

CONCRETE PAVEMENTS, NOW AND TOMORROW

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Our pavement system represents one of the most important of our public investments. Concrete pavements make up a significant portion of the pavement system which is composed of our highways, civil airports, and military airfields. This paper discusses the status of the existing concrete pavements. Lacking specific data regarding the condition of the existing concrete pavements, the discussions have been made assuming that they have performed about the same as the total pavement system. Rehabilitation of the existing pavement system is generally agreed to be the major pavement construction program for the future and the role of concrete pavements in effecting the rehabilitation is examined.

Introduction

The pavement system in the United States consists of an extensive network of highways and airports designed for the rapid and efficient movement of goods and people. The highway system, composed of nearly 6.4 million kilometers (4 million miles) of pavement (1) at a cost of about \$1 trillion (2), carries around 90 percent of the goods consumed in the country at some stage of their production and distribution (3). It has been estimated that the highway system supports an economic activity of over \$360 billion, or about 15 percent of our gross national product (4). The airport system, composed of approximately 10,000 airports, ranges from private strips to large civil and military facilities. There are about 570 air carrier airports and 300 military airfields in the system, representing around 334 million m^2 (400 million yd^2) of pavement. When the highway and airport systems are combined, the total pavement system clearly becomes one of our most important public investments. The expansion and maintenance of this viable pavement system for the continued economic development and defense of the nation must be considered to be high priority.

According to highway statistics (1), the highway system is composed of 46.3 percent unpaved and 53.7 percent paved mileage. Of the paved mileage, about 3.6 percent, or 224,254 kilometers (139,345 miles), are concrete. This latter statistic may be somewhat misleading since the pavement mileage is listed in accordance with the surface type. That is, a

concrete pavement that has been resurfaced with 25.4 mm (1 in.) or more of bituminous concrete is shown as flexible pavement and many kilometers (miles) of this type pavement are known to exist. Considering only the more recently constructed and heavily loaded pavements, 52.6 percent of the interstate and 15.3 percent of the primary arterial pavements are shown as concrete. About 108.7 million m^2 (100 million yd^2), or 20 percent, of all civil airport pavements have been constructed with concrete, but when considering only the air carrier airports, this percentage increases to around 30. Approximately the same statistics apply to the 83.6 million m^2 (100 million yd^2) of military airfield pavements; however, when only the heavy load airfields are considered, the percentage of concrete pavements increases to about 50. From these nominal statistics, it can be seen that there has been a sizeable investment in concrete pavements during the development of the pavement system and that concrete seems to be selected more frequently as the volume and magnitude of loadings increase.

Concrete pavements, constructed either on-grade or as a resurfacing of an existing pavement, are very complex structures, and there are a number of significant variables which influence their performance. As a result, the procedures that have been used to design concrete pavements have had to concentrate on only a few of these variables. Generally, these include the ultimate strength and fatigue characteristics of the materials, the magnitude and frequency of loading, and the effects of some of the major environmental factors such as freeze-thaw and moisture. Other variables, such as swelling soils, extremely moisture-sensitive soils, unstable aggregates, etc., become important in design on a case-by-case basis when they are known to exist. Numerous procedures have been used to design the concrete pavements in the existing system, but presently two basic methods are commonly used. The AASHTO design method, used exclusively for highways, is based upon the empirical relationships derived from the AASHO Road Test. They are supplemented by theory and local construction experiences. The design philosophy is based upon pavement serviceability, a subjective rating dependent upon pavement condition, rideability, etc. The second method is one based upon the flexural stress and flexural strength of the concrete with the design philosophy being fatigue cracking in the concrete under loading repetitions. This method has been developed and is used by the

Portland Cement Association (PCA), the Corps of Engineers (CE), and the Federal Aviation Administration (FAA) for the design of highway, military airfield, and civil airport pavements.

Both of these design procedures are essentially restricted to monolithic plain concrete pavements, either because of the empirically developed relationships used or because the basic theory is not applicable for layered systems. The CE has developed empirical relationships which permit the use of their method for the thickness design of reinforced pavements and concrete resurfacings. They have been used for the design of airfield and airport pavements; however, they have not been widely used for highways.

