for more effective use of resources, there is a basis for an adequate pavement. In view of the increased concern in operations such intensities that as much as 40.6 cm (16 in) of plain concrete may be required to provide such pavements, particularly for airports. As a result, the current state of the art in the design and construction of such pavements is not highly developed. Since the construction of the first prestressed concrete pavement on record on a bridge approach at Luzancy, France, in 1946, only about 100 prestressed pavement test sections and test slabs are known to have been built. These have been about evenly divided between airports and highways. The most recently constructed sections of prestressed pavement are one on an access road to Dulles International Airport in Virginia that were designed and constructed by the Federal Highway Administration (FHWA) and the Pennsylvania Department of Transportation respectively.

The gross masses of current and proposed commercial aircraft have reached such proportions and the flight operations such intensities that as much as 40.6 cm (16 in) or more of plain concrete may be required to provide an adequate pavement. In view of the increased concern for more effective use of resources, there is a basis for renewed interest in the search for resource-saving methods of constructing pavements. The desire to thoroughly evaluate a possibly expanded role for prestressed pavements stems primarily from the three basic advantages such pavements offer over conventional rigid pavements.

First, it has been demonstrated, both analytically and by testing, that prestressed pavements permit a substantial reduction in pavement thickness (50 percent or more), with corresponding savings in construction materials and possibly in costs. Second, prestressed pavements can be designed with fewer joints, a characteristic that results in quieter and smoother rides and eliminates the need for costly sealing and resealing programs. Third, the smaller number of joints and the lower probability of crack formation (both load and nonload associated) can be projected into the likelihood of extended pavement life and reduced maintenance requirements.

There are, however, potential disadvantages associated with prestressed pavements that must also be considered. First, there is an increase in the complexity of construction that leads to higher costs, which offsets the savings of materials, although there are strong indications that improved construction techniques, which would result from increased use of prestressed pavements, will help to minimize these costs. Second, the joints that are required in a prestressed pavement are expensive to construct and, due to the large horizontal movements, difficult to maintain. However, through the use of improved materials and construction techniques, more durable joint systems will probably be developed.

There are data from only a relatively few full-scale test pavements, laboratory tests on small-scale models, and observations of the performance of a limited number of operational airport pavements available for use in extending and refining the design and construction procedures. A review of the approaches to design used in the construction of the various prestressed pavement test sections showed that few attempts have been made to develop these designs by analytical techniques. Generally, pavement thicknesses and amounts of prestress have been selected on an arbitrary basis. Most highway pavement test sections have been 15 cm (6 in) thick with only longitudinal prestressing, while airport pavements have been up to 22.8 cm (9 in) thick, with both longitudinal and transverse prestressing. Frequently, such empirical designs have been subjected to static load tests after completion of construction to evaluate the load-carrying capability of the pavement. Also, frequent attempts have

**Pavement Design: Prestressed, Steel Fibrous, and Continuously Reinforced Concrete**

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Three Federal Aviation Administration reports on the use of prestressed, steel fibrous, and continuously reinforced concrete for airport pavements are summarized. The technical literature describing the construction, testing, and performance of prestressed concrete was reviewed, and the design criteria that have been best validated by experimental evidence selected. A design procedure based on the selected criteria was formulated, the recommended construction procedures described, and load-deflection measurements made on an instrumented highway test road at Dulles International Airport in Virginia to further develop or verify the design criteria. Four full-scale test sections of steel fibrous concrete were constructed and tested under controlled, accelerated traffic conditions, two field placements of this material were planned and constructed, and the efforts of other agencies with this material were monitored. A field study of a continuously reinforced concrete pavement at O'Hare International Airport in Chicago was made. This study involved (a) evaluation of existing pavements and overlays, (b) synthesis of data and methods for design of these pavements, (c) formulation of design procedures and construction specifications, (d) collections of response and performance data for an actual pavement subjected to actual aircraft loadings, and finally, (e) the development of a design procedure that can be implemented now and is compatible with Federal Aviation Administration procedures for other types of pavement.

