describe the approach used to gain information on the existing pavements, the different pavement structures constructed, the detailing of the widenings, the specification of various concrete mixes including high-early strength materials and lessons learnt from the construction phase.

Session 10: CRCP Case Studies

Field Investigation for Rehabilitation of Severely Deteriorated CRCP on Ban-etsu Expressway in Japan

Kai Koike, Tsutomu Sato, Shigeki Takahashi, Shinya Ohwaki, Sadao Sato, Tatsuo Nishizawa

A 7 km section of CRCP was constructed on the Ban-Etsu Expressway, which was opened in October 1990, in heavy snowy region of the Japan main island. Transverse cracks had opened wide and the crack spacing had become shorter just after 9 year service, resulting in punchout on the surface. The deteriorated part of the CRCP section had been repaired with the partial depth patching using SFRC and double layer asphalt overlay. However , the similar severe deterioration has appeared on the other parts of the section recently. Therefore, in 2018, comprehensive investigations including material tests, excavation of the slabs and joints, FWD tests and ground penetrator radar (GPR) survey were conducted to establish the rehabilitation strategy for the CRCP section. In the investigations, horizontal cracks were found at a depth of the reinforcement bar, which started from the transverse crack. Also, some extracted bars were severely corroded. The material tests revealed high chloride ion concentration in the upper part of the concrete slab. Based on those investigation results, it was assumed that the expansion of the corroded reinforcement bars initiated and developed the horizontal cracks at the position of reinforcement bars, which divided the CRC slab into two layers, resulting in severe punchout.

A Comparative Study Of Crack Behavior Of Continuously Reinforced Concrete Pavements (CRCP) On Three Sections In Germany

Milad Moharekpour, Stefan Hoeller, Markus Oeser

The traffic volume and the amount of heavy traffic on German motorways increased steadily. To guarantee mobility and reduce the national economic costs, road construction with maximum service life, minimum maintenance and minimum traffic restrictions for maintenance are needed. Continuously reinforced concrete pavement (CRCP) are extremely durable in terms of use and maintenance. CRCP offer lower thickness, no transversal joints and the possibility to improve skid resistance and reduction of noise emissions through a thin asphalt surface. The performance of CRCP is influenced by a number of specific characteristics such as the thickness and the quality of the concrete,

the longitudinal and transversal reinforcement, the base layer and the environmental conditions. These aspects influence the crack pattern, crack distance and crack widths. In Germany CRCP is in the stage of field testing. From 1997 to today, a total of 8 sections with many variations have been constructed. A detailed comparative study of these sections has been lacking. As part of a research project, the RWTH University and the German Federal Highway Research Institute (BASt) are investigating these sections in CRCP with and without an asphalt surface in Germany and compare it to the Belgium standard constructions. Three CRCP sections were selected and evaluated throughout Germany. The aim is to evaluate the different designs in the sections in terms of their behavior, to quantify achievable service life, necessary maintenance and availability. From this, a preferred variant of the construction is designed and implemented on a motorway in Germany as part of a trial site.

Distresses In CRCP Due To Horizontal Cracking: A Parameter Analysis

Luc Rens, Anne Beeldens

Continuously reinforced concrete pavements are known for their durability and longevity as well as for the driving comfort, thanks to the absence of transverse joints. The strength and weakness of CRCP is situated in the network of fine transverse shrinkage cracks whose spacing distance and opening width are determining the pavement behaviour. The most commonly known distress is the punch-out: a fragmentation of the concrete over full depth. During the last decade, a new type of distress was encountered at Belgian worksites. It is characterised by a delamination at the level of the longitudinal reinforcement, a partial fragmentation of the pavement, mostly positioned under the wheel tracks. The first case was the worksite "N49 at Zwijndrecht", where severe distresses were observed after three years of service. An examination with the technique of ultrasonic tomography detected the presence of horizontal cracks at the level of the reinforcement. The use of recycled concrete aggregates was supposed to be the cause. A significant indicator was also the presence of widely opened cracks. In the period 2011-2018 other cases were observed in Belgium, some of them leading to early degradation and others not. Also in other countries (South-Korea, U.S., Japan,...) distresses due to horizontal cracking were reported. Based upon observations an analysis is made of the main parameters that may cause the wide initial cracks: the use of recycled aggregates, temperature and temperature changes during construction and concrete quality. Preventative measures such as active crack control will be presented.

Laboratory And Field Tests On A Prefabricated Steel-Bar Mesh-Panel System For Continuously-Reinforced-Concrete Pavement (CRCP)

Norinobu Katayama, Kazuhiko Fujisaki, Takehisa Ueno, Ryutaro Onishi, Isamu Yoshitake

The decline in the number of persons of working age is a social problem in Japan. This is a particularly serious concern for workers in the construction field; construction systems should be considered for productivity improvements. Prefabrication systems are an effective method for shortening construction cycles and times. In fact, various precast concrete members have been employed to realize more rapid construction and improvements in quality. Using precast concrete members is difficult because jointless roads are preferable for highway pavement. Continuously reinforced concrete pavement (CRCP), which has the advantages of concrete jointless construction and high ductility, is a suitable method for highway road construction. Typical Japanese highways built with CRCP reduce the amount of horizontal cracking by arranging transverse rebars at an angle of 60° to the main rebars. Note that rebar placement and bonding in conventional CRCP are troublesome and labor intensive owing to the long construction time required. We have developed prefabricated steel bar meshes for CRCP and can report some benefits relating to their practical application. To examine the fundamental properties of mesh panels, we conducted a laboratory experiment and a simulated field test. The primary concern of welded rebars are failures induced by cyclic loading. A flexural fatigue loading test using CRCP models was conducted. In addition, a comparative survey on conventional and prefabrication systems was performed in the simulated field test to quantify the constructability of CRCP and to observe the extent of cracking in concrete. This paper reports on our experimental investigation.

Session 11: Freeze-Thaw Durability

The Damage Of A Concrete Pavement In An Alpine Cold Region

Samuel Antonietti, Christian Paglia

Concrete pavements still represent a wide range of existing infrastructure. In particular, for external parking lots. The concrete pavement in the present study was placed directly on a natural ground without steel rebar or nets, without separation layer against water upward movement and with no superficial abrasion coating. The structure was exposed to an alpine clima. The microstructure and several properties of the pavement were characterized, such as density, compression strength, porosity, and water permeability. After six years, the first damage appeared and the surface layer was restored by applying a 10 mm thick mortar. Cracks were formed due to the plastic shrinkage and hygrometric inadequate post-treatment, as well as differential ground subsidence. This latter was promoted by the too high presence of fine aggregate components, which induced a compaction problem. In addition, disgregation in an advanced stage was observed. Especially along the contraction junctions, because of a too early fresh mortar cutting. Freeze/thaw cycles in the presence of deicing salts, as well as vehicles loads, also increased the deterioration. Mortar detachment from the underground concrete was due to the insufficient surface preparation, lack of adhesion and no mechanical treatment, shrinkage tension, low direct tension of the mortar and general concrete low quality. Mortar spalling was also caused by the freeze/thaw cycles in the presence of deicing salts, in particular along junctions, that were cut only on a superficial level within the mortar layer and not in depth.

Limits For The Freeze-Thaw Resistance Of Road Concrete In The Presence Of De-Icing Salts: Results Of The GELAVIA Project

Sylvie Smets, Elia Boonen

The durability of a concrete road strongly depends on the resistance of the concrete to freezing and thawing cycles in the presence of de-icing salts. The test procedure used until now in Belgium to evaluate the resistance of concrete to de-icing salts is based on the international draft standard ISO/DIS 4846-2. Experience with this test method dates back a long time, and limits to scaling as a function of traffic loads are well established. However, since the publication of CEN/TS 12390-9 the so-called "Slab Test" is becoming the reference method in various standard specifications. In the recently completed Belgian pre-normative research project GELAVIA, the aim was to

define relevant performance classes for freeze-thaw resistance with de-icing salts as measured by this Slab Test, including scaling limits for representative road concrete compositions. Additionally, in some specific cases such as manual placement, colored and pattern-imprinted concrete pavements, hydrophobic impregnation is applied in Belgium to increase resistance to scaling. The products used for this treatment are specified according to the guidelines of NBN EN 1504-2, but the reference concretes used for testing differ substantially from typical road concrete compositions in Belgium. Furthermore, there is some question about the durability in time of the protective action of the impregnation. Hence, a second objective of the aforementioned research was to investigate and develop testing methods to evaluate the effectiveness and durability of hydrophobic impregnation products applied on representative pavement concretes. In this contribution, we will present and discuss the results and outcomes of the GELAVIA-project.

Evaluation of Internal Curing and Hydrophobic Surface Treatment on the Durability of Concrete

Yuguo Zhong, Will Hansen

The effectiveness of using pre-wetted lightweight aggregate (LWA) for internal curing was investigated based on a laboratory testing program with a primary objective to reduce or mitigate curing related shrinkage (i.e. autogenous), as this could pave the way for using LWA in concrete for repair projects such as bonded overlays or new construction (e.g. JPCP projects). A concern with the use of LWA is the high absorption coefficient and potential negative impact on freeze-thaw resistance. A laboratory study was developed to evaluate compressive strength and key durability properties, such as rapid chloride permeability, RCP, sorptivity, and freeze-thaw (F-T) resistance (i.e. combined resistance to internal cracking and surface scaling in the presence of a 3% salt solution on the surface during repeated F-T cycles). Concrete mix variables were LWA content (25% and 40%). A total of three air-entrained batches were produced. Total cementitious content was 390 kg/m^3 (658 lb/yd^3) with 30% slag cement. The major findings are: Autogenous shrinkage can be mitigated by using pre-wetted fine LWA at a 25% to 40% volume content of total fine aggregate. Excellent F-T resistance with respect to internal cracking and surface salt scaling was found for LWA contents of 25% or 40%. A silane surface treatment was found partially effective as surface scaling accelerates once a fully saturated pore condition occurs. This suggests that the hydrophobic treatment prevents pressure relief by air-voids and "surface-breathing".