Concrete Pavements, Now

To assess our current posture in the use of concrete pavements, it is prudent first to review the performance of our existing pavements. Concrete has been used to construct city streets, farm to market roads, county highways, state highways, federal-aid primary (including interstate) highways, civil airports, military airfields, and large areas of parking and storage area pavements. Jointed plain concrete, jointed reinforced concrete, and continuously reinforced concrete pavements have been the predominate types used. However, prestressed concrete and fibrous concrete pavements have been used on a limited basis and as experimental or demonstration sections. The pavements have been constructed on a variety of landforms and in a wide range of climates or environments. Subgrade treatment, subbases, drainage, frost protection, and joint type and spacing are variables which have received much attention during the construction of the existing pavements and several different designs have emerged. Much study has gone into the selection and proportioning of the concrete materials and into additives to control the concrete properties. Construction procedures have progressed from a high labor-intensive process of mixing and placing to very effective automatically controlled batching plants and electronically controlled slip-form pavers. Past design and construction practices are described in more detail by Ray (5) and Nussbaum and Lokken (6).

The existing pavement system has experienced growth of both the volume and magnitude of traffic loadings. An average daily traffic volume of 20,000 and over for rural interstates or 50,000 and over for urban interstates is no longer unusual. Other principal arterials are experiencing average daily traffic volumes of 10,000 and over and even the minor arterials experience volumes ranging from 1,000 to 10,000 (1). Of even greater significance is the fact that 26.5 percent of the annual vehicle mileage on the entire pavement system is by trucks and average daily truck traffic volumes of 2,000 to 6,000 are not unusual (1). The Surface Transportation Assistance Act of 1982 mandated that double-trailer trucks and gross vehicle loadings up to 36,287 kg (80,000 lb) be allowed to use all of the interstate system and many of the other federal-aid pavements. While double- and triple-trailer trucks have been allowed in certain states for some time, their effect on pavement wear is not yet known and is under study by the Transportation Research Board (TRB) (7). For many years aircraft gross weights increased very rapidly with the development of new and heavier aircraft. For example, aircraft gross loadings ranged from 22,680 to 45,359 kg (50,000 to 100,000 lb) in the 1940's and 1950's; 158,757 to 226,796 kg (350,000 to 500,000 lb) in

the 1960's; and 226,796 to 340,194 kg (500,000 to 750,000 lb) by the 1970's. Within the last 10 years, the aircraft gross loadings have seemed to stabilize; however, traffic volume has continued to increase, especially at air carrier airports. These increases in vehicle and aircraft gross weights and traffic volumes were generally beyond the comprehension of pavement planners and designers when many of the existing concrete pavements were constructed.

Performance is the true measure of the adequacy of the existing pavement system and the systematic collection of this type information has long been encouraged. While we have all experienced the condition of our pavement system through its rideability, and much has been said and written about its deteriorated condition, quantitative data regarding performance, especially by pavement type, have been elusive. Several performance studies have been conducted and the results used to modify design and construction methods where appropriate; nevertheless, uniform quantitative performance measurement methods are just now being implemented. Many of the performance ratings used have been subjective and based upon the observance of distress in the pavement. Such ratings have been useful for the evaluation of design methods that predict distress. One such study by Hutchinson and Vedros (8) of the performance of 25 military heavy load concrete airfield pavements in 1977 indicated that after 20 to 25 years these pavements were generally rated from good to excellent for both their structural and functional condition. The study concluded that the CE design procedure produced a pavement that met the user-stated requirements but that there might be some conservatism, especially at the higher traffic volume levels. Another important finding of their study was that the percent pavement life used was dependent more upon the aircraft gross loading than upon the traffic volume. This is simply another way of saying that the heavier loadings cause the bulk of pavement damage, a fact that is also revealed by any pavement analysis method.

It has been realized that the development of structural distress is not a true measure of the adequacy of the pavement to meet user requirements, and for several years highway pavement performance has been measured in terms of serviceability (or more specifically Present Serviceability Rating (PSR)). The PSR ranges from 5.0 (excellent) to 0 (failed) and when the PSR falls below 2.4 for interstates or 1.9 for other highways, they are considered to be deteriorated to the point of needing rehabilitation. Rehabilitation is used in its broadest sense in this paper (i.e., to restore the pavement to its former state or condition and includes restoration, resurfacing, and reconstruction). In 1977, Nussbaum and Lokken (6) reported the condition of 86 concrete highway pavements (Table 1). Most of these pavements were interstate; however, some were other principal arterial pavements carrying substantial traffic. Only one of the 86 pavements was considered to be deteriorated, having reached a PSR of 2.3. This pavement was a 228.6-mm (9-in.) plain concrete which was 9 years old and carrying an average daily truck traffic volume of 5,355. The average condition of all pavements surveyed was good, with PSR's ranging from 3.8 to 4.3. These pavements probably had a PSR rating ranging from about 4.5 to 5.0 when constructed. For concrete pavements, the decay in PSR with time is generally considered to be a hyperbolic function; assuming this to be true, the average PSR's for the 86 pavements indicate that approximately 40 to 50 percent of their life had been used. Therefore, assuming no significant change in traffic loading conditions, these pavements should provide

Table 1. Summary of Condition of Concrete Highway Pavements.

