Standing Committee on Design and Rehabilitation of Concrete Pavements (AFD50)
Georgene Malone Geary, P.E., Chair

with the former Standing Committee on Pavement Rehabilitation (AFD70)
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Concrete Pavement Design and Rehabilitation: History and Evolution

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Headed into the Transportation Research Board's (TRB's) second century, the Standing Committee on Design and Rehabilitation of Concrete Pavements remains focused on the new and rehabilitation design of concrete pavements (conventional jointed plain concrete pavements [JPCP], jointed reinforced concrete pavements [JRCP] and continuously reinforced concrete pavements [CRCP]), while also embracing new concrete pavement technologies (pervious and precast concrete pavements), thin concrete overlays (previously referred to as whitetopping), roller compacted concrete (RCC), and rehabilitation of all types of concrete pavements.

The evolution of and foundation for concrete pavement design are rooted in a number of road tests and empirical studies, including the Arlington Road Test (conducted in the early 1920s by the Bureau of Public Roads at the Arlington Agricultural Experimental Station in Arlington, Virginia), the Bates Road Test (conducted in 1920-1923 by the Illinois Division of Highways near Bates, Illinois), the Pittsburg Road Test (conducted in 1921-1923 by the Columbia Steel Company in Pittsburg, California), Road Test One (conducted in 1950 by the Highway Research Board near La Plata, Maryland), the AASHO Road Test (conducted by the Highway Research Board in 1958-1960), and, beginning in 1988, the TRB-managed Strategic Highway Research Program's Long-Term Pavement Performance (LTPP) study, now under the management of the Federal Highway Administration (FHWA). The LTPP study, along with other supplemental studies from FHWA, NCHRP, and state research programs, most notably the Minnesota Department of Transportation's MnRoad test road, played a major role in the development of the pavement community's groundbreaking mechanistic-empirical pavement design guide (MEPDG) procedure now referred to as Pavement ME Design (PMED) that was first released in 2004. The history of concrete pavement design leading up to the year 2000 is documented in the AFD50 Millennium paper *(1)*. The history of the significant efforts in concrete pavement rehabilitation is included in the AFD70 TRB Commemorative booklet (*2*). These past efforts and the integration of the concrete rehabilitation component inherited from the TRB Pavement Rehabilitation Committee (previously AFD70) will shape the future direction of AFD50.

AFD50 Has a Long History

The forerunner to the Committee on Design and Rehabilitation of Concrete Pavements was the "Committee on the Structural Design of Roads" designated as Research Committee Number 2 in the original by-laws of the Highway Research Board (see Figure 1). As the need for focused research on the emerging range of technical issues in the highway transportation field became more apparent, a "Rigid Pavement Design" Committee was created in 1940, with the original rigid pavement committee membership as shown in Figure 2. The TRB numbering designation changed over time from D-B1 to A2B02 to AFD50. The name "Rigid Pavement Design" appears to have been continuously used until it was changed in 2017.

With the sunsetting of AFD70 (Pavement Rehabilitation Committee), AFD50's name changed again in 2018 to its current version. The changes to the committee name and number over time are noted below:

1940: Rigid Pavement Design
1959: (D-B1) Rigid Pavement Design
1982: (A2B02)
Committee on Rigid Pavement Design
2005: (AFD50)
Committee on Rigid Pavement Design
2017: (AFD50)
Committee on Concrete Pavement Design
2018: (AFD50)
Committee on Design and Rehabilitation of Concrete Pavements

Committee on Structural Design of Roads (1921)

Goal: To establish all of the data required for the rational design of a road surface

Membership:
A. T. Goldbeck, U.S. Bureau of Public Roads
C. A. Hogentogler, U.S. Bureau of Public Roads
Lloyd Aldrich, San Francisco, California
H. C. Berry, University of Pennsylvania
H E. Breed, New York University
F. H. Eno, Ohio State University
E. W. James, U.S. Bureau of Public Roads
Clifford Older, Illinois Division of Highways
H. G. Shirley, Virginia State Highway Commission
E. B. Smith, U.S. Bureau of Public Roads
C. M. Strahan, University of Georgia
E. W. Templin, Akron, Ohio
C. M. Upham, North Carolina State Hwy Commission
H. M. Westergaard, University of Illinois