Freeze-Thaw Durability Of Clogging Resistant Permeable Concrete

Alalea Kia, Hong Wong, Chris Cheeseman

Permeable concrete pavements are one of the most promising flood mitigation strategies. However, they have a number of limitations including low strength, low resistance to clogging and freeze/thaw degradation, limiting their application particularly in cold climates. Through extensive laboratory work, a novel high-strength clogging resistant permeable pavement (CRP) has been developed to address these shortcomings. In this paper, we investigated the freeze-thaw durability performance of a range of conventional permeable concrete and novel CRP. Samples were exposed to repeated freeze-thaw cycles (-20 to +20oC) and their mass, ultrasonic pulse velocity (UPV) and compressive strength were evaluated over time. The results show that CRP is highly resistant to freeze-thaw cycles while conventional permeable concrete degrades rapidly. This study demonstrates that CRP is durable under frost action and therefore has the potential to be deployed in harsh wintry conditions.

Air Void System Requirements for Durable Paving Concrete–Another Look

Seyedhamed Sadati, Xin Wang, Peter Taylor, John Kevern, Kejin Wang

The resistance of concrete to freeze-thaw (F-T) greatly depends on the characteristics of the concrete air-void system, such as the air content, size, and distribution. These air-void characteristics are influenced by every step of concrete production, from material selection and mixture proportioning to mixing, and placing. The research presented in this paper summarizes the observations from a comprehensive study that combined the in-situ performance of highway concrete with laboratory investigations. The field investigation involved determining the minimum requirements of air-void systems (AVS) for long-term durability against F-T cycles. In collaboration with several state agencies across the United States and Canada, core specimens were obtained for studying the properties of AVS resulting in different F-T conditions. Hardened air content, spacing factor, and specific surface of air-voids were determined for the extracted cores. The observations were supplemented by data obtained from a wide range of modern paving concrete mixtures. AVS characteristics were investigated using a variety of different techniques in fresh and hardened states. The main outcome of this research is a series of recommendations for minimum fresh and hardened AVS requirements to secure F-T durability.

Session 12: Policy

Future Directions and Implementation Strategies for Concrete Pavement Design and Construction

Mark Snyder, Tom Van Dam, Prashant Ram, Kurt Smith, Tom Yu

The U.S. Federal Highway Administration (FHWA) hosted a "Concrete Pavement Strategic Planning Meeting" in August 2019 for the purposes of 1) identifying future needs and directions in concrete pavement design, and 2) the development of strategies to increase the implementation of long-life concrete pavement (LLCP) design and construction. The meeting was attended by an Expert Task Group (ETG) of knowledgeable concrete pavement experts and practitioners representing highway agencies, academia, industry partners and the Federal Highway Administration (FHWA). Many of the strengths and limitations of current concrete pavement design procedures were identified and discussed. It was recognized that AASHTOWare PavementME Design and other similarly sophisticated procedures represent a significant technological leap over empirical design procedures with which they compete (and often replace). However, there are concerns about performance model limitations, the cost-effectiveness of local calibration efforts, the emphasis on surface thickness design (often assuming, rather than designing, support conditions), and other issues. The potential service and economic benefits of LLCP were also discussed. The impetus for implementation (and benefits documented) by some agencies were described, as were the impediments to implementation for other agencies. Strategies were developed to help overcome the impediments identified and to facilitate broader use of LLCP. This paper summarizes key points raised on each of these issues and includes recommendations for future directions in concrete pavement design and increased implementation of LLCP.

Passive Sensing of Electrically Conductive Concrete for Lateral Vehicle Positioning

Sachindra Dahal, Jeffery Roesler

Autonomous vehicles (AV) offer multiple safety benefits for drivers and road agencies. Current AV technology allow for vehicle control, guidance, and navigation as well as communication with other vehicles and roadside infrastructure. To see significant penetration of Level 4 or 5 AV without compromising safety, redundant vehicle to infrastructure sensing capabilities are necessary especially during severe weather conditions. Existing vehicle technology is not able to communicate with the concrete and

asphalt pavements without embedded sensors. An eddy current technique is proposed that detects local changes in the concrete's electrical conductance so that AV can determine their lateral lane position. Concrete slab specimens with varying dimensions and dosages of steel-fiber reinforced concrete (SFRC) were tested under normal and adverse surface conditions (standing water or ice) as well as separation distance from the transmitter coil. The longitudinal segment of SFRC's material was successfully located as the coil moved laterally across the surface even under these adverse surface conditions. This pilot study demonstrates a reliable and robust technique using changes in the concrete's electrical conductance to provide lateral positioning redundancy to AV control and guidance.

Industry Training for Concrete Paving Crews in Australia The "Grey Card" Course 2006 to 2020

John Hodgkinson

In addition to advances in materials and construction equipment there is a continuing need to ensure adequate skills are available within paving crews. Since 2006 concrete pavement crews and their supervisors in Australia have been required to undertake a mandatory one-day course. Known in industry as the "Grey Card" course it was developed jointly by NSW Roads and Maritime Services (RMS) and industry applicable to highway and similar classification roads. It demonstrates a commitment from both sectors to relevant training. Over 180 courses with 3,800 participants have been completed in four States and the Australian Capital Territory. Successful participants are issued with a card that is recognised throughout industry irrespective of changes in an individual's employment. The course is presented by instructors accredited by RMS and drawn from industry professionals who have demonstrated considerable construction experience. There is no other course of this type in Australia. The course has the primary objective of consistently high quality construction. Based on agency Specifications the course sets out the reasons for various construction requirements and site practices necessary to achieve them at paving crew level. Sessions include the basics of making good concrete, setting forms reinforcement and dowels, placing paving and compaction, surface finishing and texturing, curing and protection. This paper sets out the development and presentations of the courses.

Using Environmental Product Declarations for Green Public Procurement and Life Cycle Assessment of Concrete Pavements

Milena Rangelov, Heather Dylla, Nadarajah Sivaneswaran

Environmental impacts of concrete production have been evaluated for more than a decade. As a result, a national program for environmental product declarations (EPDs) of concrete has been initiated. The main objective of this paper is to analyze concrete EPDs produced to date and evaluate their applicability for green public procurement (GPP) and life-cycle assessment (LCA) of concrete pavements. EPDs provide transparent and verified quantification of environmental impacts, calculated per predetermined guidelines, known as Product Category Rules (PCRs). PCRs for concrete were developed through involvement of stakeholders from the building industry; therefore, these PCRs may not be fully applicable to paving concrete. The analysis included over 70 published EPDs and revealed that there are marked variations in underlying data sources and data quality, which hinders comparability of EPDs and use of EPDs for benchmarking. Concrete EPDs were created primarily using proprietary data sources suitable for the private sector. However, in the public sector, the use of proprietary data may be cost-prohibitive for agencies, disable transparency, and present the impediment to wider GPP and LCA adoption. To that end, reliable public datasets offer more promise for the development of paving concrete EPD. This study also compares concrete PCR to that of other paving materials (cement, aggregate, asphalt), all of which were created with no overarching entity. Accordingly, the potential options for harmonization and synergetic use of these EPDs in GPP and pavement LCA are also investigated.

Session 13: Joint and Crack Optimization

Optimized Spacing Of The Longitudinal Reinforcement In CRCP To Avoid Horizontal Cracking

Muhammad Kashif, Pieter De Winne, Muhammad Wisal Khattak, Amelie Outtier, Hans De Backer

Continuously reinforced concrete pavement (CRCP) is characterized by the absence of transverse contraction joints and the presence of longitudinal and transverse reinforcement. The continuous longitudinal reinforcement holds the transverse cracks, caused by the longitudinal shrinkage of concrete, tightly together and thus provides long term performance with minimal maintenance cost. Field investigations on recently constructed CRCP's in Flanders region of Belgium indicated horizontal cracking in the vicinity of the longitudinal reinforcement under the transverse cracks which eventually causes the punch-out distress at the edge of the pavement slab. This paper shows the results of a finite element (FE) study to investigate the effect of varying longitudinal reinforcement on the risk of horizontal cracking in CRCP under typical Flanders conditions. For this purpose, a (3D) FE model of CRCP is developed using a FE package Diana 10.2. The varying longitudinal reinforcement with a most narrow spacing of 125mm in the outer region of the pavement slab is applied while keeping the same CRCP reinforcement ratio. A comparison is made with the conventional longitudinal reinforcement spacing (170mm). Development of concrete stress in the vicinity of the longitudinal reinforcement is plotted against the different longitudinal steel spacing. Findings show that the stress in concrete near longitudinal reinforcement is significantly reduced up to maximum 17% when the narrow spacing is used. In addition, the steel stress in the longitudinal reinforcing is reduced up to maximum 31.75% in the outer region of the pavement slab.

Optimized Design Details for Continuously Reinforced Concrete Pavements

Shiraz Tayabji, Michael Plei

Continuously reinforced concrete pavement (CRCP) is widely used by several highway agencies in the United States, typically for heavily-trafficked roadways. CRCP has the potential to provide long-term "zero-maintenance" service life under heavy traffic loadings and challenging environmental conditions, provided that proper design and quality construction practices are utilized. CRCP design focuses on managing the

cracking that develops so as to reduce the structural distresses that may develop as a result of traffic and environmental loadings. These distresses include punchouts, steel rupture, and crack spalling. CRCP design involves determining the proper combination of slab thickness, concrete mixture constituents and properties, and steel reinforcement content and location; providing for sufficient slab-edge support; strengthening or treating the existing soils; and providing non-erodible bases that also provide friction, which leads to desirable transverse cracking patterns. In addition, CRCP design details must ensure that the large movement that can occur at CRCP terminal ends is managed adequately. Over the years, many improvements in the best practices in the design of CRCP have been implemented to improve long-term performance. These improvements have resulted from experience from the field, better understanding of CRCP behavior, improved structural modeling of CRCP, improved materials, and improved construction processes. This paper provides guidance on optimizing several key design features based on the information included in the previously cited references and recent refinements implemented in the field. These key design features include: Optimizing longitudinal steel content, Simplified details for terminal ends, Improved transverse construction joint detail, Shoulder type, and Concrete slab/base interface.