Type Pavement	No. Surveyed	Age, yr		PSR	
		Range	Avg	Range	Avg
Jointed Plain	32	4-25	10.0	2.3-4.6	3.8
Jointed Reinforced	31	5-18	10.5	3.2-4.6	3.9
Continuously Reinforced	23	2.5-14	7.8	3.9-4.7	4.3

about 20 years of service before reaching the deteriorated state. While many consider this to be about the normal for concrete pavements, it is, of course, a gross approximation because so much depends upon the amount and type of maintenance that is performed throughout the life of the pavement.

According to the 1981 Highway Statistics (1), 64.9 percent of the interstate pavements were rated as good with a PSR of 3.5 to 5.0; 29.4 percent were rated as fair with a PSR of 2.5 to 3.4; and 5.0 percent were rated as deteriorated with a PSR rating of 0.1 to 2.4. For the other principal arterial and the minor arterial pavements, 45.1 percent were rated good with a PSR of 3.5 to 5.0; 47.8 percent rated fair with a PSR of 2.0 to 3.4; and 7.1 percent rated deteriorated with a PSR of 0.1 to 1.9. Interestingly, in 1983 it was estimated that nearly 12,875 km (8,000 miles) (about 20 percent) of the interstate pavements were in immediate need of resurfacing or reconstruction, with nearly 3,219 km (2,000 miles) more reaching that condition each year (9). Thus, it appears that the pavements are deteriorating at a higher rate than they are being rehabilitated. Although similar statistics were not given for pavements other than interstate in 1983, it is probable that they have deteriorated at a similar or more rapid rate and, if so, it would appear that as much as 804,672 km (500,000 miles) of our paved highway system may have reached the deteriorated stage and are in need of rehabilitation. These highway statistics are for all paved surfaces since they are not available for concrete pavements separately. Nevertheless, it is apparent that many miles of concrete highway pavements are nearing, or have reached, the deteriorated state and are in need of rehabilitation. In support of this conclusion is the signing found on a concrete pavement portion of I-20 in Louisiana which encourages truckers to use the left lane because of the deteriorated condition of the right lane.

Performance data for civil airport pavements are minimal; however, considering the rapid growth in civil aircraft gross loadings and traffic volume that has taken place through the 1970's, it is reasonable to conclude that many square meters (yards) of airport pavements have reached the deteriorated stage and are in need of rehabilitation. As far back as 1970, the Airline Pilots Association was expressing concern about the hazards of rough pavements (10) and need for improved skid resistance, especially in concert with the developing high-performance aircraft such as the 747, DC-10, L-1011, and SST Concorde. In 1984, the staff of the TRB's Technical Activities Division (11) concluded that "General aviation airport runway deterioration continues to be a major problem in most states."

The use of concrete to resurface existing highway and airport pavements dates back to 1913 (12); however, performance data are minimal. Many of these concrete resurfacings were designed based upon local experiences and engineering judgment or, more simply, a minimal thickness was used. During the 1950's and 1960's, concrete resurfacings (overlays)

played a major role in strengthening existing military airfield pavements as aircraft gross loadings increased. Continued observations of many of these resurfacings for 10 years or more indicated that they performed equally well with completely new pavements (13). As a result of a 1975 condition survey of continuously reinforced concrete overlays (resurfacings) on several highway pavements, it was concluded that "Performance to date points to the conclusion that concrete overlays will provide good performance, low maintenance requirements, and long service, with performance surpassing that of most bituminous overlays." (14) Similarly, one of the most significant and encouraging findings of a 1977 condition survey of plain and reinforced concrete resurfacings (15) was "that with proper attention to detail, concrete resurfacings with a number of different basic designs can be built to last more than 20 years." A detailed description and discussion of the design, construction, and performance of concrete resurfacings is contained in a synthesis report (12). The performance of concrete resurfacings has varied, but many have given 20 to 25 years of service with some lasting 40 years or more. In fact, several of the earlier concrete resurfacings have reached the deteriorated stage and have been subjected to yet another resurfacing. These latter pavements are often referred to as composite pavements and they represent a very complex pavement section insofar as analysis is concerned. Although no statistics are available regarding the quantity and condition of concrete resurfaced pavements, it would be reasonable to assume that any approaching 20 years old are nearing the deteriorated stage and are in need of rehabilitation.

