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Procedures for Airport Pavement Management

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The results of runway surveys at Chicago-O'Hare International Airport are summarized, and the causes of the deterioration of these runways are evaluated. Procedures for their rehabilitation and reconstruction are described.

One of the goals of airport pavement management procedures is economy. This encompasses all costs—loss of revenue, delays to aircraft and passengers, aircraft maintenance, pavement maintenance, pavement strengthening, and reconstruction or new construction.

The cost of operational delays to aircraft are fairly easy to determine, but the option of some airlines to shift connecting points to other cities and thereby decrease the landing fees at an airport where delays are excessive is not as obvious.

The cost of delays to passengers, although not directly included in maintenance costs, can also ultimately result in loss of revenue to the airlines and municipality. There are a number of options available to passengers, such as canceling travel, holding conventions in other cities, or using other modes of travel. Aircraft maintenance costs are difficult to assess, but tire damage is one visible effect.

Consequently, it is necessary to ascertain the maintenance required for the life of a pavement and establish a maintenance program. From this program, schedules can be arranged to minimize disruptions and prepare budgets for financing.

The deterioration of an airport pavement can be directly correlated to the traffic using it. Although runways are not as traveled as highways are, the number of load repetitions is as important as their magnitude. For example, in 1975, there were 694 000 operations at Chicago-O'Hare International Airport, which distributed among the six primary runways is more than 100 000 operations/runway.

On March 22, 1946, the United States, under provisions of the Surplus Property Act of 1944, conveyed to the city of Chicago the area known as Orchard Place Airport (Figure 1). In 1949, the city of Chicago began development of the Chicago-O'Hare International Airport with what is now the International Terminal. Runway 14R-32L was constructed, runways 9L-27R and 4L-22R were lengthened, and various taxiways and aprons were built. The typical pavement section was 178-mm (7-in) thick portland concrete cement (PCC) with 254-mm (10-in) thick edges and 381-mm (15-in) gravel on a minimally prepared subgrade.

In 1955, runway 14R-32L was rebuilt, and in 1958 and 1959, it was extended to 3540 m (11 600 ft) in length. The width has remained constant at 60.1 m (200 ft), and the shoulders are 1.2 m (4 ft) wide. In 1968, the center 30.5 m (100 ft) of the northern 2350 m (7200 ft) (between stations 98 and 175) was removed and replaced with 305 mm (12 in) of continuously reinforced concrete pavement (CRCP) on a 762-mm (30-in) thick granular subbase. Therefore, this runway consisted of either 178 mm of PCC on 381 mm granular material or 305 mm (12 in) CRCP on 762 mm (30 in) granular material. This was the runway rebuilt to handle jets when O'Hare opened.

Runway 14L-32R was one of the original runways. It was 1676 m (5500 ft) long and consisted of 178 mm of PCC with 254-mm-thick edges on 381 mm of gravel base on a minimally prepared subgrade. It was extended to 2286 m (7500 ft) in 1951 and to its present length of 3048 m (10 000 ft) in 1965. The types of sections are described below (1 m = 3.28 ft):

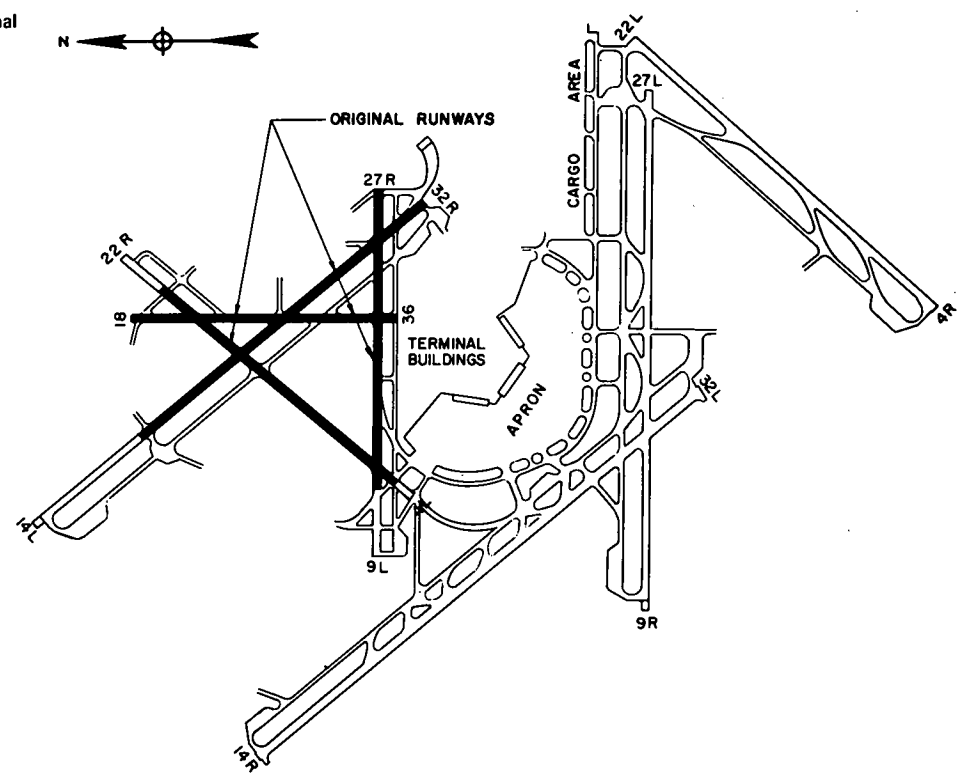
Length (m)	Description
457	76 mm asphalt on 305 mm PCC and 381 mm base
1402	279 mm asphalt on 178 mm PCC and 381 mm base
365	76 mm asphalt on 305 mm PCC and 381 mm base
822	305 mm CRCP on 305 mm base