Re-Evaluation of Continuously Reinforced Concrete Pavement Structural Model

Lucio Salles de Salles, Lev Khazanovich, José Tadeu Balbo

Transversal shrinkage cracks are allowed to develop freely at the slab's surface of continuously reinforced concrete pavements (CRCP). It is commonly believed that cracking pattern significantly affects CRCP performance: small crack spacing (cluster cracking) is considered to be problematic due to the higher potential for cracks intersection and punchout development whereas large crack spacing can be detrimental for load transfer efficiency (LTE) at the crack due to the development of wider cracks. The Mechanistic-Empirical Pavement Design Guide (MEPDG) procedure for prediction of critical structural responses in CRCP is based on ISLAB2000 finite element model with constant crack spacing and equal LTE for every crack. The critical stresses are assumed to be at the top of the CRCP surface mid-distance between the cracks. However, results of experimental studies suggested that this model may not adequately describe CRCP's structural behavior. This paper presents a re-evaluation of the procedure for critical stress predictions. A finite element model with a variable crack spacing was developed. Different load positions, thermal differentials, crack LTE levels, axle types and voids were also simulated. Results point out that the location of critical stresses depends on many parameters, including crack spacing, magnitude of temperature gradients, type of axle load and presence or not of voids. Therefore, other modes of punchout initiation, currently not taken into account in the MEPDG,

should be considered in the design process.

Validation Of A New Method For Determining The Remaining Service Life Of Rigid Pavements

Pia Mandahus, Lukas Eberhardsteiner, Bernhard Pichler, Mehdi Aminbaghai, Ronald Blab

About a half of the Austrian highways are rigid pavement constructions, and increasingly more money has to be invested in their renovation and redevelopment. However, there are different approaches for the evaluation of the condition assessment of concrete pavements. The aim of the research presented in this paper is a concept for assessing the condition of a road section in rigid pavement. This consists of a structural and a visual assessment scheme for selecting appropriate maintenance actions. For the verification of this new method of assessment of the structural condition of concrete pavements, several field tests were examined. Furthermore, a case study was carried out to examine the level of influence of several input parameter. This analysis shows that the influence of the layer thickness is very high, while the influence of the modulus of elasticity of the existing concrete is significant lower. The FWD measurements were carried out radial (instead of linear) for the first time. The results show possible inhomogeneities in the subgrade or in the bedding, which would not be recognized by the standard linear measurements. With the results from the already mentioned measurements, the remaining service life of the test tracks could be calculated.

Session 14: Sustainable Materials

Hydration and Air-entrainment Challenges of High-Volume Fly Ash Concrete Pavement

Aniruddha Baral, Jeffery Roesler

The goal of high-volume fly ash concrete (HVFAC) is to produce concrete pavements at a lower cost and carbon footprint while maintaining its desired durability. Previous research has demonstrated that the required fresh and hardened concrete properties can be achieved at higher replacement rates of cement with fly ash such as 40%. However, most transportation agencies do not permit more than 30% cement replacement with fly ash primarily because of the potential inconsistencies in early-age properties such as variable air entrainment, delays in setting times, and lower strength gains. In this paper, the heat evolved during hydration of HVFAC are presented with respect to the source of the cement and fly ash, the variability of fly ash from the same source, and addition of nano limestone. Isothermal calorimetry showed longer setting times were dependent on the specific fly ash-cement combination as well as the degree of sulfate imbalance. For this study, HVFAC mixes with class C fly ash had a larger sulfate imbalance than class F fly ash with final setting times 4.5 hours and 1.9 hours longer than straight cement system, respectively. Replacing cement with 10% nano limestone in HVFAC system accelerated the initial set time by 3.2 hours which was much greater than the set time acceleration (1.3 hours) with the replacement of straight cement with 10% nano limestone. The various types of inorganic and organic carbons in fly ash remain a challenge for predicting and maintaining air content but the foam index still offers a rapid and straightforward quality control test with operator variability within ± 1 μL AEA/gm fly ash.

Guidance for Increasing the Use of Recycled Concrete Pavement Materials

Tara Cavalline, Mark Snyder, Tom Cackler, Peter Taylor

Recycling concrete pavements has been a common practice in the US for decades, and recently, public agencies have been more closely examining recycling opportunities. Reasons supporting recycling include the diminishing quantity of good natural materials, economics, improved project execution, minimizing traffic disruption, and supporting sustainability goals. Many states, however, have specifications or policies that restrict concrete pavement recycling. The contracting industry may overlook opportunities to

use recycled concrete aggregates (RCAs) due to a lack of familiarity with technical requirements or uncertainty of performance. The National Concrete Pavement Technology Center (CP Tech Center) recently completed a comprehensive set of technical resources for the Federal Highway Administration to assist practitioners with sound approaches to project selection, scoping and construction requirements to support increased use of recycled concrete pavement materials. This paper describes the results of a 2016 survey of agency and industry RCA usage, presents an overview of the technical resources prepared as part of this initiative, and presents recommendations for supporting broader application of recycling concrete pavement materials.

Evaluation of Tensile and Flexural Strength and Water Absorption of Concrete Pavements Containing Fly Ash and Calcium Carbonate Nanoparticles

Fereidoon Moghadas Nejad, Morteza Tolouei

The use of complementary or alternative cement in concrete has always been considered. The most important challenges are the use of suitable and optimal distribution of materials. In this paper, tensile and flexural strength and absorption of concrete pavement containing calcium nano carbonate and fly ash are investigated. For this purpose, 48 concrete specimens of 7 and 28 days were constructed. In order to investigate mechanical behavior, tensile and flexural strength tests were performed under four-point loading. In order to examine the durability, the water absorption test (vpv) was performed. FESEM observations were performed to determine the distribution of nanomaterials and their size and the microstructure of the samples. For determination of the elements and their reactions, XRD and EDX analysis was performed. The results of tensile strength and flexural strength under four-point loading indicated that the concrete sample containing 0.5% nano-particle (N0.5) was the most resistant. The results of the total water absorption (vpv) test showed that sample 1% nanoparticles and without fly ash (WFN1.0)had the least water absorption and porosity. FESEM observations indicate that nanoparticles are well distributed. The nanoparticles are well spread in the sample and fill the pores of the concrete, and also the nanoscale results in an increase in the Ca (OH) 2 and the further formation of the gel (C-S-H) (with maintaining the size of Sio2). XRD analysis shows the superiority of quartz composition. EDX analysis shows the effective presence of Si.

Session 15: Specifications

Multi Criteria Analysis On Surface Treatment Method For Concrete Pavement

Ali Ali Aryo Bawono, Bernhard Lechner, Stephan Freudenstein, En-Hua Yang

Surface pavements have been studied for decades. Many surface treatments have been done by roadway authorities to improve the functional performance of concrete pavements: skid resistance, surface water drainage, pavement evenness, noise, and durability. However, there are so many different standards for those criteria applied, which might be causing misinterpretation when decision-makers are about to select the right surface treatment method. For example, roadway authorities mostly need to compare in which texturing methods can be applied for their roadways. Yet, they will find the methods are sometimes applied by using different standards. Firstly, there are various standards related to the functional surface performance of the pavement applied by different agencies. Secondly, there are many different measurement methods for the functional performance of the surface pavement. Thirdly, the surface treatment methods used to improve the surface pavement are varying. Therefore, it is not an easy task to understand and to compare different surface treatment methods with different criteria, and then to select the most optimum one. Yet, fewer studies were found on comprehensive analysis on determining which surface treatment method leads to the optimum functional performance. The objective of the research is to find a multi-criteria analysis method to define the most optimum surface treatment methods for concrete pavements that provide high functionality (safety and comfort). More than 15 surface treatment methods for concrete pavement are analyzed based on their functional performance includes skid resistance, pavement drainage, tire-pavement noise, and pavement roughness.

Specification Proposal For Fiberglass Dowels For Concrete Pavements

Bryan Barragan, Doug Gremel

Since their appearance in the 1990's in North America, fiberglass dowels have been extensively tested at laboratory-scale and in real infrastructure projects, demonstrating to be a viable alternative capable of providing the necessary performance both in terms of load transfer capacity and corrosion resistance, the latter being its key value proposition. Today, fiberglass dowels are often a solution of choice in pavements

where electromagnetic considerations, such as high-speed tolling are paramount. It is anticipated that with standardization, they will begin to replace ferrous reinforcing in traditional highway jointed paving where they are impervious to aggressive deicing salts or chlorides from marine environment and their lower modulus is beneficial to minimize concrete stresses in joints. Still, there is no material specification standard in the world but efforts to draft GFRP material standards are under way. This paper presents an overview of some successful fiberglass dowels' research projects and applications after more than 20 years of experience, and based on such, a material specification proposal for glass fiber reinforced polymer (GFRP) dowels. Additionally, the work includes some basic parameters for the design and construction of slabs-on-ground with fiberglass dowels.

A Users Guide to Performance Engineered Mixtures

Jim Grove, Mike Praul, Jagan Gudimettla, Robert Conway, Peter Taylor

Performance Engineered Mixtures is an initiative, spearheaded by the Federal Highway Administration and the National Concrete Pavement Technology Center, in cooperation with state Departments of Transportation and the concrete paving industry, to develop a comprehensive approach to modernizing the way concrete is specified, tested, and accepted. It focuses on three components: testing of six critical concrete properties, a robust approach to quality control, and the replacement of prescriptive specifications. Many new tests have been recently developed that provide the ability to test concrete properties more easily and quicker than in the past. This paper provides background of how this initiative began. It elaborates on each of the six properties of concrete that are the focus of PEM. The new tests that are integral to the PEM process are described. The effects PEM will have on the acceptance process and the quality control responsibilities are outlined. Finally, tables are included which list the properties and the tests that are associated with each property, as well as how each is applied to each step of the paving process.