The deterioration, or loss of serviceability, of concrete pavements is generally associated with joint faulting, slab-cracking, spalling, buckling, and subgrade pumping (6). Other factors include unevenness due to settlement, swelling soils, frost heaving, and concrete curling or warping; concrete material deterioration due to chemical reaction; and loss of skid resistance from surface wear. While some of the deterioration can be directly associated with inadequacies of construction and/or environmental effects, many are attributable to our inability to adequately consider the interaction of the variations in material properties, the environment, and the traffic loading conditions over the lifespan of the pavement. Many have attempted to relate pavement performance to the effects of the environment, such as excessive moisture, frost conditions, temperature gradients, etc. That these effects do affect performance can hardly be disputed. Nevertheless, these effects must be associated with traffic loadings for significant damage to occur. Carey (16) stated "Although there has been a good bit of 'smoke' from time to time about the ravages of the environment, of chemicals and the like, there has never been much doubt that the design and performance of real-life highway pavements that are to operate under truck traffic are clearly related to the axle loads that they must carry and the number of such loads."

Ray (5), summarizing concrete pavement design and performance based upon 35 years of experience, stated "Preference on the use of plain or reinforced, continuously reinforced or even prestressed pavement is a subject of great controversy, prejudice, and in many cases almost fanaticism." He concluded that each of these pavement types would give good performance if the subgrade, subbase, jointing, and use of steel, if any, are properly considered and provided for in the design, and if traffic is reasonably well forecast. Existing design procedures are considered adequate for these pavement types but, as pointed out earlier, because they are heavily supported by experience-based or empirically developed relationships, they are severely limited in application.

Cohn (9), discussing where we are with the existing transportation system, said "The U. S. transportation system is, in brief, inventory intense, underfunded, and not complete. It is inventory intense in the sense that it represents many billions of dollars of facilities put in place in the last 100 years. It is underfunded in the sense that maintenance needs alone now appear to demand more capital than is available through existing funding policies. And it is not complete in the sense that current and projected problems and needs demand transportation solutions that have yet to be implemented." While Cohn was addressing the transportation system as a whole, pavements make up a large part of that system and, based upon their performance to date, it is logical to conclude that they are in a similar situation.

Where are we NOW with concrete pavements? The performance of our existing concrete pavements and resurfacings indicate that they have generally provided at least 20 years of relatively low-maintenance service before rehabilitation must be considered. We must conclude that they have functioned well and support the economic recovery that has been, and is being, experienced in this country. Existing design methods have served well but because they are heavily dependent upon empirically developed relationships they are severely limited in application. There are questions regarding their ability to adequately interrelate the major influencing factors, especially for pavement sections incorporating reinforcement and multiple layers of paving materials. Plain, reinforced, and continuously reinforced concrete pavements have been extensively used and prestressed and fibrous concrete are on the threshold of being considered for construction. There is ample evidence that concrete pavement deterioration is the result of the interaction of the material characteristics, environmental effects, and traffic loading conditions, with the magnitude of load being the dominant factor. Many kilometers (miles) and square meters (square yards) of concrete pavement in our pavement system are approaching, or have reached, the need for rehabilitation. They are growing old, wearing out, and are beset with problems; however, this should not be alarming because to wear out is a normal function. Young, of the PCA, cited three reasons for the present condition of our roads and bridges. First, "most of the interstate system has simply outlived its 20-year design life. That is as long as it was supposed to last." Second, "the traffic on many highways is three to four times greater than expected at the time the roads were built." Third, "the allowable vehicle weights have increased in the past two decades." He concludes, "The wonder is not that our highways are in need of rehabilitation, but that they are still performing as well as they are." (2). The future of our concrete pavements may well depend upon our ability to develop and implement

innovative methods for their rehabilitation (i.e., resurfacing and/or reconstruction).