Figure 1 – HRB Research Committee 2

Current and Recent Past Chairs for AFD50 are noted below:
2016 – current: Georgene Malone Geary
2010-2015: Dulce Rufino Feldman
2004-2009: Anastasios (Tasos) Ioannides
1998-2003: Kathleen (Katie) Hall
1992-1997: Gary Sharpe
1986-1991: Walt Kilareski
1980-1985: Richard McComb
1976-1979: Ronald Hutchinson
1970-1975: B. Frank McCullough

Rigid Pavement Design Committee (1940)

Membership:
Chair: Royall D. Bradbury

A. A. Anderson	J. W. Kushing
H. F. Clemmer	C. Older
A. T. Goldbeck	E. C. Sutherland
O. L. Kipp	L. W. Teller
	H. M. Westergaard

Figure 2- Original Rigid Pavement Committee

Historical Concrete Pavement Research

A review of TRID identified a vast number of reports related to concrete pavement design produced even before the first AASHO Pavement Guide was published in 1972. The earliest identified was a 1925 paper on "Traffic Stresses produced in Concrete Roads" that was issued in HRB, Volume 4, from the 4th annual meeting of what is now known as TRB. In 1928 Westergaard shared the "Theory of Pavement Design" in the

Selected Historic Concrete Pavement Design Reports

Westergaard 1928 HRB Paper (*3*)
Design of Joints 1932 HRB *(4)*
Teller and Sutherland reports, 1930s (*5-8*)
Bradbury 1938 report (*9*)
Friberg Dowel Bar report (*10*)
HRB Report 2B, Joints (*11*)
HRB Report 17B, Joint Spacing (*12*)
AASHO Road Test reports, 1962 *(13)*
FHWA Zero maintenance reports, 1976-77

Figure 3 – Research Highlights in Concrete Pavements

proceedings of the 7th annual meeting. Additional selected historic reports are highlighted in Figure 3.

TODAY

AFD50 Scope and Mission

AFD50 is concerned with aspects of pavement design and rehabilitation that are specific to concrete pavement structures. Areas of interest include modeling of concrete materials for design and performance purposes, as well as selecting and designing effective pavement rehabilitation strategies using concrete. As such, the committee is focused on advancing the best practices for design of new and rehabilitated concrete pavements that lead to concrete pavements that are long-lasting, remain smooth and safe over a long period of time, incorporate measures that allow for expedited construction and are sustainable and cost-effective.

The committee membership comprises all stakeholder groups – highway agency personnel, industry groups, consultants, and academia. The committee regularly reviews gaps in the knowledge and examines the need for continuing advancements in design to optimize the design process. These reviews lead to the development of research problem statements, many of which get funded by the NCHRP, FHWA, and various highway agencies.

The committee has strong relationships with other committees of the Pavement Section (AFD00), the AHD50 (Concrete Pavement Construction Committee), and committees within the Concrete Materials Section (AFN00). These interactions ensure that advancements in related TRB committees are incorporated in the work of AFD50. The committee also interacts actively with American Concrete Institute's Committee 325 (Concrete Pavements), the International Society for Concrete Pavements (ISCP), AASHTO's Committee on Materials and Pavements (COMP) and pavement related committees of American Society of Civil Engineers (ASCE). Many AFD50 committee members serve in leadership roles in these external organizations.