Runway 9L-27R was another of the original runways. It was 1676 m long and consisted of 178 mm of PCC with 254-mm-thick edges on 381 mm of gravel base on a minimally prepared subgrade. It was extended in 1957 to its present length of 2260 m (7410 ft). The types of sections are described below (1 m = 3.28 ft):

Length (m)	Description
548	381 mm PCC on 305 mm base
1716	178 mm PCC on 381 mm base

Runway 4L-22R was the third of the original runways and consisted of 178 mm of PCC with 254-mm-thick edges on 381 mm of gravel base on a minimally prepared

Figure 1. Pavements at O'Hare International Airport.



subgrade. This runway was extended to 2290 m (7515 ft) in 1965, which is its present length. The types of sections are described below (1 m = 3.28 ft):

Length (m)	Description
264	305 mm PCC on 305 mm base
1766	178 mm PCC on 381 mm base
274	305 mm PCC on 305 mm base

Runway 9R-27L was built in 1967 and consisted of 305 mm of CRCP in the critical areas and 254 mm of CRCP in the noncritical areas on 914 mm (36 in) or 457 mm (18 in) of base course. This design was limited to 305 mm by standards in use at that time. In addition, the reduction to 254 mm (10 in) was in accordance with design theory on CRCP at that time.

Runway 4R-22L was built in 1970 and consists of 427 mm (14 in) of CRCP on 152 mm (6 in) of cement aggregate mixture on a prepared subgrade from which unsuitable material had been removed. This runway was not placed into unrestricted use until 1975 when obstructions in the nearby railroad yard were removed.

In 1973, a meeting of the Chicago Department of Aviation, Chicago Department of Public Works, Federal Aviation Administration, and airline representatives was convened to analyze and develop a program of pavement-strengthening construction, repairs, and maintenance. The various options available were investigated, although a number of restraints had to be considered. The first was that because of increased environmental pressures, it would be impossible to construct a new runway in the foreseeable future. The second was that traffic would continue at its present rate even though wide-bodied jets are now being used. Consequently, repairs requiring long shutdowns could not be tolerated. It is estimated that normal delays at O'Hare cost $44 300 000 without runway shutdowns in 1976 (1).

PCC construction necessitates longer shutdowns than do asphalt concrete overlays, and reconstruction in the intersections can be accomplished on weekends with asphalt concrete but not with PCC. Thus, asphalt concrete was chosen for the strengthening, which would be staged over a period of years. (Because asphalt concrete oxidizes with age and the surface grooving wears down, periodic rejuvenation and regrooving are necessary.)

The first step was a detailed inspection of the runways to locate all failures, including hairline cracks. These were then plotted on runway plans in colors depicting various levels of severity. Normally, a runway inspection is carried out by six men and a supervisor, who can survey two 2430-m (8000-ft) runways in average condition in 1 d.

This detailed inspection of the pavement sections and failures demonstrated some important facts. First, the airport pavement was generally below strength for the imposed loading. This was not caused by original underdesign, but by increases in loading above the design. Also, financial constraints have sometimes been imposed that limited the pavement sections.

Second, the failures occurred in all types of pavement similarly loaded. In the case of runway 14R-32L, both the 381-mm-thick conventional PCC and the 305-mm-thick CRCP failed in the center half.

Third, the various runways have multiple types of pavement sections, which precludes uniform overlays or repair procedures. The conditions found by the surveys are summarized below:

1. Runway 14R-32L—(a) centerline keyway failures in center half of runway, (b) CRCP failures in center half of runway, and (c) failures in the 381-mm plain concrete in center half of runway;
2. Runway 9R-27L—(a) centerline keyway failures in eastern half of runway, (b) CRCP failures in eastern half of runway, but (c) no failures in portions of runway overlaid with 51-mm (2-in) asphalt concrete;
3. Runway 14L-32R—(a) centerline keyway failures in CRCP in center half of runway, (b) CRCP failures in center half of runway, (c) reflective cracks in asphalt concrete overlay (indicating insufficient strength of pavement), and (d) rutting in asphalt concrete on 32R end;
4. Runway 4L-22R—(a) excellent condition of PCC concrete on 22R end but (b) failures in asphalt concrete throughout (indicating insufficient pavement strength);
5. Runway 9L-27R—deterioration of asphalt concrete overlay from intersection with runway 14L-32R to high-speed turnoff with grooving worn down to 1.6 mm (1/16 in); and
6. Runway 4R-22L: unused in 1973.