Concrete Pavements, Tomorrow

That future work with pavements will be concentrated on rehabilitation of the existing pavement system can hardly be argued. Cohn (9), addressing where we are going with the transportation system, said "The year 2004 will present a transportation system more than 99 percent of which will be identical to 1983, but 20 years older. As a result, maintenance and rehabilitation will receive the greater emphasis. On an overall basis transportation systems seem to be headed more toward "4R" type activities (i.e., resurfacing, restoration, rehabilitation, and reconstruction) and away from new construction." Nevertheless, rehabilitation will not be our only concern, for as our economy expands so must our pavement system expand. New highway and airport pavements will continue to be needed to serve developing areas and to accommodate the continual population shift. Also, there are segments of existing highways, especially in our urban system, that have experienced a traffic volume to traffic capacity (V/C) ratio sufficiently high to necessitate the construction of new lanes, reconstruction of the segment, or even construction of alternate routes (e.g., reconstruction of Atlanta's freeway system (17)). However, only about 5 percent of the overall highway system has a V/C ratio greater than 0.71 (1), indicating that the bulk of the system can sustain a significantly greater traffic volume before expansion will be necessary.

Some growth can be expected for our airport system. The FAA expects an annual growth of 4.6 percent in air traffic well into the 1990's (9). This could double the number of passengers served by 2004 and the FAA has identified a need for \$13.5 billion in airport development requirements by 1993, much of which will be for new as well as rehabilitated pavements. General aviation, which for the past few years has been fairly stable, can be expected to expand as the nation's economy expands. No major new military pavement construction program is foreseen. The B-1B aircraft is in production and will replace the B-52 aircraft. While the B-1B will be no heavier than the B-52, it can be expected to exhibit its own operational characteristics, hence it may require some expansion or alteration of the existing pavements. The major military pavement program is expected to be rehabilitation of the existing pavement system which has reached, or is approaching, the end of its design life.

General frameworks for pavement rehabilitation have been proposed, and many states are in the process of developing and implementing pavement management systems that will include rehabilitation. Thus, we are cognizant of the need for rehabilitation and, while we are poised to accomplish this important task, the need for research and development of procedures can be identified. Although we can expect improvements in both materials and techniques, no major breakthrough in rehabilitation philosophy is foreseen in the immediate future. It is logical to conclude that the rehabilitation of our existing pavements will continue to consist of restoration (localized repairs or patching), resurfacing, and reconstruction. In either case, a comprehensive study of the condition and quality of the deteriorated pavement will be essential for the determination of the most cost-effective method for rehabilitation. It will also be important to investigate the cause of the deterioration and correct

it, if possible, as a part of the rehabilitation. Finally, it will be necessary to design the rehabilitation. Recent developments in nondestructive testing shows promise for the rapid and economical evaluation of the existing pavement quality and great strides have been made in the development of theoretically based methods for modeling the performance of the complex layered pavement sections. Nevertheless, there is an absence of a nationally accepted and standardized rehabilitation design methodology and for tomorrow this becomes a challenge and a necessity.

It must be borne in mind that pavement rehabilitation is not new. While it has often been said that there is a tendency to "build them and forget them," the truth is that we have been maintaining and rehabilitating pavements since they were first constructed. Many existing pavements, especially those other than interstate, have been patched, resurfaced, and some have even been reconstructed. Although much of this has been accomplished without the benefit of a systemic approach and proven techniques, lessons have been learned which, if applied, will aid future rehabilitation. Localized repairs should be initiated as soon as distress is evident and continued until studies indicate that rehabilitation by resurfacing or reconstruction is more cost effective. Repair techniques that have commonly been used include full and partial depth patching, slab removal and replacement, joint reconstruction or restoration, surface grinding, pressure grouting, subsurface drainage, joint resealing, crack sealing or cementation, installation of pressure relief joints, and repair of junctures between slab edges and shoulders. These techniques have been developed primarily by trial and error and there is need for organized research to evaluate and improve them. In fact, there have been instances when moratoriums have been placed on new construction because proven repair or rehabilitation techniques were not available. Nevertheless, as concluded by Barenberg (18), localized repairing has the potential to provide a substantial increase in the serviceable life at an annual cost well below either resurfacing or reconstruction. He also pointed out that localized repairs can generally be performed with less interference to the overall traffic flow--an important consideration in the selection of the rehabilitation method. Experience has shown that there is no one method of repair which is most cost effective for all types of concrete pavements and generally the selection and design of the repair will depend upon the type and cause of pavement distress.