**PRESTRESSED CONCRETE PAVEMENTS**

Prestressing to strengthen concrete has been used widely and successfully for bridges, buildings, storage tanks, and pressure pipes for the past 25 years; however, only a modest interest and a limited investment of research funds have been directed at prestressed concrete for pavements, particularly for airports. As a result, the current state of the art in the design and construction of such pavements is not highly developed. Since the construction of the first prestressed concrete pavement on record on a bridge approach at Luzancy, France, in 1946, only about 100 prestressed pavement test sections and test slabs are known to have been built. These have been about evenly divided between airports and highways. The most recently constructed sections of prestressed pavement are one on an access road to Dulles International Airport in Virginia that were designed and constructed by the Federal Highway Administration (FHWA) and the Pennsylvania Department of Transportation respectively.

The gross masses of current and proposed commercial aircraft have reached such proportions and the flight operations such intensities that as much as 40.6 cm (16 in) or more of plain concrete may be required to provide an adequate pavement. In view of the increased concern for more effective use of resources, there is a basis for...
been made to quantify such design parameters as (a) the
effects of hygrothermal stresses, (b) the effects of sub-
grade restraint, and (c) prestress losses associated with
the stressing tendons and anchorage systems. Other
than the studies conducted by the Corps of Engineers
(CE), there is little evidence to indicate that the effect
of frequency of load applications has been considered in
design.

Purpose

The purpose of this study was to develop suitable pro-
cedures based on available data for the design and con-
struction of prestressed pavements at airports serving
the civil aviation community.

Scope

The study included (a) review of the technical literature
describing the construction, testing, and performance of
prestressed concrete pavements; (b) selection of the de-
sign criteria that have been best validated by experi-
mental evidence; (c) formulation of a design procedure
based on the selected criteria; and (d) description of
recommended construction procedures. In addition,
load-deflection measurements were made on the
prestressed concrete highway test road to Dulles Inter-
national Airport to further develop or verify the design
criteria.

Summary of Work Accomplished

In the review of previous research, studies pertaining to
both highway and airport pavements were included. How-
ever, because of the differences in design requirements
for highway and airport pavements, primary considera-
tion was given to the research pertaining to airport pave-
mements. In the mid 1950s, CE at its Ohio River Division
Laboratories (ORDL) conducted a program of theoretical
studies, model studies, and full-scale test sections that
resulted in the design and construction of a prestressed
concrete pavement for a heavy-load taxiway at Biggs Air
Force Base, Texas, in 1959. This pavement has per-
formed well except for some problems at the joints,
which are spaced on 152-m (500-ft) centers. The design
procedure developed at ORDL was selected as the basis
for the design procedure developed in this study.

One component of the ORDL design procedure involved
predicting load-stresses based on small-scale tests by using the gear configurations of specific mili-
tary aircraft. However, present-day commercial air-
craft have gear configurations that are different from
those used in developing the ORDL procedure. Thus, it
was necessary to develop load-stress relations for
present-day commercial aircraft. This was accom-
plished by using a computer program based on a discrete-
element procedure for plates and slabs. The data ob-
tained from previous small-scale models were used to
establish the necessary input parameters for the com-
puter model. With this modification, the design pro-
cedure was adapted for the standard dual and dual-tandem
gear aircraft now operating at civil airports and also for
the newer wide-body jet aircraft. The final Federal
Aviation Administration (FAA) design procedure permits
interrelating magnitude of loading, load repetitions,
flexural strength, subgrade conditions, pavement thick-
ness, slab dimensions, and amount of prestress; and the
effects of elastic shortening, creep, shrinkage of concrete,
relaxation in steel tendons, anchorage systems, tendon friction, subgrade restraint, and temper-

ature changes can also be included.

In an effort to further validate and refine the design
criteria, full-scale static and moving load tests were
conducted on the prestressed concrete test road near
Dulles airport. This highway pavement was constructed by FHWA as part of the airport road network serving the
1972 International Exposition (Transpo 72). Strain gauges
and pressure cells were installed within the pavement
structure during construction in two separate prestressed
concrete slabs. Tests were conducted on the instru-
mented slabs by using a truck to represent highway loads
and a load cart equipped with one dual-tandem component
of a B-747 aircraft to represent aircraft loadings. These
tests consisted of measurements of stress and strain in
the prestressed concrete pavement structure under vari-
ous loading conditions.