AFD50 Operations

AFD50 encourages the continuous improvement and evolvement of concrete pavement design while also partnering with the concrete pavement construction committee (AFH50) to ensure that the design changes are feasible and address issues identified in the field. Most of the focus on concrete pavement design currently focuses on making improvements and enhancements to the mechanistic-empirical AASHTO Pavement ME Design (PMED) program that was originally developed by NCHRP as the Mechanistic Empirical Pavement Design Guide (MEPDG). PMED uses mechanistically based analytical approaches that predict key distresses using transfer functions that are calibrated using field performance data. Recently, AFD50 has developed research need statements related to improving slab/interlayer friction modeling for use with the PMED and supported research needs for modeling unbonded granular layers for pavements in an effort to improve PMED. AFD50's Advanced Concrete Pavement Modeling subcommittee, AFD50(1), focuses on supporting the development of more accurate mechanistically-based modeling and finite element modeling of concrete pavements to address gaps in current modeling approaches and to incorporate innovations in current concrete pavement design practices.

AFD50 and AFH50 started holding joint mid-year meetings (MYM) in 2012 and has continued these collaborations to this day. The 1½- day MYM provides an opportunity to discuss issues more in-depth and to also visit nearby construction projects to see some of the research implementation in action. The MYM have included visiting construction projects featuring the implementation of PMED, stringless paving, performance engineered mixes, and porous cementitious layers among others.

AFD50 was profoundly changed by the recent strategic organization effort of the Pavements Section (AFD00) with the incorporation of rehabilitation into the committee's scope. The committee sees this as a very positive change that will allow the consideration of rehabilitation to be tied directly with design and vice-versa. As many pavements of the Interstate era have aged to the point of requiring major rehabilitation or reconstruction, it is important that the impact of new pavement design decisions on future pavement repair and rehabilitation be considered early on. Concrete pavement service life expectations have changed from an expectation of 20 years during the 1960s to an expectation of 40 or more years today. This has resulted in advancements in concrete pavement design procedures, discussed previously, and advancements in concrete technology and construction processes.

In the near term, the committee is focusing on incorporating rehabilitation into the work of the committee. The American Concrete Pavement Association, the Iowa State University's Concrete Pavement Technology Center, and the State DOT pooled-funded National Concrete Consortium (NC^2) already consider rehabilitation and design, and they are all represented on the AFD50 Committee, so this will assist in the transition. Looking forward, the committee will continue to focus on areas such as long-life concrete pavements, different types of concrete pavements, and overall sustainability issues.

AFD50 Focus Areas

Long Life Concrete Pavements

Long Life Concrete Pavements (LLCP) will continue to be one of the focus areas of the committee. Research in improving and optimizing design and rehabilitation options are necessary to realize the LLCP goal while meeting the budgetary constraints faced by all U.S. highway agencies. Research needs that exist in current design methods include modeling addressing longitudinal cracking, furthering the understanding of concrete slab curl and warp, more reliable joint faulting models, and improvements in the overall modeling process including the use of finite element models. Improving the design and rehabilitation process for specific concrete pavement types and applications—such as continuously reinforced concrete pavement (CRCP), precast concrete pavement (PCP) and airfield concrete pavements—are critical components on the long-life concrete pavement journey.

Concrete Overlays

Concrete pavements have undergone a significant shift during the past several years that will continue well into the future. With the completion of the Interstate system, tighter environmental impact controls, reduction in available natural resources, greater emphasis on sustainability and constrained State DOT agency budgets, new construction is becoming less frequent. States are relying primarily on additional structural layers for rehabilitation of existing pavements. Specifically, the past practice for rehabilitating concrete pavements has been with asphalt overlays, but to some degree this has given way to a general acceptance of either performing concrete restoration on existing pavements or placing concrete overlays, which can be designed to be bonded (in which the concrete overlay is bonded to the existing underlying pavement) or unbonded (in which the concrete overlay is separated from the existing underlying pavement).