Understanding the Value of Comprehensive Material, Performance Models and Real Failure Modes in Modern Rigid Pavement Designs

Juan Pablo Covarrubias Vidal, Pelayo Del Rio Baeza, Feng Mu, Sherry Sullivan

Rigid pavements traditionally have been designed using either empirical or mechanistic-empirical methodologies. Historically, common design methods included AASHTO

(1993 and 2008) and the PCA Method (now known as Street Pave or Pavement Designer). These design methods were calibrated using a relatively limited number of pavements with slab dimensions of 12ft (3.5m) wide and 15ft (4.5m) long, different traffic levels, local climate conditions and materials and construction practices from the era of the testing. In addition to these methods, modern methods including bonded and unbonded concrete overlays and slabs with optimized geometry are becoming increasingly common.

While historical methods might provide appropriate designs for certain geometries (slabs sizes), applications and locations like those to which they were calibrated, the appropriateness of their application should be in question (e.g., AASHTO 93's limit of testing to a certain amount of ESALs and climatic conditions). Mechanistic performance methods allow the incorporation of new materials and conditions, but understanding the mechanistic principle that the method is trying to extrapolate and the resulting failure mode of this new condition is an important consideration.

This paper contrasts historical and modern rigid pavement design methods and their results, with an emphasis on illustrating when historical designs might yield unconservative and possibly dangerous or incorrect designs because of their lack of consideration of comprehensive performance models.

Session 16: Precast and Rapid Repair

Prestressed Precast Concrete Pavement: A Case Study

Ameen Syed, Ranjan Sonparote

One of the major problems with the construction of concrete pavement in India is obtaining the required quality. The quality of Cast-In-Place concrete pavement is difficult to maintain due to the site conditions. To address this issue, a 500 m trial stretch of Prestressed Precast Concrete Pavement (PPCP) is developed in Inner Ring Road, Nagpur. The design of PPCP is performed by a simple spreadsheet considering the cumulative fatigue damage caused to the pavement over its design life. The spreadsheet includes the effect of temperature, prestress, axle loads, and modulus of subgrade reaction for calculating the thickness of the pavement and can be useful for professional designers. The size of the panels for the trial section is 2.625 m x 4 m and 3.5 m x 4 m. The panels are interconnected using a sliding slot dowel model and a top slot dowel model. The construction aspects and design revisions required to incorporate the site difficulties have been discussed in the paper.

Performance Summary Of Precast Concrete Inlay Panel Trial In Ontario

Dan Pickel, Dahlia Malek, Susan Tighe

In order to address deep-seated rutting issues on high-volume asphalt highways in Ontario, Canada, the Ministry of Transportation of Ontario (MTO) was interested in the design and testing of a Precast Concrete Inlay Panel (PCIP) trial section. The PCIP was used to increase the stiffness of the pavement section within the short overnight construction windows that the MTO specifies to minimize the effects on road users. The trial section was designed to include three separate methods of panel support, which is understood to be a primary consideration in the performance of precast concrete panels. The trial section was constructed in September 2016 on the traffic lane of Highway 400 and has been in continuous service since that time. Instrumentation was installed during construction to measure the pressure, moisture, and temperature conditions at the interface between the panels and the existing asphalt layer. This paper summarizes the performance of this trial during the more than three years of service, including findings from the sub-panel instrumentation, falling weight deflectometer testing, and condition assessments. Additionally, the findings of an analysis of the construction aspects of the different support conditions are included to

reinforce recommendations regarding the best support technique for future applications of the PCIP rehabilitation technique.

Implementation of Precast Panels for Improved Maintenance of Traffic and Long-Life Performance

Sam Tyson, Shiraz Tayabji

The Office of Preconstruction, Construction, and Pavements in the Federal Highway Administration (FHWA) has assisted more than 30 highway agencies throughout the United States of America (USA) to implement the use of precast concrete panels for rapid repair and rehabilitation of both concrete and asphalt pavements. Precast concrete pavement (PCP) provides several advantages over traditional cast-in-place concrete with benefits accruing to both owners and users of the roadways. These advantages include better concrete quality and durability, long-life pavement performance, and improved maintenance of traffic. Although the initial cost of PCP typically is higher than that of cast-in-place concrete, the quality of concrete in the precast panels delivered to the project site is assured by well-written specifications and professional inspection, the precast panels can receive traffic loadings immediately after installation, and repeated interruptions of traffic and extended work zones are either reduced or eliminated. Extended lane-closure durations must be avoided to prevent unacceptable levels of traffic congestion, which means repair and rehabilitation work must be completed rapidly. Numerous projects have been completed by using rapid-hardening concrete; however, the results have been inconsistent. The use of PCP has been shown to be a promising alternative [1]. The service life of PCP in intermittent full-depth repairs of concrete pavements is expected to be at least 20 years. The service life of PCP in longer lengths of heavily trafficked pavements is expected to be 40 years or more without significant maintenance.

Overnight Renewals of Concrete Runway at Sabiha Gökcen International Airport Istanbul

Jakob Melchior, Martin Bäuml, Felicia Constandopoulos

Over the last couple of years, new rapid-hardening concretes were developed. They do not only stand out by their high early strength, in excess of 20 MPa already 90 minutes after setting, but are also adjustable to the needs of the construction site in regards to fresh concrete properties and setting behavior. This allows the rapid-hardening concrete to be placed using traditional means and the construction program to be

optimized in order to perform the renewals during very short closure windows. After many years of usage, the single runway at Sabiha Gökcen International Airport Istanbul was in need of large-scale renewals due to severe damages in the high wear areas around the centerline. But, with it being the only runway at the airport, closing it for multiple weeks to perform the renewal was not an option. The nightly closure of only 5 hours, due to late-evening and early-morning flights, placed additional demands on the rapid-hardening concrete, the logistics of the construction site and the concretes long-term durability for a permanent solution. This article presents the step-by-step over-night renewals at Sabiha Gökcen Airport, which is the largest project ever performed involving rapid-hardening concrete. Each night up to 5 slabs (94 m^2) of the runway were replaced for a total area of 8700 m^2 over 117 nights between March and September 2018. Such large area applications without affecting regular airport operations are possible thanks to the latest generation of rapid-hardening cement and this article shows these possibilities to project owners, design engineers, and contractors.

Recent Advances In Jointed Precast Concrete Paving: Hawai'i H-1 Reconstruction

Peter Smith, Mark Snyder

Jointed precast concrete pavement was recently used to reconstruct large multi-lane areas of one of the busiest areas of Interstate H-1 near Honolulu, Hawai'i, USA. The design-build project was awarded in early January 2018 and more that 1200 precast panels were designed, fabricated and installed less than 7 months later using mostly 8-hour overnight work windows. There were several unusual and innovative aspects to this project, including: variation in the type and layout of joints when replacing travel lanes with rectangular precast panels adjacent to existing skewed, random-length cast-in-place panels; the use of ground-penetrating radar to map original pavement structures that varied greatly along the project length and between lanes; the development of "3-D" design models for the new surface to improve ride quality and cross-slope; the use of "3-D" panel fabrication techniques; the use of laser-controlled construction equipment to construct contoured foundation surfaces that fully support the non-planar precast panels and allow immediate temporary use without grout, thereby extending productivity in short overnight work windows; the use of optimized dowel placement (below mid-depth) and headed "dowel-in" tie assemblies to reduce slot sizes, improve panel integrity, and reduce panel grout requirements; the placement of temporary asphalt layers to eliminate major drop-offs between lanes during construction; and the development of specially shaped transition panels and bridge approach panels.

This paper describes the unique aspects of precast pavement design and construction for this project and presents "lessons learned" and recommendations developed from

the project.

Session 17: Functional Evaluation

Effect PCC Slab Curling and Warping on Pavement Roughness

Hyung S. Lee, Syed Haider, Karim Chatti, Neeraj Buch

Longitudinal profile measurements are vital for assessing the functional performance in terms of smoothness for new and existing pavements. However, the longitudinal profiles of Jointed Concrete Pavements (JCP) are significantly affected by temporal and diurnal changes that influence curling and warping of the concrete slabs. Therefore, consideration of such effect is essential for accurate assessment of pavement smoothness. The longitudinal profile measurements are commonly summarized by the International Roughness Index (IRI) that reduces the thousands of elevation values into a single value. However, no matter which index is calculated from a longitudinal profile, the quality of the information is only as good as the profile measurement. Thus, there is a need to evaluate the impacts of temporal (seasonal temperature/moisture and daily temperature) variations on longitudinal profile measurements, especially for JCPs. In this study, a new method is proposed for separating the curvature related IRI (i.e.,due to curling and warping) from the non-curvature related IRI (i.e., due to other distresses such as spalling, faulting, etc). The level of curling and warping within each profile was summarized in terms of the Pseudo Strain Gradient (PSG). Examples from a couple of JCP sections indicated that temporal variations during a single day could have significant impacts on IRI. Results show that diurnal variations in PSG explained many of the changes in roughness over time. Such influence of seasonal and daily IRI variations can influence current practices—how highway agencies collect surface roughness for pavement management purposes and perform smoothness measurements for construction quality control.

Friction Retention of Concrete Pavements with Carbonate and Siliceous Aggregates

Satyavati Komaragiri, Amit Bhasin, Armen Amirkhanian

In the late 1980s and early 1990s, the Alabama Department of Transportation (ALDOT) noticed a decline in skid trailer numbers on concrete pavements shortly after grinding operations. The engineers at the time suspected that the coarse aggregate led to decline of skid trailer numbers and the resulting conclusion led to a ban of carbonate aggregates in mainline concrete pavement that is still in place. Recently, ALDOT has decided to reexamine the ban on carbonate aggregates in mainline concrete pavement

and perform a comprehensive and detailed study of the issue.

An extensive laboratory study examining 96 different mixture, grinding, and grooving combinations was undertaken. Each of the 96 specimens was polished with the NCAT Three-Wheel Polishing Device (TWPD) for 160,000 cycles and Dynamic Friction Testing (DFT) was performed at set intervals to monitor the friction loss. The results indicate there are numerous factors affecting the ability of the pavement to retain friction. Blending siliceous and carbonate aggregates can improve the performance compared to sole source mixtures. Independent of aggregate type, the affect of the grinding and grooving texture is also pronounced. The conclusion of the study is that there is no single factor that can be used to retain friction and a comprehensive evaluation is needed for an agency. A set of recommendations was provided to ALDOT which provided a framework to reintroduce carbonate aggregates into mainline concrete paving in Alabama.