As the concrete pavement continues to wear (and it will with time and traffic), localized repairing will cease to be cost effective for maintaining serviceability and resurfacing or reconstruction will have to be considered. Both will present traffic handling problems that will be difficult, but not insurmountable, because total access must be provided to the pavement for extended periods of time. The traffic flow problems can be minimized by proper advance planning, as demonstrated during the construction of a resurfacing on I-59 in Mississippi (12) and reconstruction of Atlanta's freeways (17).

Concrete resurfacing will be a viable method for rehabilitating existing pavements in the future. The five types of concrete resurfacing (jointed plain, jointed reinforced, continuously reinforced, prestressed, and jointed fibrous) and three interfaces (bonded, partially bonded, and unbonded) provide wide latitude in the selection of a resurfacing alternative to provide long service at minimal annual cost. Recent developments in equipment to clean and/or to scarify the surface of existing concrete

pavements has made thin bonded resurfacings practical and effective. They provide an excellent solution to the rehabilitation of concrete pavements that are structurally sound but have experienced surface deterioration (i.e., wear, unevenness, "D" cracking, scaling, etc.). Similarly, partially bonded resurfacings are most applicable for increasing the load-carrying capacity or extending the life of structurally sound pavements. When the existing pavement has suffered structural distress and local repairs have been employed to extend serviceability, the unbonded resurfacing becomes the more practical rehabilitation method. Interestingly, concrete resurfacing has been gaining attention as a method for rehabilitating existing flexible pavements. Since 1976, Utah has resurfaced several miles of deteriorated flexible pavement using jointed plain concrete, and in Iowa, jointed plain concrete has been used to resurface deteriorated flexible pavements in their county highway system. Based upon such experience, it is probable that concrete will receive increased attention in the future for rehabilitating flexible pavements.

Reconstruction, as a form of rehabilitation for concrete pavements, is expected to receive increased attention in the future as the existing pavements continue to deteriorate and increasing traffic volumes demand geometric improvements. For reconstruction, the existing pavement is removed and either wasted or recycled and used as a fill material, filter course, subbase, or as aggregate for the new pavement (concrete or flexible). Removal and wasting of the existing concrete pavement and construction of a new pavement using virgin materials was common practice for earlier reconstruction and may still be most economical when virgin materials are readily available. However, in a growing number of areas, especially where quality concrete aggregates are scarce, it is becoming advantageous to recycle the existing concrete. The conservation of materials, problems of solid waste disposal, reduction in construction costs, and conservation of energy are several reasons for the increasing interest being shown in recycling.

There are several examples of the use of recycled concrete in the reconstruction of pavements (19 and 20). The following are illustrations of the different uses of the recycled material. In 1977, a keel section in a runway at Jacksonville International Airport in Florida was reconstructed by recycling the structurally deteriorated plain concrete into a filter course and econcrete subbase. A new plain concrete surfacing was then constructed using virgin materials. Similarly, the Edens Freeway in Chicago, Illinois, was reconstructed by recycling the existing jointed reinforced concrete and asphaltic concrete resurfacing into porous granular fill and capping material. A new stabilized subbase and continuously reinforced concrete pavement, using virgin materials, was then constructed. In 1980, 26 km (16 miles) of US-59 in Minnesota, which was 25 years old and exhibiting a great deal of distress primarily in the form of "D" cracking, was rehabilitated through reconstruction. The existing concrete was recycled and the fines used for a granular base and the coarse material used as aggregate for the new concrete pavement. Contractors, aggregate producers, and equipment developers will continue to improve methods for the breaking and crushing of concrete, removal of embedded steel, and materials handling which will make recycling more attractive in the future as a reconstruction option. But cost-effective studies will be needed to determine whether the existing pavement

should be wasted or recycled when reconstruction is being planned.

Even though only a minor amount of new concrete pavement construction is anticipated for the near future, it will be extremely important that they be designed and constructed to provide the required serviceability at minimum life-cycle costs. Transportation officials are being required to provide efficient facilities for current and projected increases in use with fewer dollars. While increasing revenues would help, most officials are not hopeful that this will occur soon. Thus, it behooves us to search for solutions which will not significantly increase the cost of construction but which will lengthen the serviceable life of the pavement facilities at reduced maintenance costs. Two possible areas are in the design and construction of the new pavements. This is not to imply that either have been grossly inadequate, for existing pavement performance indicates otherwise.