For each of these overlay types, new design procedures are providing for more effective structural designs. For example, the BCOA-ME design method, developed through a pooled fund study at the University of Pittsburgh, provides a proven design procedure for concrete overlays on existing asphalt pavements. In addition, a design procedure for unbonded concrete overlays is currently under development and is expected to be available in 2019. These type of advancements in concrete overlay design should provide more opportunities for project implementation by transportation agencies. To keep pace with the expected acceleration of concrete restoration and concrete overlay projects, future research and training will need to cover a variety of topics in relation to these strategies. This is important because not all transportation departments with sizeable concrete pavement infrastructure, particularly local public agencies, have kept pace with current developments. Validated restoration practices and overlay design procedures must be disseminated across a broader audience.

Precast Concrete Pavement

Precast concrete pavement (PCP) technology is gaining wider acceptance in the U.S. for rapid (overnight) repair and rehabilitation of concrete pavements, as well as for reconstruction of heavily trafficked asphalt concrete intersections and freeway ramps. Widespread use of PCP in the U.S. is fairly recent, with most projects in service less than about 15 years old. Nonetheless, dozens of projects have been constructed, and advances continue to be made in all aspects of the technology, including panel design, fabrication, and installation. PCP technology is being used for intermittent repairs (both full-depth repairs and full panel replacement) and for continuous applications (longer-length/wider-area rehabilitation) with service life expectations of at least 20 years for repairs and at least 40 years for continuous applications, without significant future corrective treatment.

Available PCP systems include jointed PCP with reinforced or prestressed panels installed singly or in a continuous series, as well as PCP that typically incorporates thinner reinforced or prestressed panels installed and posttensioned in a continuous series, resulting in fewer active joints. The use of PCP technology can significantly reduce the impacts that roadway repair and reconstruction projects have on traffic, particularly on heavily traveled routes. The use of both jointed PCP and posttensioned PCP systems has advanced during the last decade and innovations continue to be made to improve the design process and efficiency and quality of construction, and to reduce costs. AFD50 will continue to monitor and support these advancements and develop appropriate research needs statements to support future improvements in the technology.

Concrete Pavement Rehabilitation

With the aging of the pavement infrastructure, the importance of effectively maintaining the serviceability of existing concrete pavements remains paramount. A range of maintenance and rehabilitation treatments are available, ranging from preservation and maintenance treatments (such as joint sealing and slab stabilization) to minor rehabilitation activities (such as dowel bar retrofit and full- and partial-depth repairs) and to major rehabilitation activities (such as concrete overlays, as discussed previously). Key aspects related to these treatments is targeting them to address the specific deficiencies in the pavement and ensuring that they are placed in a timely manner before the pavement is exhibiting excessive levels of deterioration as noted in Figure 4. Through the application of the proper treatment in a timely manner, a number of significant benefits can be realized, including improved pavement condition, increased safety, higher customer satisfaction, and cost savings.

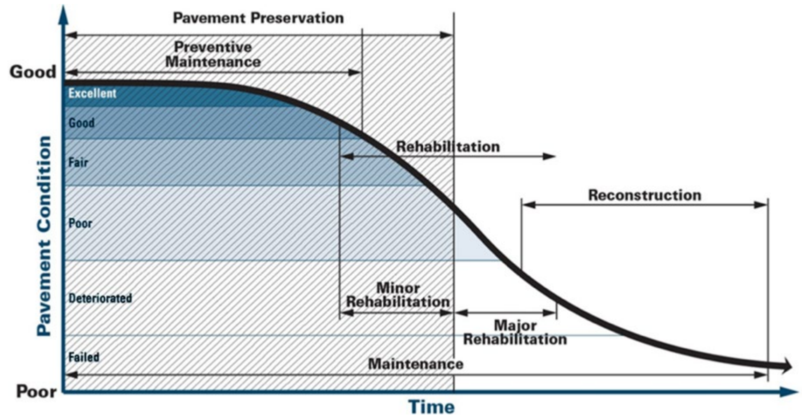

Figure 4- Pavement Preservation, Rehabilitation and Reconstruction Timeline

Newly Adopted Topics and Emerging Areas

Roller compacted concrete (RCC) has been constructed for several decades but the advent of improved methods for compacting concrete with high density pavers and finishing the surface with chemical admixtures have created possibilities for more conventional uses. Unknowns which must be explored include load transfer issues/jointing, acceptability of surface ride and texture, and life cycle costs.