The load tests showed a good correlation between the
measured subgrade behavior directly beneath the loads
and that determined by using linear elastic layer theory.
For the subgrade conditions, pavement-slab conditions,
and load conditions at Dulles, this correlation indicates
that the subgrade can be modeled by elastic layer theory.
The load tests were deliberately held within the initial
prefailure behavior of the pavements so that no cracks
or failures would occur. The results of these tests
showed that the initial maximum elastic deflections and
stresses of the pavement slab can be closely approxi-
imated by linear elastic layer theory and that the maxi-
mum subgrade deflections or deformations determined
by using layer theory can be used to calculate the slab
bending moments and stresses by the various slab-
behavior models. The results of the layer theory model
can also be used with Westergaard's analysis and his
correction factors based on measured deflections. Layer
theory deflections could be specifically incorporated in
Westergaard's subgrade reaction corrections. (This
discussion applies only to the Dulles test pavements;
future work should further investigate modeling the sub-
grade by linear elastic layer theory.)

Construction techniques and alternatives were based
on an examination of prototype test pavements and oper-
ational prestressed facilities constructed in this country
and abroad. Special emphasis was given to developing
an expansion joint that could withstand the relatively
large daily and seasonal movements of the slab ends that
occur because of the increased length of prestressed
slabs as compared to that of conventional slabs. After
investigations of existing projects and discussions with
manufacturers, several alternative types of joints and
joint materials were selected for inclusion in the con-
struction procedure. Other construction features as-
essed were the relative merits of prestressing with and
without tendons, pretensioning versus posttensioning,
types of stressing tendons and conduits, friction-reducing
layers, and amounts of prestressing.

FIBROUS CONCRETE PAVEMENTS

Fibrous concrete is a composite material consisting of
a concrete matrix containing a random dispersion of
small fibers. Numerous types of fibrous materials have
been investigated—e.g., steel, fiberglass, nylon, asbes-
tos, polypropylene, and polyethylene. The introduction
of fibers into the concrete matrix imparts to the concrete
certain characteristics such as increased tensile
strength, increased toughness, increased impact and
dynamic strength, increased resistance to spalling,
resistance to propagation of cracks, and the ability
to sustain load and to keep cracks tightly closed after
cracking.

For pavement applications, steel fibers have been
used almost exclusively. Although the term fibrous con-
crete generally implies the use of any of a number of
fibers, in this chapter, it will be synonymous with con-
crete containing steel fibers.

For comparable design loadings, the required thickness of fibrous concrete pavement is less than that of plain or conventionally reinforced pavement. In situations in which a thin pavement is necessary because of factors such as vertical grade or drainage considerations or in areas where there is a shortage of quality aggregate or other material, it may be advantageous and become economically feasible to use fibrous concrete.

**Purpose**

The purpose of this study was to develop a design procedure for fibrous concrete airport pavements based on known properties of fibrous concrete mixtures and to provide guidance for mix proportioning and construction of such pavements.

**Scope**

The study included (a) construction and testing of four full-scale pavement sections under controlled, accelerated traffic conditions; (b) planning and construction of two field placements; and (c) monitoring efforts of other agencies. The design criteria developed and the construction practices recommended reflect the findings from these tests and observations.

Because only four pavement sections were tested, it was necessary to extrapolate performance from that of three slab-on-grade sections to that of all other foundation conditions and from that of a partial bond overlay to that of all other overlay conditions. It was also necessary to assume that long-term field performance would be comparable to performance under accelerated test conditions. The construction practices recommended were developed from experience gained during the construction of relatively small quantities of pavement.