Design Sensitivity of Cross-tensioned BFRP Concrete Pavement

Yating Zhang, Jeffery Roesler, Zhiyi Huang

Basalt fiber-reinforced polymer (BFRP), a lightweight and corrosion resistant reinforcement, has potential to be an alternative for steel in cross-tensioned concrete pavements. In this study, the structural response and design input sensitivity of cross-tensioned BFRP concrete pavement was assessed with 3-D finite element analysis. The results show that the oblique BFRP tendons with a pre-stressing level at 65% of its ultimate strength produced significant slab compressive stresses in both transverse and longitudinal directions, which leads to higher flexural capacity and longer performance life. The slab analysis determined preliminary pre-stressing in the longitudinal and transverse direction requires BFRP diameters approximately 14 to 18mm at a spacing between 500 to 1000 mm and 25° to 40° skew angle for slab thickness of 16 to 20 cm. The exact BFRP design parameters (diameter, spacing and skew angle) and slab thickness depends on the specific site traffic loading and environmental conditions. The coefficient of friction and slab length have a significant impact on the tensile stresses in the concrete during the initial pre-stressing but has limited impact on slab stresses due to traffic loading. Other factors that have limited effects are elastic modulus of the concrete, base and soil.

Has diamond grinding been a cost-effective pavement preservation treatment in Australia?

George Vorobieff

Australia introduced conventional longitudinal diamond grinding of highway concrete pavements in 2010. The availability of these machines in Australia has allowed contractors to improve ride quality of new pavements, rather than accept a deduction to the tendered rate for the supply and placement of concrete pavement. More importantly, with the introduction of the grinding machines asset managers have the opportunity to use diamond grinding to treat existing concrete pavements that may have had a rough ride or the textured surface no longer meets specified levels for skid resistance.

Diamond grinding treatments to concrete pavement allows asset preservation and avoids high reconstruction costs.

The Austroads concrete pavement design procedure is based on the PCA design method and road smoothness is not a design parameter, unlike the USA approach to concrete pavement design where ride quality is a design input. There is still much work to be done to convince asset managers in Australia that the removal of the high areas of a concrete pavement to smooth the surface reduces the dynamic wheel loading and therefore, less accumulated fatigue stress in the concrete.

This paper reviews the last 10 years of diamond grinding projects and their success as a pavement preservation treatment for existing urban and rural concrete pavements. Recommendations are included in the paper to reduce the cost of diamond grinding concrete pavements in Australia to extend the use of the treatment.

Session 18: RCC and Heavy Loads

Fracture Energy of Roller Compacted Concrete Pavements

Emin Şengün, Burhan Alam, Reza Shabani, İ. Özgür Yaman

This study is set out to examine the bending, toughness and fracture energy of RCC pavements produced by double drum vibratory hand roller (DDVHR) to simulate the real performance of RCC in the laboratory environment. To this end, four different binder dosages (200, 300,400, and 600 kg/m3) and two different aggregate gradations (Dmax 12 and 19 mm) were selected to investigate the effect of mixture design on bending, toughness and fracture energy of RCC mixtures. The different mixtures were poured into a large pavement mold (LPM), which was fabricated in laboratory, and compacted by DDVHR. After that, in order to determine the bending, toughness and fracture energy of RCC mixtures, LPM were cut to beam specimens with sizes according to Japan Concrete Institute (JCI). In addition, cores were taken from LPM to compare 28 days' compressive strengths and compaction ratios of the mixtures. At the end of the study, contrary to expectations, the fracture energies for all RCC mixtures except one combination were very close to each other. The increase in cement dosage or the maximum aggregate size did not lead to a significant change in the fracture energy. The mixture that was developed to obtain a high performance RCC appeared to have the lowest fracture energy. Above all, the compaction ratio of the mixtures was effective in the all results.

Success story of RCC for Heavy Loaded Pavement at Port of Montreal's Container Terminals

Louis D'Amours

At the port of Montreal, port pavements, particularly those of container terminals, are literally bombed with various types of loadings, such as gantry cranes, forklifts or front-end loaders, non standard single-axle trucks and conventional trucks. The typical features of this transhipment equipment are such that it can generate significant loads and stresses in pavement structures. Indeed, wheel loads for some gantry cranes can even reach 63.7 T per wheel, which is definitely higher than the usual conventional truck load, usually a maximum of 5 tons per dual wheels. This communication will first set out the significance of such equipment and its influence on pavements, and how container terminals design methods have evolved over the past decades. Subsequently, the sustainable pavement concept, which has been in use these past years, will be

presented, as well as how the design methodology has evolved through the design development. These composite pavements, which consist of RCC slabs overlaid with bituminous concrete, were developed from past experience with RCC slabs, in order to reduce maintenance requirements for transhipment area operators. The communication will also show how the methods and specifications used to construct these pavements have evolved over the past years.

Aggregate Source Effects on RCC Green Properties

Jordan Ouellet, Gail Scott, Jeffery Roesler

Interest in roller-compacted concrete (RCC) pavement has been increasing because of its low initial cost, construction efficiency, and ability to open to traffic early. Current RCC mixture design methods do not directly consider the aggregate source or optimal cement content. An experimental testing plan was developed to batch RCC mixtures with several aggregate sources, gradations, paste contents, and water-cement (w/c) ratios. Each aggregate blend was compacted in order to determine the intergranular volume of voids. The volume of cement paste was varied to underfill, equifill, and overfill the compacted aggregate voids. Green properties (green strength, green modulus, and softening modulus) were measured on the lab compacted specimens to assess the fresh RCC capacity, stability, and plasticity. Green and hardened properties were then related to the RCC mixture volumetric parameters. Green properties were sensitive to aggregate type and gradation, ratio of voids filled by paste, w/c ratio, and total paste content, which all affected the mixes adhesion and shear resistance. In most cases, high cement contents did not improve green or hardened properties. RCC mixtures containing crushed aggregates achieved maximum green strength and stability with underfilled voids, while RCC with rounded aggregates required overfilling the voids. Workability (Vebe time) measurements were not sensitive unless voids were overfilled and not highly sensitive to w/c ratio.

Investigating the Effects of Superloads on Fatigue Performance in Jointed Plain Concrete Pavements

Nathanial Buettner, Qianyun Zhang, Julie Vandenbossche, Jeffrey Oswalt

Superloads are commonly defined as vehicles that carry loads over 890 kilonewtons (200,000 pounds). There has been little research on quantifying the stresses caused by superloads of various axle loads, spacings, and configurations on jointed plain concrete pavements. The purpose of this paper is to characterize the maximum tensile stresses

caused by Pennsylvania superloads on jointed plain concrete pavements. Common superload axle loads, spacings, and configurations were determined using information supplied by the Pennsylvania Department of Transportation (PennDOT). The maximum tensile stresses caused by these superloads were then found for jointed plain concrete pavements of several thicknesses and shoulder types under critical loading conditions. The magnitudes and locations of superload-induced tensile stresses were evaluated and related to fatigue performance. This analysis provides insight regarding a potential need for transportation departments to adjust their superload permitting procedures to account for superload fatigue damage.

Establishing Effects of Superloads on Doweled Jointed Plain Concrete Pavements

Charles Donnelly, Julie Vandenbossche

Superloads are typically defined as vehicles weighing greater than 890 kilonewtons (200,000 pounds), although the geometrics of the vehicle are also a consideration. The damage of these superloads on jointed plain concrete pavements (JPCP) as compared to a standard 80-kN (18-kip) single axle design load are not well defined. The purpose of this study is to identify the effects of these superloads on the performance of JPCP joints in comparison to that of standard traffic loads. One mechanism of failure at the transverse joints in JPCP is the degradation of dowel performance. This can decrease the effectiveness of the joint load transfer efficiency; thereby resulting in large differential deflections and the development of faulting. Therefore, to quantify the damage caused by superloads, typical load configurations were identified using superload permit data obtained from the Pennsylvania Department of Transportation. Using the typical superload profiles established from permit data, the effect on dowel performance is evaluated.

Session 19: Modeling

Reducing Rigid Pavement Modeling Complexity: An Exercise Using the Principles of Similarity

Peter Bly, Lev Khazanovich

Pavement design and evaluation analysis use mechanistic models to estimate pavement responses to applied loads. Finite element modeling is a common technique used to quickly and efficiently model rigid pavements that incorporate more complex phenomenon a constructed, in-service slabs experience. While adding complexity increases the accuracy of the modeling, it requires additional computing effort to account for its effect on the scenario modeled. When combined with a cumulative damage based structural analysis, multiple model runs are needed to estimate damage over the number of incremental steps used. To bypass direct finite element modeling for multiple pavement systems, design methodologies such as the Mechanistic-Empirical Design Guide use artificial neural networks to store specific pavement response information for rapid recall as a type of non-linear regression made from pre-analyzed cases of a known set of input variables. These methodologies use the Principles of Similarity to reduce the complexity of modeling the pavement layering and environmental loads by considering a single reference pavement structure without introducing error and minimizing the total runs used. Complexity can be reduced from 20 variables to 9 key variables. This paper provides a review of the Principles of Similarity and discusses how they are used to generate an efficient dataset for artificial neural network development. Examples showing how single representative pavement system can yield proportional and scalable responses to numerous equivalent pavement systems are given to illustrate the power of the Principles of Similarity in reducing modeling complexity and computational demands for higher level pavement analysis efforts.

