Summary Discussion

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At the Symposium on the Structural Design of Asphalt Concrete Pavements to Prevent Fatigue Failure, we were impressed with the advances that have been made in the understanding of pavement failure and in our ability to predict that failure with respect to the fatigue phenomenon. The other modes of failure, rutting and roughness, have also been covered to some extent by several of the authors, especially Havens and Deen. However, one of the big unanswered problems has to do with the interaction of those failure modes and its effect on pavement life. We are currently able, in a rough way, to predict fatigue performance and rutting performance, but as yet we are unable to combine the two with much certainty or to actually include the roughness effect as a performance modifier.

Barksdale and Hicks listed the many factors inherent in the design of pavements: environment, traffic, material properties, construction variables, maintenance variables, and economics. Because of the many factors and the many variables associated with those factors, we at the Federal Highway Administration are striving toward a probabilistic or stochastic approach to design. Barksdale and Hicks also pointed out that the characterization of the materials, especially granular materials, is not a straightforward linear problem but that moduli and Poisson's ratios vary with the stress state. That is true; however, it is yet to be shown that this effect is important enough to warrant complicating the testing and analysis procedures to account for it. Stress was also placed on the effects of moisture and temperature on pavement performance. Nearly everyone working on new methodology for flexible pavement design seems to be confident that the temperature variations can be accounted for, but so far I have heard little if any assurance that moisture variations can be as easily handled.

In their discussion of layered systems analysis, Barksdale and Hicks presented a rather detailed outline of the history of what might be termed "The Struggle to Develop a Rational Design Method for Flexible Pavements." I first entered into that struggle in 1946 as Don Burmister's assistant at Columbia University—not that I played a great part, but I was exposed to it. Later at Purdue University I spent about 2 years measuring and analyzing stresses and strains in layered systems. As you can see, this struggle has

been going on for at least 25 years, and only now are we beginning to see what could be a "negotiated peace."

Pell performed an excellent job of defining the technical terms and criteria used in the fatigue analysis of pavement performance. He also related the problems associated with fatigue testing and fatigue characterization of the pavement components. According to him, one of the major problems associated with the testing is that of duplication of in situ stress states in laboratory test procedures. Here again, we all agree that it is a problem, but we differ as to how much of a problem it is. The situation is still in such flux that I can continue to hope that the problem is negligible. I am convinced that if Majidzadeh continues to make progress in his work in fracture mechanics the problem will disappear. In fact, he states that in his work the prediction of fatigue life of pavements from laboratory tests is independent of the mode of loading or the specimen geometry.

Pell also stated that the slope of the fatigue line (fatigue characteristic) appears to depend on the stiffness characteristics of the mix and the nature of the binder. He said further that the 2 factors that appear to be of primary importance are binder content and voids content with an existing optimum fatigue life dependent on the relations of binder, filler, and voids. For good fatigue performance of thick asphalt construction, a mix of maximum stiffness should be the objective, and the quantities of filler and binder should be such that a condition of maximum tensile stiffness associated with minimum voids is produced.

Hudson provided a great deal of information concerning input variables, how they may or should be obtained, and how they may be used in the design system. One aspect of fatigue that has not been extensively discussed is that of thermal fatigue. Some excellent work in that area has been done in Texas.

Deacon outlined a design process that is basically a trial-and-error procedure wherein (a) a trial structure is assumed; (b) the structure is analyzed by estimating the levels of the critical stresses and strains anticipated under in-service loading; (c) the structure is evaluated by comparing the estimated stresses and strains with tolerable levels derived from failure criteria; and (d) modifications are made to the structure as necessary, and the process is repeated until a satisfactory design has evolved. He defined failure, as do most of the authors, but there is still much room for agreement among them.

Finn reminded us that we must determine how much cracking is bad, what kinds of cracking are bad, and what happens to a pavement after cracking occurs. Those are all questions that need to be resolved in order for cracking predictions to be meaningful. A certain amount of cracking is acceptable in terms of riding quality, but so far we are not sure what it means in terms of structural integrity. Finn discussed possible criteria for using cracking as a performance parameter and suggested that subjective evaluations of the future utility of a given pavement together with objective measurements of the amount of cracking existing on the pavement be used to develop useful cracking criteria.

Terrel gave excellent reviews of several of the important field and test track studies. He has done some fine work with his test track and has provided much data that have been used in comparison with predicted results. He concluded by saying, "It would appear that prediction of fatigue failure in actual pavements is feasible. However, there appears to be a basic lack of knowledge in the actual behavior of pavements under varying loads and environments."