**Summary of Work Accomplished**

The pavement sections constructed included the following: (a) a 15-cm slab over a 10.2-cm (4-in) sand filter on a clay subgrade; (b) a 17.8-cm (7-in) slab over a 50.8-cm (20-in) membrane-encapsulated layer of lean clay on a clay subgrade; (c) a 10.2-cm slab over a 45.2-cm (17-in) cement-treated clay gravel base on a clay subgrade; and (d) a 10.2-cm partially bonded overlay of a failed 25.4-cm (10-in) plain concrete pavement. The applied traffic consisted of simulated C-5A and B-747 loadings. Figure 1 illustrates the deterioration of the 10.2-cm-thick slabs as simulated B-747 traffic was applied. From the results of these tests, the design criteria were developed.

The field installations investigated included the following: (a) 10.2- and 15.2-cm overlay sections constructed on a taxiway at Tampa International Airport and (b) a 10.2-cm-thick roadway constructed at the U.S. Army Engineer Waterways Experiment Station (WES). Tampa overlays were constructed with conventional paving equipment to determine the feasibility of constructing fibrous concrete pavements with this type of equipment. Figures 2 and 3 illustrate the construction techniques used. Figure 4 illustrates the crack pattern in the base pavement and those that developed in the overlay after 6 and 28 months in service. The roadway was constructed at WES to study joint requirements for fibrous concrete pavement. A 300-m (1000-ft) long section was constructed without provisions for joints. Seven cracks formed in the pavement resulting in slabs 44.3, 19.1, 26.4, 46.4, 47.3, 21.2, 27.3, and 72.6 m (146, 63, 87, 153, 161, 70, 90, and 240 ft) in length. The average slab length was 38.2 m (126 ft), indicating that joints on about 30.3-m (100-ft) spacings should be used.

An effort has been made to stay abreast of work being conducted by other agencies on material characteristics of fibrous concrete and on its use as a paving material. Most of the recent work has been on mix design and fatigue and durability characteristics. Other agencies have concentrated their efforts toward the use of fibrous concrete for overlays, particularly of highway pavements. In the past several years there have been a number of trial placements of thin overlays on highway pavements.

**CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS**

Continuously reinforced concrete (CRC) pavement is defined as portland cement concrete pavement having longitudinal reinforcing steel continuous for its length and no transverse joints other than the construction joints. Transverse cracks develop in CRC, but are held tightly closed by the steel reinforcement. The resulting riding surface is generally smoother, and the problems associated with sealing and maintenance of transverse joints are eliminated. Thus, it may be advantageous and economical to use CRC for airport pavements.

CRC pavements and overlays have been used on highways for a number of years. They have also been used at a few airports. The most extensive use of CRC has been at O'Hare International and Midway airports in Chicago, Illinois, and at U.S. Air Force Plant 42, Palmdale, California. For highway pavements, the various state highway departments have developed design and construction procedures tailored to their particular conditions. These procedures have been used extensively in the development of the design and construction procedures for airport pavements.

**Purpose**

The purpose of this study was to develop design procedures for CRC airport pavements and overlays. The procedures include methods for selecting slab thickness, for designing the reinforcing steel, and for controlling slab end movements. In addition, guidance for the construction of CRC pavements and overlays was to be provided.

**Scope**

This study was accomplished both in-house by WES personnel and through a joint U.S. Air Force-WES contract with a private engineering firm. The city of Chicago, through its Bureau of Engineering, provided support for a field study at O'Hare International Airport. The study involved (a) evaluation of existing CRC airport pavements and overlays; (b) synthesis of data and methods for design of CRC pavements and overlays; (c) formulation of design procedures and construction specifications for CRC airport pavements and overlays based on the evaluations of the existing pavements and existing design methodology; (d) collection of response and performance data for a CRC pavement subjected to actual aircraft loadings and environmental conditions; and (e) from the results of the entire study, development of a design procedure for CRC pavements and overlays that can be implemented now and is compatible with FAA procedures for other types of pavement.

**Summary of Work Accomplished**

The evaluation of existing CRC airport pavements and overlays involved data collection at the following locations:
1. U.S. Air Force Plant 42, Palmdale, California;
2. O'Hare International Airport, Chicago;
3. Midway Airport, Chicago; and
4. Byrd International Airport, Richmond.

The data collected at all four locations consisted of dynamic load versus deflection response measurements, characterization of the materials composing the pavements, and pavement conditions. An example of the load-deflection data collected is illustrated in Figure 5.