Relating Field Energy Attenuation in Portland Cement Concrete Pavements to Fracture Mechanics

Carl Lenngren, Maria Inmaculada Garcia Hernandez

Asset management of infrastructure is fundamental for maintenance planning and preservation of common property. A robust testing program is needed to assess the present-day status and for proper actions in time to minimize the ongoing depreciation of value. As a matter of fact, Portland Cement Concrete pavements show very little deterioration even after many years in service. Thus, it may be difficult to accurately

predict the present asset value, other than using linear relations to the presumed design life. The primary reason for failure is cracking in concrete pavements, so assessing the dissipated energy from the load-deformation relation from a given load could be utilized for the purpose. The dissipated energy, i.e. the work data can be assessed by a falling weight deflectometer test, mimicking the passing of a truck or aircraft wheel load. In the present study, dynamic field data are evaluated, and the input data needed for the fracture mechanics model are used to predict the pavement life regarding cracking. To predict fracture energy and assess rolling resistance as well in concrete pavements, we need to consider the energy balance of the pavement system. To assess dissipated energy, falling weight deflectometer time histories are used to evaluate the pavement contribution to rolling resistance. Such analyses include all layers in the structure including the subgrade, so in the present case a way of sorting the dissipation at various depths is investigated. Field data were collected from a site, at mid-life of the predicted design life. The failure was confirmed several years later, and the remaining life was compared with the assumption that the dissipated energy near the edge was enough to initiate the cracks within the actual time to failure. Conversely, the dissipation at the mid-slab position was below the limit. The data from the field test were also used as an input for a finite element model to see if it was viable to further improve the prediction. The method seems to be promising, but more data are needed as the present set only represents the mid-life status.

Comparison of Pavement Layer Responses between HMA/PCC Pavement Designs with Heavy Vehicle Loads Using RPAS

Nancy Beltran, Abbasali TaghaviGhalesari, Richard Rogers, Cesar Carrasco

The rapid energy sector development and the strong increase in vehicle axle loads has resulted in premature failure of asphalt pavements and, as a consequence, concrete pavements are being considered. However, current design methods assume the significantly heavier vehicle loads will have an elastic impact on the pavement layers and has led pavement engineers to thicken the concrete layer to withstand the heavy loads resulting in a more costly option compared to an asphalt pavement design. Moreover, the current design procedure of concrete pavements discretize the supporting layers using the Winkler foundation model, which makes it incapable of properly considering the impact that heavier truck loads have on the foundation layers. For this reason, researchers at the University of Texas at El Paso (UTEP) developed the Rigid Pavement Analysis System (RPAS), a finite element analysis program that has the capabilities of modeling the foundation layers using a 3-D foundation model, which considers the additive impact of adjacent wheel loads in the subgrade. RPAS has linear elastic theory capabilities and can also be used for the analysis of asphalt pavements when considering the appropriate material properties. This paper presents

a comparison study conducted for the Texas Department of Transportation (TxDOT), Odessa District, between a hot mix asphalt (HMA) pavement design and a Portland cement concrete (PCC) pavement design to evaluate the effects that heavy loads have on each pavement layer responses (stresses and strains). The results determined that the PCC pavement provided adequate concrete stresses and significantly reduced the subgrade strains.

Accounting of Strain Cycles Sustained by Airfield Rigid Pavements

Anastasios Ioannides, Andrew Harrison, Carlos Gonzalez, Peter Bly

The so-called 72-in. rule, employed in U.S. Department of Defense rigid pavement design in establishing the number of strain cycles arising under a pass of any aircraft on a particular pavement system, is re-examined using mechanistic tools, particularly layer elastic theory and dimensional analysis. Field data collected at Denver International Airport are reproduced using analytical simulations, which permit the generation of analogous synthetic results pertaining to different pavement systems and aircraft gear configurations. The analysis affirms the expectation that the criterion for establishing the number of strain cycles cannot be simply a fixed value, defined by the tandem wheel spacing. Rather, the dual wheel spacing and the radius of each tire-print must also be taken into consideration. In addition, the radius of relative stiffness of the pavement system needs to be accounted for. In this study, these variables are accommodated in the form of three dimensionless independent input parameters. The single dependent variable is the ratio (trough strain ÷ maximum strain), denoted herein as ν. A process is formulated to ascertain whether ν is positive or negative: if $\nu>0$, then one strain cycle may be expected; if $\nu<0$, then two strain cycles may be expected. Comparisons of the process outcomes to those from the 72-in. rule show excellent agreement for the Denver conditions, testifying to the admirable simplicity and laudable wisdom of the latter. The process may be further refined for application to more complex gear configurations, e.g., tridems.

Session 20: Joint Quality

A Survey Method For Measuring Load Transmission Rates In Concrete Pavements Covered Using Asphalt

Tomotaka Ueta, Ikuo Matsushita, Kenichi Takejiri, Atsuma Yamashita

National Road No.17 starts from Nihonbashi(which means the name of Bridge in Tokyo)and connects the metropolitan area and Northwestern Region of Japan. Among them, Omiya Bypass which runs through the central area of Saitama Prefecture was started as concrete pavement in 1963.However, damage to concrete slabs and joints progressed due to increasing the large car traffics and deteriorations, at present, it has been changed to the overlaid structure with asphalt pavement on a concrete slab (3.25m—10m). In recent year, in Omiya Bypass, cracks on the road surface and vibrations become noticeable and repair work is being carried out from the high urgency area with priority. From a large-scale research implemented in 2017, the cause of vibration is considered to be the impact of passing large vehicles and cracks occur on the road surface due to damage(break of Dowel bar, gap) near the joints of concrete plates that laid under asphalt. Surface cracks can be used to determine the damage status by road surface survey but joints in asphalt covered concrete slabs cannot be surveyed directly and the efficient investigation is required because the repair wide range extending. In this paper, in order to evaluate the soundness of the joints between asphalt covered concrete slabs we can describe the content of the method of efficiently investigating the load transfer rate which is one of the items to evaluate the joints.

Degradation Process of Doweled Transverse Joint of 30 Years Old Concrete Pavement on Expressway in Japan

Tatsuo Nishizawa, Kenji Takai, Naofumi Noro, Nobuhiro Kurato, Yasuhiro Nakamura

A section of jointed concrete pavement on Tokai-Hokuriku Express-way in the central region of Japan main island was opened in 1986.After 30 year service, small faulting has begun to appear at many joints. In order to grasp the entire situation of the joints, FWD tests were performed at transverse joints in 2011 and 2017, and the structural condition of each joints was evaluated from the results of the tests with a backcalculation method developed in this study. Some of the joints, which were judged to be severely damaged, were excavated to check the actual condition of the joint and validate the developed evaluation method. The evaluation on the joints of this particular concrete pavement revealed that the number of degraded joints has increased

rapidly from 2011 to 2017, getting worse in re-cent years. Also, some backcalculation results imply that many dowels of the joints with the high load transfer efficiency and low deflections were corroded and some of them completely broke, and that avoid formed underneath the joint.

Innovative Test Method For The Reliable Evaluation Of Joint Sealants In Concrete Pavements

David Ov, Rolf Breitenbücher, Martin Radenberg, Dominik Twer

Joint sealants as indispensable filling systems in jointed plain concrete pavements (JPCP) are permanently exposed to various stresses during their service life, which often leads to a replacement of the sealing after approx. 7 to 10 years. Aside from seasonal unsteady climatic changes, the cyclical stresses caused by traffic and the ageing of joint sealants are especially significant. Considering the rising number of damages that occur within the overall "joint" system, an increased demand for a durable solution is requested as it is a relevant element for the life cycle costs of concrete pavements. In this context, a testing and ageing method was developed which comprises of the entire "joint" system, including the saw-cut concrete joint flanks, the primer as well as the joint sealant. This procedure depicts the decisive scenarios of in-situ stresses and allows the characterization of joint sealants. For this purpose, specimens were subjected to horizontal and vertical loads (static/cyclic) as well as to various ageing effects (temperature conditioning, UV-conditioning and freeze-thaw-cycles). After conditioning, a significant influence of the artificial ageing on the residual strength was observed in the tensile/shear tests. By comparing the artificially aged samples tested in the laboratory with extracted and in-situ aged samples, a reliable correlation was determined. Considering these system tests an initial approach was established which enables the evaluation of joint sealants in both unaged and artificially aged conditions on the basis of scientific parameters and limits.

Comparison Between Visual and Ultrasonic Tomography Joint Deployment Detection Methods

Michael Wallace, Thomas Burnham

Thin bonded concrete overlays placed on existing asphalt (BCOA) pavements perform best when they are designed and constructed with small square panels. The closely spaced contraction joints help to control the location of slab cracking that develops due to the restraint stresses caused by concrete shrinkage and thermal contraction, reflective

cracking forces, differential movement between the concrete overlay and asphalt, and curling and warping stresses. These joints are only able to fulfill their function if they deploy shortly after hardening of the concrete. Due to common observations of sequential joints not deploying, experimentation has begun with applying early loads to the panels to encourage more frequent deployment. While visual observation of joint deployment along the side of the concrete overlay is possible before shouldering material is placed, it becomes difficult thereafter. Questions also arise whether visual observation of a cracked joint on the side of the pavement reflects that the joint is fully deployed across the lanes. This study examined the efficacy of visual joint deployment detection along the side of a BCOA project that had been loaded early, compared to ultrasonic tomography conducted across those same joints. Analysis shows both that visual observations and ultrasonic tomography can be used to reliably detect joint deployment, and that it is uncommon that joint deployment is not fully engaged across lanes.

Session 21: AASHTO PavementME

Developing New Approach to CRC Pavement Punchout Model Calibration

Issa Issa, Dan Zollinger

Local calibration of the punchout model in the Pavement ME software is a vital step in achieving performance predictability for the design of Continuously Reinforced Concrete (CRC) pavement. In Oklahoma, there was only limited performance data available in the General Pavement Studies (GPS) database for CRC pavement. This set of circumstances required a different approach as to the type of data used for calibration. The type of data originally utilized in NCHRP 1-37A essentially represented visually evident damage that is clearly observable at the surface of the pavement structure. Non-observable damage however is actually of greater value as a source of calibration data since it represents the deteriorative conditions that lead to the visual manifestation of the damage process. Since visually validated distress is the end result of the distress cycle the traffic level associated with it is often subject to a considerable amount of error. In this regard, non-observable data such as erosion damage is shown to be a good indicator of and a substitute for actual punchout data since it represents the deterioration of the slab subbase interface that has be found to closely aligned with the punchout process. The amount of erosion is evaluated based on FWD data and is shown it to be a reliable way to determine the calibration coefficients for the punchout model. This paper proposes an approach for calibrating local coefficients for CRC pavements based on non-observable performance data. The main process of this methodology requires estimating erosion percentage damage using Falling Weight Deflectometer data (FWD), determining the percentage of punchout from the Long-Term Performance Program (LTPP) records, and establishing the relationship between both components to estimate the existing punchout distresses. This relationship can be used to calculate the actual damage including erosion damage and to calibrate the local coefficients used in the pavement ME punchout model. This methodology was carried out on one section from Oklahoma and one section from Texas in order to validate its applicability and conclude on the pavement ME punchout model and its ability to predict punchout distress in the field.