Performance engineered mixes (PEM), new supplementary cementitious materials, new fibers and nano-engineered admixtures, fly ash changes and changes in deicers, and other maintenance operations can all affect the long-term performance of concrete pavements. All are related to the issues with shrinkage, permeability, and durability of concrete. These changes can affect design or rehabilitation strategies.

With pavement reconstruction, the opportunity arises to make use of aggregate from old concrete pavement in new applications. Most agencies permit the use of recycled concrete aggregate (RCA) in bases, subbases, and granular fills. However, only a few agencies have used recycled concrete as aggregate in new pavement slabs, which should be encouraged as new aggregate resources decline.

Sustainability of Concrete Pavements

Sustainability considerations continue to play a significant role in the design of pavement structures as highway agencies look to consider key environmental, social, and economic factors in the decision-making process. Opportunities for improving the sustainability of concrete pavements exist in all stages of the pavement life-cycle, with the following life cycle stages of relevance to AFD50:

- **Materials.** Sustainability benefits can be obtained through reductions in portland cement and increased use of supplementary cementitious materials, blended cements, optimized mixtures, and recycled aggregates. Alternative, non-cementitious materials, such as polymer concretes, may also emerge as viable paving products.
- **Design**. The use of improved mechanistic design procedures and optimized structural designs that also consider the benefits of durable-fatigue resistance supporting pavement layers will contribute to long-life designs and more sustainable pavements.

- **Use**. This stage refers to the period during which the pavement is in service and is interacting with vehicles and the environment, with sustainability benefits achieved through smooth and quiet pavement surfaces that provide adequate friction.
- **Maintenance/Rehabilitation**. Generally, sustainability benefits are derived by applying maintenance/rehabilitation to maintain smoothness and safety of the roadway while also extending the service and structural life of pavement.
- **End of Life**. The end of life refers to the final disposition and subsequent reuse, processing, or recycling of the pavement after it has reached the end of its useful life. Simple disposal of concrete slabs in landfill locations should be avoided, with opportunities explored to incorporate the old PCC pavement as a structural layer in the pavement or rubblizing and reusing the material as aggregate for use in new pavement structures (either as a base, subbase, or granular fill, or in a new concrete slab).

The use of life-cycle assessment (LCA) procedures to assess environmental sustainability is starting to take hold in the transportation arena, especially as related to pavements with the recently released Sustainable Pavements document (*16*). Improvements to the methods and data on issues such as resiliency of pavement structures under flooded conditions and more accurate maintenance and use phase statistics are still needed.

Additional Issues

The current design software (PMED) focuses on transverse cracking of concrete pavements, but longitudinal cracking in concrete pavements and curling/warping continues to be an issue that needs additional research to address. Along with the TRB Concrete Materials committees, AFD50 recognizes the need for durable concrete pavements and test measures to ensure durability. A specification on Performance Engineered Mixes (PEM) is still in provisional status and these PEM concrete mixes are just starting to be used; therefore, documentation and research on their performance will benefit the future of concrete pavements. Other improvements to the concrete pavement area that could be advanced through targeted research include alternative load transfer devices, an updated review on the effect of joint sealing, appropriately accounting for foundation effects on performance, and use of fibers in concrete pavement design.

TOMORROW

The Committee’s latest Triennial Strategic Plan (2017-2020) identified some new areas that the committee sees as coming or relevant for this committee as related to national asset management policy, maintenance of traffic in our increasing congested roadway network, and the coming of automated/connected vehicles. The Committee will also continue to address the latest advancements in concrete design methodologies.