The data from the study of existing CRC airport pavements and overlays were combined with data and design methods from other sources, and tentative design procedures were formulated. In addition, specifications for construction of these pavements were proposed.

The proposed design procedures consider stochastic variations in material properties and load location. The variability of material properties is translated into a reliability that can be attached to the resulting pavement. The variability in the loading is directly included by assuming that the loads will be normally distributed transversely across the pavement so that the number of loads applied to any transverse pavement segment can be determined. The proposed design procedure considers the total mixture of aircraft operating on the facility by the determination of the pavement damage caused by each different type of aircraft, or conversely by the determination of the thickness required by each different type of aircraft. The effects of each aircraft and the variability of their locations are then combined and added which shows the deflection obtained along runway 9R-27L at O'Hare by using a Dynaflect vibrator and the WES 71,4-kN (16 000-lbf) vibrator. The material characterization portion of the study involved the collection of samples of the pavement material (disturbed and undisturbed), and laboratory testing to determine their strength and load-deflection properties. Data from the condition surveys included crack spacings, crack widths, percentage and condition of spalled cracks, longitudinal cracking, and joint condition.

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to determine a total thickness requirement that varies transversely across the pavement.

There are separate procedures for the design of overlays and of slabs on grade. The elastic layered model is used as the response model for the development of the overlay design procedure, while a slab on a dense liquid foundation is used as the basic response model for the pavement design procedure. The use of different response models requires different procedures for defining the input for characterizing the response of the underlying material. For overlay design, the material in each layer is characterized by two constants (the modulus of

Figure 4. Joint and crack patterns in base pavement and overlays at Tampa International Airport.

Figure 5. Measured dynamic deflections along runway 9R-27L at O'Hare International Airport.
elasticity and Poisson's ratio). For pavement design, the response of all layers below the slab is defined by one constant referred to as the composite foundation modulus or \( k \)-value. The procedures for characterizing the load-deflection response and the strength of the portland cement concrete are the same, as are the other procedures for the determination of the required overlay slab thickness.

The design of the steel reinforcement is accomplished by procedures relatively well established and widely used, and recommendations concerning jointing and terminal treatment system designs are provided.

Gauges—Bison coils for measuring the strain in the various layers and linear variable differential transformers (LVDTs) for measuring the total deflection of the pavement when loaded—were installed at four locations on runway 4R-22L at O'Hare International Airport to determine the load-deflection responses of the pavement. Also, thermistors were installed to measure slab temperatures, and reference plugs were installed for use with a Whitmore strain gauge for measuring the opening and closing of transverse cracks with temperature changes.

The initial load-deflection response measurements were made in June 1973. The pavement deflection was measured with the loads [a B-727-100 aircraft and a 556-kN (125 000-lbf) aircraft tug] located at various positions with respect to the gauge. The magnitudes of the deflections thus obtained were compatible with those of the deflections obtained previously when the pavement was loaded with the Dynaflect and the WES 71.4-kN (16 000 lbf) vibrator. Strain measurements within the individual layers (Bison coils) could not be obtained because the masses of the tug and the B-727-100 aircraft were insufficient to cause measurable strains in the various layers. Collection of traffic data, environmental data, and temperature-crack width data was initiated at this time by the Chicago Bureau of Engineering.

Additional load-deflection response measurements were made in May 1975. These included pavement deflections measured with the LVDT gauges with a plate load device that simulated the load of a B-727 aircraft and dynamic load-deflection measurements made with the WES 71.4-kN vibrator. Material sampling was accomplished at the sites where the LVDT gauges were located and pavement condition surveys made.

An analysis of all the data collected, both from the evaluation of existing CRC pavements and from the load-deflection tests on runway 4R-22L, was accomplished by the private engineering firm. The analyses included a comparison of the measured load-deflection response with the predicted response (Figure 6), a determination of the relation between crack spacing and crack width, and an evaluation of the performance of the pavement. The performance analysis was limited because, since construction of the pavements in 1971, they have experienced low use and showed no signs of structural deterioration.