Evaluation Of Pavement ME Locally Calibrated Distress Models For Jointed Plain Concrete Pavements In Pennsylvania

Luis Ramirez, Dennis Morian

The Pennsylvania Department of Transportation is currently in the process of implementing the Mechanistic Empirical Pavement Design Guide and its associated software AASHTOWare Pavement ME Design into its standard procedure for designing pavements. Among the key tasks of this implementation effort are the verification of the software's "global" pavement distress and smoothness prediction models and their local calibration to Pennsylvania conditions. These key tasks have been completed in a different study based on test sections located in Pennsylvania. This paper presents an evaluation of the locally calibrated pavement distress models for new Jointed Plain Concrete Pavements using three pavement sections outside the pool of test sections included in the verification and calibration tasks. Three approaches were used in the evaluation. The first two correspond to global and local models with field and laboratory measured input values, and the third one correspond to local coefficients with PennDOT default recommended input values. Additionally, 20-year designs were executed using Pavement ME and compared with designs completed using the 1993 AASHTO design guide. The results of this investigation indicated that for the sections evaluated the local calibration improved the prediction of joint faulting but had a negligible effect in the prediction of fatigue cracking. The global and local distress models under-predicted fatigue cracking and over-predicted faulting for the majority of cases evaluated. Additionally, it was found that the difference in slab thickness designs for Pavement ME and AASHTO93 tend to be larger when the input values deviate more from the local default recommended values.

Iowa Experience on Local Calibration of AASHTOWare Pavement ME Design (PMED) for Jointed Plain Concrete Pavements

Orhan Kaya, Leela Sai Praveen Gopisetti, Halil Ceylan, Sunghwan Kim, Bora Cetin

The AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG) pavement performance models and the associated AASHTOWare pavement ME design (PMED) software are nationally calibrated using design inputs and distress data largely obtained from National Long-Term Pavement Performance (LTPP) to predict Jointed Plain Concrete Pavement (JPCP) performance measures. To improve the accuracy of nationally-calibrated JPCP performance models for various local conditions, further calibration and validation studies in accordance with the local conditions are highly recommended, and multiple updates have been made to the PMED since its initial release in 2011, with the latest version (i.e., Ver. 2.5.X) becoming available in 2019. Validation of JPCP performance models after such software updates is necessary as part of PMED implementation, and such local calibration and validation activities have been identified as the most difficult or challenging parts of PMED implementation. As one of the states at the forefront of implementing the MEPDG and PMED, Iowa has conducted local calibration of JPCP performance models extending from MEPDG to

updated versions of PMED. The required MEPDG and PMED inputs and the historical performance data for the selected JPCP sections were extracted from a variety of sources and the accuracy of the nationally-calibrated MEPDG and PMED performance prediction models for Iowa conditions was evaluated. To improve the accuracy of model predictions, local calibration factors of MEPDG and PMED performance prediction models were identified and gained local calibration experiences of MEPDG and PMED in Iowa are presented and discussed here to provide insight of local calibration for other State Highway Agencies (SHAs).

Session 22: Thin Pavements

Innovative Road Coating: An Original Solution To Improve Safety And Durability Of Concrete Pavement

Duc Tung Dao, Nicolaos Vlasopoulos, Ech Mohsen, Nicolas Miravalls, Eugen Florescu, Christophe Chevalier

The use of pervious concrete with high water permeability has been limited to date to the construction of low traffic roads, car parks or walkways in urban areas. This paper presents an innovative and sustainable pervious pavement structure which offers increased safety, comfort and durability while ensuring an attractive initial cost. The new structure is composed of an ordinary concrete layer offering the required structural capacity and an ultra-thin wearing course providing high standards in terms of safety and riding comfort in addition to aesthetic possibilities (color choices). Structural performance and pavement service life were analysed using French method. Structure durability under heavy traffic was tested by the FABAC heavy traffic simulator of IFSTTAR Nantes using a total of five millions cycles of 6.5 tons half-axle load. Placement in a new highway project using a modified slipform under real conditions is presented with positive results. Finally, a comparison of the carbon footrprint of this innovative pavement structure versus established asphalt and concrete structures is provided which shows and overall reduction in CO2 impacts.

Behavior of Ultra-thin and Thin Fiber-Reinforced Pavements on Granular Base

Manik Barman, Corey Crick, Tom Burnham

With the increasing application of fiber reinforced concrete (FRC) in rigid pavements, the paving industry is now keen to construct thin FRC concrete pavements directly on the granular base layer for low volume roads. In order to understand the feasibility of such thin FRC pavements and to understand the structural responses and distress patterns, experimental test sections were built at the Minnesota Road Research facility (MnROAD) during the summer and fall of 2017. Six different cells were constructed varying in slab thickness, fiber dosage, and base layer thickness. All six of the cells were equipped with various sensors for measuring temperature gradient, dynamic and environmental load responses, as well as joint movement. Periodical distress surveys were conducted to quantify distresses. The joint performance was tested and analyzed for different seasons. The structural responses and distress patterns observed during

the first year of the evaluation are presented in this paper. The early age contribution of synthetic structural fibers in reducing joint faulting, fatigue cracking and spalling are assessed based on the comparative performance of the test cells.

Construction Practices of Short Paneled Concrete Pavements (SPCP) for High Volume Roads

Sridhar Reddy Kasu, Amaranatha Reddy Muppireddy, Nilanjan Mitra

The state of research on narrow and non-dowel short jointed paneled concrete pavements (SPCP) is gaining attention on a large scale across the different parts of the world especially in Chile, the USA, and India. The jointed plain concrete pavements (JPCP), which are designed with slab sizes around 3.5 m x 4.5 m results in thicker slabs with a thickness of paving quality concrete (PQC) layer ranging from 280-330 mm depending on load and temperature stresses on Indian highways. In addition to thicker slabs, JPCP requires dowelled joints, which increases the initial cost of pavement. In order to reduce the thickness and initial cost of construction, the use of cast-in-situ SPCP laid on a strong foundation consisting of a dry lean concrete (DLC) base, cement treated sub base (CTSB) and subgrade is being studied. The square short slabs of size: 1 m, 1.5 m and 2 m joint spacing and of thickness 180 to 220 mm were designed and constructed as two full-scale test sections of SPCP on national highways (NH-2 and NH-33) in India. Slabs were constructed by introducing an initial vertical saw-cut of 3 to 5 mm wide and to a depth of 1/4th to 1/3rd of the thickness. The adopted construction practices through field demonstration and implication of SPCP for highways is the main thrust of the paper which helps the practitioners, designers for adopting such projects in the future.

Determining The Influence Of Concrete Drying Shrinkage In The International Roughness Index Of Newly Constructed Rigid Pavements In Bolivian Altiplano

Christian Rojas Torrico, Orlando Rojas Torrico

In the last decade, the design and the construction of concrete pavements in Bolivia focused on prevention of fatigue damage of concrete by the design and construction of locally named “semi-short slabs” concrete pavements, a solution with slab size between traditional JPCP and short slab concrete pavements. Although the structural performance of these new pavements is adequate so far, it was observed that the length of the slab, which commonly is between 2.4 to 3.0 m, affects functional

performance. Because of the slabs are affected by differential drying shrinkage, they develop permanent curling with wavelengths that have more influence on IRI with respect to other lengths due to the sensitivity of the Quarter-Car model. This article describes the studies conducted to determine the slab curling influence on IRI of concrete pavements built with semi-short slabs in the last years in the Bolivian Altiplano. Longitudinal profile data was collected by means of a laser profilometer in highway sections located in western Bolivia, in regions with high altitudes and arid climate. Based on profile information, mechanistic analyses were done in order to estimate the theoretical deflections along the slabs that correspond to the observed curling. Deflections calculated were then used to estimate a Pseudo Strain Gradient that represent the effects of curling along the evaluated sections. IRI related to slabs curling was calculated and compared to IRI calculated from artificially generated profiles for various slab lengths. Results indicate that slab curling of these pavements has an important influence on IRI of evaluated sections. Recommendations for specifications of new construction projects are presented.

Session 23: Construction Practice

A Review Of The 'Trigger' To Reseal Contraction Joints In Plain Concrete Pavements

George Vorobieff

In NSW all contraction joints are sealed with a highway grade silicone sealant. When these joints are sealed with the reservoir clean and dry, the sealant remains in place without cracking for at least 20 years. Poor joint cleanliness or sealing too early has shown that the seal is likely to be distressed under the wheel paths within the first 2 years. Those sealed joints that are installed correctly will tend to fail in adhesion failure.

Many life cycle costs analysis will nominate resealing these joints at 15 years and while this is generally conservative, limited maintenance funding for road agencies results in fewer opportunities to reseal these joints just prior to or after sealant failure has been observed by roadside inspection. It is also common for the sealant to become distressed in the slow (outer) lane and the sealant is in satisfactory condition in the fast (inner) lane. In addition, sealing distress may be limited to a part of an asset segment and may be related to localised slab cracking in the segment.

In NSW safe work practices for maintenance works is mandatory and to achieve these safe practices represents a significant cost and "just-in-time" resealing is not practical.

This paper provides a critical review of the "trigger" to reseal PCP contraction joints given that distress is not uniform, traffic management costs are significant, minimising traffic disruption and maintenance funding being limited and directed to "safety first" maintenance activities.