The need for improved design methodology has been recognized and considerable work has been accomplished in this area over the past 10 to 15 years. But as Witczak (21) has pointed out, there has been an increasing number of studies directed toward the development of design methodology which parallels, if not duplicates, each other but which are not properly coordinated or pointed toward a particular approach. Consequently, it is difficult, if not impossible, to apply the study results to the implementation of design methodology on a national or global level. A significant part of the problem lies in the absence of a universally accepted and standardized design system methodology for pavement performance modeling. While the standardization or acceptance of a uniform design philosophy for concrete pavements will be extremely difficult to attain, it would serve as a vehicle for bringing related research together and undoubtedly would accelerate the development of analysis methods to better interrelate all of the variables that affect pavement performance. This is a challenge for the future and a goal worthy of attainment.

Based upon a 1976 Federal Highway Administration (FHWA) study of highway condition and quality of highway construction, it was concluded that there was a considerable gap between the quality of work specified and the quality of work received. Although not documented, it is probable that this is also true for civil and military airport pavement construction since similar methods are used for quality control. As a result of the FHWA study, many states took steps to improve their quality control through increased inspectors, increased inspector training, and more frequent testing. Nevertheless, a subsequent FHWA study in 1979 indicated that 73 percent of 311 projects studied exhibited observable distress within 3 years following construction. Although no specific relationships between the quality of construction and the observed distress could be established for these projects, it is highly probable that the premature distress was related to construction inadequacies. Manning (22) suggests that increasing our inspection efforts may not be the answer to quality control problems and that "Perhaps we need to work smarter." By this, he means that we need to optimize our efforts - and even our control philosophies - to identify those materials and those operations that are most critical, and to determine what specifications are really needed. Manning also suggests that the specifications should be made more communicable through the use of good statistical language rather than adjectives such as equal to or better, reasonably close, conformity, etc. The development and implementation of a workable and reasonable quality assurance program can materially reduce construction

deficiencies and premature distress in the pavements. This would, in turn, translate itself into improved serviceability and reduced maintenance costs, not only for new concrete pavements but for rehabilitated concrete pavements as well.

The FHWA recently completed a study to develop zero-maintenance pavements which were defined to be one that will provide at least 20 years of maintenance-free operation on a high-volume expressway and at least 10 more years with routine maintenance before rehabilitation is required. Their study brought forth several innovative concepts for future pavements which have yet to be analyzed and performance evaluated. It also brought forward suggested design improvements for the conventional pavement systems such as that for plain jointed concrete pavements presented by Darter and Barenberg (23). The evaluation and validation of the innovative design concepts will be both time-consuming and costly; therefore, they are not expected to be widely used in the near future. However, many of the suggested design improvements for the conventional pavements are readily implementable and could significantly improve serviceability at reduced maintenance costs if not provide zero-maintenance pavements.

A new concept in concrete pavement construction which may receive consideration in the future, and which will be further discussed during this conference, is roller-compacted concrete. This concept has been used to construct vehicle parking and maintenance areas and haul roads where surface texture and smoothness are not critical. Its cost is perhaps one-third to one-half of that for conventional concrete pavement construction and further developments in construction techniques may expand its applicability to highway or airport pavements.

What does TOMORROW hold in store for concrete pavements? It appears that rehabilitation of the existing pavement system will represent the major emphasis in concrete pavement construction. New pavement construction will continue but will probably represent a minor role for the near future. Rehabilitation philosophy is expected to continue to be restoration, resurfacing, and reconstruction, with increased emphasis on the latter two. Through life-cycle costing analysis, concrete pavements are expected to produce the most economical rehabilitation alternative, but because of revenue producing policies, the use of thin bituminous concrete resurfacings, which will provide a shorter life but dramatic improvement in rideability at minimal initial cost, will be popular. To accomplish the monumental task of rehabilitation, pavement management systems incorporating improved design methodology, innovative construction techniques, better construction quality control methods, and improved techniques for predicting future traffic loading conditions will be essential. Traffic handling during the rehabilitation phase will present major problems and will require innovative advance planning.

Many of the areas that I have only briefly mentioned, as well as others, will be further discussed during this conference. It is expected that we will all go home after this meeting a little the wiser on how to protect and improve our pavement system - one of our most important public investments.

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