Witczak presented an excellent example of the use of the latest available methodology in the development of an actual design procedure for airfield pavements. When a truly rational design method is established, we should be able to leave off the labels of airport or highway and say we have procedures for the design of any pavement for any purpose.

At FHWA, we are particularly proud of the presentation by Havens and Deen. It is a good example of the work of the personnel of a state highway department research group. It typifies the attitude of many of the state departments toward research and their efforts to take advantage of every opportunity to improve their operations. Although it cannot be labeled as truly rational, it is a major step forward.

Most of the presentations at the symposium were directly or indirectly associated with the FHWA research project on the rational design of flexible pavements. That project originated in 1965 and is currently carried as Project 5C, New Methodology for Flexible Pavement Design. Administrative funding of this project will end with fiscal year 1973 funding; however, in-house and HPR portions of the project will continue for several more years.

Recently an administrative fund contract that was concerned with the subject of this symposium was completed. The results of that study will be reported by Smith and Nair in a paper to be published in the 1973 Highway Research Record series. The authors report the following conclusions.

1. The predominant parameter variation causing uncertainty in fatigue life is that associated with construction control of air voids in the asphalt concrete.
2. A more accurate definition of the fatigue failure criteria for asphalt concrete would be more beneficial than improvement of the constitutive material characterization beyond isotropic linear elasticity.
3. The uncertainty associated with characterization of pavement materials by isotropic linear elasticity can contribute significant uncertainty to the prediction of fatigue life. However, that induced uncertainty in fatigue life is of less significance than the uncertainty induced by field control of air voids or fatigue criteria definition.
   a. Improved characterization of asphalt concrete would be most beneficial for full-depth and thick asphalt concrete surface pavements.
   b. More accurate characterization of untreated granular base course material would also be advantageous, especially for pavements located in hot climates.
   c. An isotropic linear elastic characterization of subgrades is adequate if the characterization is performed under levels representative of in-service subgrades.
4. Consideration of variations in water content and densities of in situ base course and subgrade materials would be beneficial for pavements located in hot climates.
5. Within the existing techniques for considering temperature in the analysis, the ability to predict the temperature is sufficiently accurate.
6. Thickness control of the asphalt concrete layer is now sufficiently accurate.

It should be recognized that the adequacy of a material characterization is a dynamic phenomenon. As our ability to describe and control the effects of other parameters influencing the fatigue life of flexible pavements improves, characterizations that are now adequate may become inadequate.

At a meeting at the University of Nottingham in September 1972, I announced that the FHWA would have a flexible pavement design system developed and ready for use by fiscal year 1975. Many of those attending that meeting intimated that this was an impossible goal. However, I still stick by that estimate even though Bill Kenis says it is his neck I am sticking out.

Many of us in the FHWA Offices of Research and Development are essentially research managers, although we do have a very active in-house program. Our superiors insist that we produce a useful product in the shortest time and at the least cost possible. It is my belief that the only way to produce a rational design method is to assemble all available knowledge into the most logical and feasible system and give it a trial. Such trials will soon point out whether we have a good system or whether our information is deficient and more research is needed. Therefore, we are progressing along those lines.

Briefly, our plan is to assemble together in a modular system all of the subsystems we have or will have when our staff research and contract effort is completed. We will use much of the information presented at this symposium. The fatigue concept will be a modular subsystem with a fracture mechanics module as an alternative; elastic and viscoelastic stress analysis and strain computation modules will be included. We will then try those alternatives in actual designs and compare them in highway department designs, test tracks, and other accelerated test facilities. In fact, we have already started that program at Pennsylvania State University. The university, the Pennsylvania Department of Transportation, The Asphalt Institute, the Crushed Stone Association, and FHWA are cooperating in an evaluation of some of the existing

methodology. We are particularly interested in evaluating the M.I.T. viscoelastic methods for predicting rutting. The materials will be tested in the laboratory; predictions will be made of cracking, rutting, and roughness; in-service measurements will be taken; methods will be adjusted; and new predictions and new measurements will be made until methods are calibrated or discarded.

Once we have developed a workable pavement design system, we can then determine whether many of the refinements about which we now worry are really essential or whether they are more or less window dressing for the purist. We will also be able to concentrate on what I think is an important problem—designing a positive environment for pavement that will allow us to predict more accurately the performance characteristics of the designs. With those tools, a pavement design system, and a roadway system design guide, each agency will be able to predict and finance a well-planned, well-managed service life for each pavement constructed.