Quality Assurance Methods Applied For Exposed-Aggregate Concrete Pavement Construction

Adam M. Glinicki, Michal A. Glinicki

The exposed aggregate pavement technology for construction of concrete highways is used in European countries, including Poland, mostly for heavy trafficked strategic roads. It is mainly a two-lift slip-form technology with a special treatment of the top surface after the final smoothing operation. This is a demanding technology that leaves a little

margin for mistakes. When properly done the pavement layer with exposed aggregates ensures designed skid resistance for vehicle wheels even in adverse weather conditions without excessive traffic noise. The challenge is to provide its cost-effective long term performance including both the adequate roughness and the desired smoothness of the pavement. The paper presents tools and methods for construction quality assurance specific for exposed aggregate concrete pavements. Required monitoring of the stability of concrete mix properties is discussed. The importance of concrete curing is analyzed in respect to the long term durability in wet-freeze regions with heavy use of deicing salts. Macrotexture assessment at the early stage of pavement construction is seen as the key factor for assurance of the proper skidding resistance. Local evaluation of smoothness is also a useful approach to assure the target IRI. Examples of quality assurance efforts applied on concrete highways recently constructed in Poland are presented.

Challenges in the Construction of Concrete Pavements: An Indian National Highway Construction Experience

Venkata Joga Rao Bulusu, Kusam Sudhakar Reddy, Muppireddy Amarnatha Reddy

The construction of cement concrete pavement is a very complex and sensitive process with many factors influencing the quality of concrete and the quality of finished pavement surface. In this paper, the authors presented the construction related issues faced during the construction of a national highway section in India. The major issues discussed are the edge collapse near horizontal curves in winter season in slip form paving method, uneven surface profile caused due to frequent starting and stopping of paver machine due to the difference in the mix delivery speed and the paver speed, the unexpected random cracking in a section of concrete pavement due to the delayed joint sawing, and the insertion marks of dowel bars in the concrete layer to name a few. The range of reasons that lead to theses challenging situations vary from the slope of super elevation to the frequency of vibration used for the dowel bar insertion. To further complicate the construction process, the variability in the quality of cement and super-plasticizer supplied to the construction site necessitate the frequent adjustments in the mix proportions to match the requirements of strength and workability. The selection of joint sawing time is equally difficult with many variables controlling the setting and hardening of concrete mix. The details of the highway section are: concrete layer thickness is 280 mm and concrete mix is of M40 grade, constructed over dry lean concrete sub-base of 150 mm thickness with a 125 microns' thick polythene separation sheet used for de-bonding.

Comparative Study Through Tests Of The Different Concrete Pavement Systems

Jose Manuel Lago Carrera, Aida Badaoui

When the design of a concrete pavement is addressed, one of the most important points is to determine which type is the most appropriate to satisfy the requirements.Based on the classification of concrete pavements indicated in ACI 360[1](Plain concrete, continuously reinforced(bars or welded wire reinforcement), fiber reinforced concrete, shrinkage-compensating and post-tensioned), a series of tests have been developed that allow us to establish a comparison at the level of load capacity.To evaluate the capacity to bending and shear a battery of tests were performed including a beam test and square slab testing.Different systems were designed: Continuously reinforced, steel and macro-synthetic fibers, combined solutions, post-tensioned and shrinkage-compensating concrete pavement.The results show that with an equal amount of steel the load capacity of the continuously reinforced is more than 50% higher than the fiber, and this difference increases when increasing thickness. With equal volume of fiber, the capacity with steel fiber is 25% higher than the synthetic. In Shrinkage-compensating, an expansion of 300 microns/meter was generated, increasing the flexural strength at 0.3 Mpa, improving load capacity and energy absorption. In the post-tensioning system, an effective post-tensioning tension of 2 Mpa was introduced and, consequently, this increase was observed in the appearance of the first crack.In the square slab test the formation and development of the yield lines was observed. Based on the results of the tests and having analyzed the ACI 360 and TR34 to determine the moment capacity of fiber-reinforced concrete and continuously reinforced, it is considered that in the case of continuously reinforced the guides should incorporate a nonlinear method with plasticity considering the ultimate tensile strength of steel. In this way,the comparison between both systems would be closer to reality.Considering only moment capacity and punching shear capacity, it is concluded that solutions with continuous reinforcement (bars or welded wire reinforcement) are more effective for high loads than fibers

Session 24: Curing and Repair

Performance of Non-Cementitious Repair Materials for Concrete Pavement Partial-Depth Repairs In Wisconsin

Prashant Ram, Kurt Smith, Ayesha Shah, Jan Olek, Myungook Kang

The Wisconsin Department of Transportation (WisDOT) is continually looking for state-of the-art technologies, materials, and methodologies to cost-effectively preserve the condition of their pavements so as to extend the service life and delay the need for major rehabilitation or reconstruction. In a search for a more durable and sustainable concrete pavement repair strategy, WisDOT has used non-cementitious materials for partial-depth repairs (PDR) on concrete pavements but with varying levels of success. Where poor performance from these repairs has been observed, it has been attributed to either poor workmanship or inappropriate use of the repair material for the prevailing conditions. These factors suggest that the non-cementitious materials may have been used as a "band-aid" fix to allow for early opening to traffic rather than selected and implemented as the most suitable repair strategy to effectively address the specific distresses in the existing pavement. This paper presents a summary of an investigation into the use of non-cementitious repair materials for concrete pavement PDR applications. A field survey of five different non-cementitious repair materials used in PDR applications throughout Wisconsin was performed and the results documented. Additionally, the findings from a limited laboratory testing program conducted to assess the bond and dimensional stability properties of three non-cementitious materials at different testing temperatures are also presented. The paper concludes with guidance on the use of non-cementitious repair materials for concrete pavement PDR applications in Wisconsin.

On the Differences in Chemistry and Performance Between Types of Rapid Strength Concretes (RSC)

Eric Bescher, John Kim, Michael McNerney

Rapid-setting cements are used in concrete under a variety of acronyms (HES for High Early Strength concrete, or RSC for Rapid Strength Concrete, etc.). Their use is becoming increasingly important because our ageing highway and airport concrete infrastructure requires fast construction in order to minimize downtime. A simple but broad nomenclature for RSC concretes hides several important differences between materials. In some respects, there is no such thing as single RSC; there are several

different types of RSCs with different mineralogies and characteristics. Specifications, appropriately so, focus on performance instead of chemical composition. One key RSC specification is early-age strength, for example 2.76 MPa (400 psi) flexural strength at 4 hours in order to re-open pavement to service. Yet, differences in materials usually result in differences in durability. For example, if only early strength is specified, what is the impact of mineralogical differences on other characteristics like freeze-thaw resistance or shrinkage? Protocols are also important: if pavement enters service at 4 hours, shouldn't a shrinkage measurement also start at 4 hours? Standard shrinkage testing protocols do not. This paper reviews the chemistry and hydration of three commercially available RSC materials (accelerated portland cement, belitic calcium sulfoaluminate cement and calcium sulfoaluminate blended with portland cement and calcium sulfates).

Paste Curing Effectiveness with Contactless Sensing and 2D Wavefield Analysis

Quang Tran, Jeffery Roesler

The serviceability and performance life of concrete pavement are improved by temperature and moisture management during the initial cement reactions, which has been done successfully by various curing methods and compounds. However, the effectiveness of all curing compounds and methods has been difficult to measure spatially and rapidly in the field. In this paper, a new contactless ultrasonic testing system (UTS) and 2D wavefield analysis are introduced to evaluate the effectiveness of curing methods and compounds through monitoring of the near-surface damage of early-age hydrating paste. Cement paste specimens were cast and exposed to elevated drying conditions(23°C air temperature, 46% humidity, and 6.6 m/s windspeed) while subjected to no curing, plastic cover curing, and a wax-based compound. The UTS employed a fully contactless 50kHz ultrasonic transmitter and an array MEMS receivers. The paste specimens were monitored at ages 1, 4, 7 days after casting for the evolution of near-surface cracking. The non-contact UTS monitored the energy of leaky Rayleigh waves (LR-waves)signal overtime and analyzed the frequency-wave number (f-k) domain to characterize the quantity of near-surface damage in the cement paste specimens. An ultrasonic surface damage index (USDI) was defined from f-k wavefield domain based on the ratio of the non-propagating and forwarding LR-waves. The contactless sensing and 2D wavefield analysis easily distinguished the specimen damage differences between the no curing surface, the plastic sheet cover cure,and the wax-based curing. Surfaces with low surface damage had little to zero non-propagating wave energy, which was seen in the wax-based curing specimens and the unexposed bottom surfaces of all cast specimens.

System Design Improvements of Heated Pavements: Recommendations for Future Projects

Amir Malakooti, Sajed Sadati, Halil Ceylan, Sunghwan Kim

Many agencies allocate a great deal of resources to clearing infrastructure systems (e.g., roads, bridges, and airports) from ice and snow during winter seasons using traditional snow-removal equipment and application of salt or de-icing chemicals. Using an electrically-conductive concrete (ECON) heated pavement system (HPS) is a cost-effective and environmentally friendly approach to melting ice and snow. ECON is a carbon-fiber-reinforced form of concrete that uses carbon fiber (conductive agent) with low median electrical resistivity to conduct electrical current through the concrete ECON layer through embedded stainless-steel electrodes. The inherent electrical resistance in the concrete generates heat used in the ECON HPS to melt ice and snow on the surface. ECON HPS construction is different from regular concrete construction in using two-lift paving, two different concrete mixes, and embedded stainless-steel electrodes with electrical connections to a power supply. An ECON HPS demonstration project has recently been constructed at the south parking lot of the Iowa Department of Transportation in Ames, Iowa. This project consists of 10 instrumented slabs, and this paper is focused on the ideas for improvement and lessons learned emerged from the full-scale demonstration project with respect to the construction methods the ECON mix design, control system design, electrode, cross slope design, and instrumentation of the concrete pavement system. These improvements in the construction of this unique concrete pavement system are expected to increase future paving quality, ECON HPS performance, and significantly decrease construction time and cost of such systems.