The results of the entire study were drawn together, and a design procedure for CRC airport pavements and overlays that can be implemented was developed. This procedure is compatible with the procedures currently used for the design of plain and reinforced jointed pavements. Guidance for handling construction problems that are unique to CRC pavements was formulated.
Modifications to the first procedures developed were made as indicated appropriate by the O'Hare study and as needed to preclude requirements for estimating traffic, characterizing materials, and computing thickness requirements that are different from those used for other types of pavement. The procedure, as illustrated by the flow chart in Figure 7, includes recommended methods for selecting design parameters (traffic estimates and material characteristics), determining slab thickness, and determining amount and size of reinforcing steel, details for terminal treatment systems, and details for required construction joints.

As shown in Figure 7, the site investigation is identified with those used for other types of pavement. The procedure for selection of a composite support value provides a method for evaluating the increase in support provided by subbase and treated subgrade layers. The methods for considering traffic are compatible with FAA procedures for selecting the critical design aircraft and relating all other traffic to equivalent traffic with the critical aircraft. The methods for selecting the design thickness have the same basis as current methods, but the charts and nomographs are of different format than the design charts used for plain and reinforced jointed pavement. However, they are rather simple and straightforward and should present no problems in use. And this format may offer the designer more flexibility to consider variations in the design parameters. The provisions for design of end-anchorage systems, reinforcing steel and construction joints, and construction guidance include recommended details that are unique for CRC (e.g., details for laps at splices in reinforcing bars, details for transverse construction joints, steel placement, and end anchorage systems). Procedures are provided for determination of the amount of both longitudinal and transverse steel.

CONCLUSIONS AND RECOMMENDATIONS

Prestressed concrete pavements can be designed for airport pavements with a reasonable degree of accuracy with respect to load-carrying capability and number of load repetitions that can be sustained.

Construction of airport pavements with prestressed concrete rather than with conventional concrete will result in a saving of concrete because of the smaller thicknesses required. Also, the long prestressed slabs will have fewer joints to be maintained and provide a smoother operating surface.

The design criteria and construction procedures are conservative in some areas because of the uncertain state of the art in these areas. All recommendations are subject to refinement after further study.

The following experimental work is recommended to refine the design procedure for prestressed concrete and improve its reliability:

1. The relation between the ratio of the loaded area to the pavement radius of relative stiffness and the percent single-wheel failure load (the ratio, expressed as a percentage, of the load on a single tire to the load on a multiple-wheel gear that would cause cracking in the prestressed pavement) plays an important role in the selection of prestress level and pavement thickness and should be verified before widespread use of the criteria is made. This verification should be by model tests using procedures similar to those used in the earlier tests by ORDL.

2. Sections of instrumented, prestressed pavement should be constructed for a range of types of foundations and tested to verify the design criteria presented and to modify them as necessary.

Fibrous concrete pavements and overlays will perform better than plain concrete pavements of comparable thickness and strength. This means that, for comparable design conditions, the required thickness of fibrous concrete would be less than that of plain concrete. The reduced thickness requirements for fibrous concrete will result in increased vertical deflection of the pavement and increased induced stresses in the underlying material. Provisions are made in the design procedure to limit the deflection of the pavement to minimize this effect.

Fibrous concrete can be produced and placed with conventional batching, mixing, and paving equipment and techniques. Bulk handling of fibers and a mechanical system for introducing the fibers during batching operations will be required to produce fibrous concrete in sufficient quantities for large airport paving jobs.

To improve the reliability of the proposed design criteria and construction techniques for fibrous concrete pavements, the following areas should receive further study:

1. Additional performance data, in particular for overlays of flexible pavement and unbonded and partially bonded overlays, are needed. Additional observations of pavement performance and deflection are needed to improve the correlation between the two.

2. Long-term observations of fibrous concrete pavements under in-service conditions are needed to assess the effects of environmental factors on the performance of these pavements.

3. Mix design studies are needed to establish more specific guidelines for selecting a workable mixture that will produce the desired properties in the hardened concrete.