Asset Management

The latest protocol for pavement management from the FHWA is based on traditional data collection distresses. This data collection method (the protocol) was also based on visual or limited “manual” distress collection methods. Today data collection is performed predominately by using 2D or 3D (dimensional) lasers at highway speed to collect the data for pavement distresses. International Roughness Index (IRI) is the major measure related to the roughness of pavement. Apparently, pavement curling/warping will have a compounding effect to any “real” faulting. This in turn will affect the results of the IRI that is the major influence in asset management.

Construction under Traffic

Maintenance of traffic (MOT) while constructing or reconstructing concrete pavements is more of an issue for concrete pavements than asphalt pavements primarily due to the elevation difference in the layers and curing requirement. A recently completed NCHRP synthesis (*17*) on MOT for concrete pavement construction and rehabilitation identified additional research needs in this area. Maintenance of traffic (MOT) is not only an issue with the pavement rehabilitation (patching), but also in pavement reconstruction. In practice, some contractors are practicing "half width" pavement for MOT and constructing the other half when they switch traffic. Others have built the pavements over thick and milled the pavement down to reach final grade. There is no guidance at all about practice and design of these techniques, and it is unclear at this time if these techniques will continue to be used; consequently, this is an area that the committee needs to continue to discuss and potentially identify research to address. Complicated MOT also involves informing the public, an area this committee could coordinate with other committees on addressing.

Driverless/connected vehicle connection: sensors, pavement markings

The committee needs to maintain awareness of actions in this area, although current developments are in their infancy and it is premature to determine precisely what actions may be required. In discussions, the committee felt that concrete may be preferable to asphalt to house any pavement sensors needed for the new technology. Concrete pavements are now standard in high quality weigh-in-motion (WIM) sites due to their durability and stability. Pavement markings on concrete pavements are another area that may increase in criticality, dependent on the technology used. Currently, some areas are having trouble maintaining pavement markings on concrete on high speed areas. Causes and solutions may be needed to allow the markings to be used as guidance in the future.

Advancements in Concrete Pavement Design Methodologies

As discussed, it is becoming an established practice in the United States to require that concrete pavements provide low-maintenance service lives of 40 or more years, although some would argue that 75 to 100 years should be the goal. Long-life concrete pavements have been attainable for a long time (as evidenced by the fact that a number of very old pavements remain in service); however, advances in design, construction, and concrete materials technology continue to give us the knowledge and technology needed to achieve consistently what we already know to be attainable. This knowledge and technology, together with on-going developments/innovations in concrete and concrete pavement technologies, continue to refine our best practices, as indicated below:

Today's Best Practice + New Developments/Innovations => Tomorrow's Best Practices

We expect that the concrete pavement design procedures will continue to evolve beyond the current practice (mechanistic-empirical pavement design) and incorporate a better understanding of how concrete pavements behave under traffic and environmental loadings. This will allow us to design concrete pavements more reliably for a longer initial service life (60+ years from the current 40+ years) and allow us to incorporate sustainable design features. While our understanding of how concrete pavements behave has improved over the last 20 years, we expect the following factors will result in significant advancements to existing concrete pavements design procedures, allowing consideration of a range of design features and paving materials options for longer-lasting and sustainable concrete pavements:

1. Improved finite element based concrete pavement structural analysis models to better characterize the pavement systems, including foundations.
2. Improved paving material characterization.
3. Continued availability of long-term concrete pavement performance data from FHWA's LTPP study and highway agency pavement management databases.
4. Use of advanced automated pavement condition data collection to populate pavement performance databases that can be used to recalibrate/validate pavement performance models used in design procedures.
5. Consideration of two-layer concrete pavements where thickness and materials can be proportioned to optimize local and recycled materials use.
6. Use of optimized joint spacing that allow use of thinner and smaller dimensioned slabs.

SUMMARY

Committee AFD50 has a proud tradition of supporting innovations in concrete pavement analysis that lead to better understanding of how concrete pavements behave under truck and environmental loadings. The improved understanding leads to continual improvement in the best practices for design of new and rehabilitated concrete pavements. The committee expects to continue this tradition in future years.

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