CRC offers the designer an additional alternative to consider when designing a pavement system. The procedures presented, although based on limited experience with CRC airport pavements, provide a way to design and construct CRC airport pavements and overlays that will be adequate to prevent load-induced cracking during the pavement design life. This is the type of distress that is most detrimental to the structural performance of the pavement. The procedures, however, do not consider nor make allowances for load-induced spalling or distress due to environmental factors or construction conditions. These types of distress are usually not catastrophic, in the sense that the pavement becomes structurally unsound, but they may require maintenance and minor rehabilitation to maintain its function adequacy.

The use of CRC should not be postponed until all the answers are available, because many of the problems can only be solved through experience. The following areas are recommended for further study to improve the reliability of the design of CRC pavements and overlays:

1. Additional data for improving the performance criteria should be collected.

2. Failure modes (in addition to cracking of the slab) should be identified and described, and the feasibility of developing design criteria to account for these failure modes should be determined.

3. The effects of environmental factors (temperature and moisture regimes) and construction conditions on the performance should be identified and quantified.

ACKNOWLEDGMENT

This paper summarizes material presented in a series
of FAA reports on airport pavements (1, 2, 3, 4, 5, 6).

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Design of Civil Airfield Pavements for Seasonal Frost and Permafrost Conditions

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The principal adverse effects of frost action on pavements are roughness and cracking, which are caused by the upheaval of the pavement during freezing and the weakening of the subgrade and base course and loss of supporting capacity during thaw. Design procedures for pavement section thicknesses to minimize these effects in both flexible and rigid pavements in areas of seasonal frost and permafrost conditions have been developed for the Federal Aviation Administration. The design charts are based on a classification of frost-susceptible soils and the depths to which freezing and thawing will occur for the specific location. Design procedures for pavements incorporating extruded polystyrene insulation have also been developed.

In the United States, only the more southerly states have climatic conditions that provide relative freedom from effects of seasonal frost action. Yet the current Federal Aviation Administration (FAA) criteria for airport pavement design do not account adequately for the detrimental effects of frost action on pavements. These criteria do not provide design alternatives based on degree of roughness, proposed use, or funding available, and they often result in unsatisfactory performance or excessive life-cycle cost of pavements. In addition, these criteria do not recognize parameters known to affect the depth of frost penetration, which has a major influence on the severity of some of the detrimental effects of seasonal frost conditions.

Permafrost is widespread in Alaska and affects pavement design in most of that state, but the current FAA standards provide no criteria or guidance applicable to the design and construction of pavements in areas of permafrost. This is a subject for which existing technology needs further development; however, available information could be adapted for incorporation into FAA design criteria.

Recognizing the need for updating their criteria, the FAA requested that a study be carried out that would draw on existing technology and provide the needed adaptation of currently available guidelines and design procedures for application to airports that serve civil aircraft. The primary objects of the study, the results of which are summarized here, were to

1. Delineate the frost susceptibility of the various FAA soil groups;
2. Provide a methodology for the determination of frost-penetration depths;
3. Develop methods of engineering design based on various levels of frost protection;
4. Prepare design curves for flexible and rigid pavements for various levels of frost protection;
5. Provide guidance on construction control, new materials, and construction techniques to reduce the detrimental effects of frost on pavement performance;
6. Present appropriate testing procedures necessary for the use of the design methods; and
7. Provide methods for engineering design of pavements in permafrost areas.

EFFECTS OF FROST ACTION ON PAVEMENTS

The principal adverse effects of frost action are roughness and cracking, caused by the upheaval of the pavement surface during freezing and by the weakening of the subgrade and base course and loss of supporting capacity during thaw. Frost heave, the raising of the pavement in winter, is caused by the freezing of the soil moisture. In its most damaging form, it is associated with ice segregation, the formation of lenses of ice in the subgrade or base course or both. Frost heave may not be detrimental if adjacent areas of a pavement are heaved by equal amounts, but nonuniform heave can result in extremely severe roughness and in the cracking of both flexible and rigid pavements. Small structures inserted in paved areas, such as fueling hydrants and light bases, may be progressively heaved to levels significantly above the surrounding pavement. The degree of uniformity of pavement heave is enhanced by horizontally uniform soil characteristics and moisture conditions, uniform surface exposure to sun and wind, and uniformity of pavement