Because the patterns of failures on the runways seemed inconsistent, further observations and tests were made. Runway 9R-27L parallels Lake O'Hare, which could cause a higher water table under the runway, but tests did not indicate this. However, observations of traffic made from the tower unlocked the puzzle. For example,

1. On runway 14R-32L, (a) aircraft landing 14R land long and roll down to the terminal; (b) aircraft landing 32L land normally and turn off at the terminal; (c) aircraft taking off 32L start at taxiway T-1 (except for heavies); (d) aircraft taking off 14R are airborne before reaching the terminal; and (e) these operations result in an overlap of traffic in the center half by the landing aircraft and takeoffs in the 32L direction and
2. On runway 9R-27L, (a) aircraft landing 27L land normally or short and attempt to turn into the terminal before crossing runway 14R-32L; (b) aircraft taking off 27L are normally airborne before reaching runway 14R-32L; (c) aircraft landing 9R land long and cross runway 14R-32L before turning into the terminal; (d) aircraft taking off 9R are normally airborne before reaching the north-south taxiway; and (e) the predominant use of this runway, which carries about 28 percent of the total traffic, is in the 27L direction so that the failures on the east end can be explained by overlapping of takeoffs and landings and the resulting heavy usage.

Similar analyses of traffic on the other runways confirmed the correlation of traffic and pavement failures.

The inspections indicated that runways 14L-32R, 14R-32L, and 9R-27L needed base repairs before overlays. At that time, these three were the primary runways because runways 9L-27R and 4L-22R needed major repairs and overlays and were restricted in use because of their lack of shoulders. Thus, it was operationally necessary to keep the primary runways unrestricted in use, and repairs would have to be made before major failures occurred. It was thus decided that base repairs would be made in 1973, and overlays would be made in 1974.

A contract was bid and awarded in the fall of 1973. The pavements were restored to their original strengths, and the keyway in the distressed areas was sawed.

In 1974, the primary runways were strengthened at a cost of $5 053 910. Runways 14R-32L and 9R-27L were overlaid with 152 mm of asphalt concrete, and runway 14L-32R was overlaid with 152 mm of asphalt concrete on the CRCP portion. The overlay design on the CRCP was based on studies by the British (2).

The overlay between the intersections of runways 4L-22R and 9L-27R was held to 76 mm (3 in) to minimize

the transitions and await the final overlay design for those runways.

Because shoving was observed on 32R, it was decided not to overlay the PCC on the ends of the runways, which was also consistent with the observed traffic. For uniformity of marking, a slurry seal that tapered from 152 to 19 mm (6 to ¾ in) was applied from the end of the runway to the beginning of the asphalt overlay.

In 1973, the U.S. Army Corps of Engineers conducted nondestructive tests on the CRCP runways at O'Hare Airport, and in 1974, a regular program of such testing was begun. The purpose of these tests was twofold: First, because stage construction was being used, it was necessary to monitor the conditions of the runways very closely. Conventional condition surveys were being made each spring and fall to determine when the next pavement strengthening would be required, but these surveys record events only and do not predict failures accurately. It was hoped that the nondestructive tests would indicate degradation of the pavement before the occurrence of surface defects so that orderly repairs could be scheduled.

Second, because these tests can be made so easily on a pavement, it is advantageous to use them for design and checking construction.

It is fortunate that this program was begun before the overlays on the CRCP runways were constructed because this permitted a comparison of strengths. Since then, tests have been run in 1975 and 1976 (Figure 2).

In 1975, the overlays of runways 4L-22R and 9L-27R were completed at a cost of $6 850 000. This was not according to the original proposal, which had called for building new runways parallel to 4L and 9L and converting the present 4L-9L to taxiways, but environmental and financial constraints precluded this. By 1968, passenger traffic had ceased to grow at an annual rate of 10 percent, and many expansion plans were canceled. Consequently, pavements designed in 1942 to handle bombers from the Chicago Aircraft Assembly Plant were upgraded to handle fan jets, including the Boeing 747.

A very careful investigation, including a complete soils testing analysis, was made. The soils tests were made by a consultant who also prepared the plans and specifications for runway 4L-22R. The plans and specifications for runway 9L-27R were prepared in-house. The records for the original construction were not available, nor had a soil profile been taken. Therefore, the first step was to take 41 cores at selected locations and prepare subsurface profiles. After analysis of the samples and examination of the profiles, test pits for plate-load tests were located. There were eight test pits on runway 4L and seven test pits on runway 9L. High-early-strength concrete was used to repave the test pit openings, and suitable strengths were obtained in 16 h. Based on these results, full-depth pavement repairs near the intersections were made during the weekends under the runway overlay projects. Several methods of design—Federal Aviation Administration (FAA), Army, Navy, Air Force, Asphalt Institute, Portland Cement Association, and limiting subgrade deflection—were investigated; the FAA method, which resulted in the most conservative overlay requirements, was chosen.

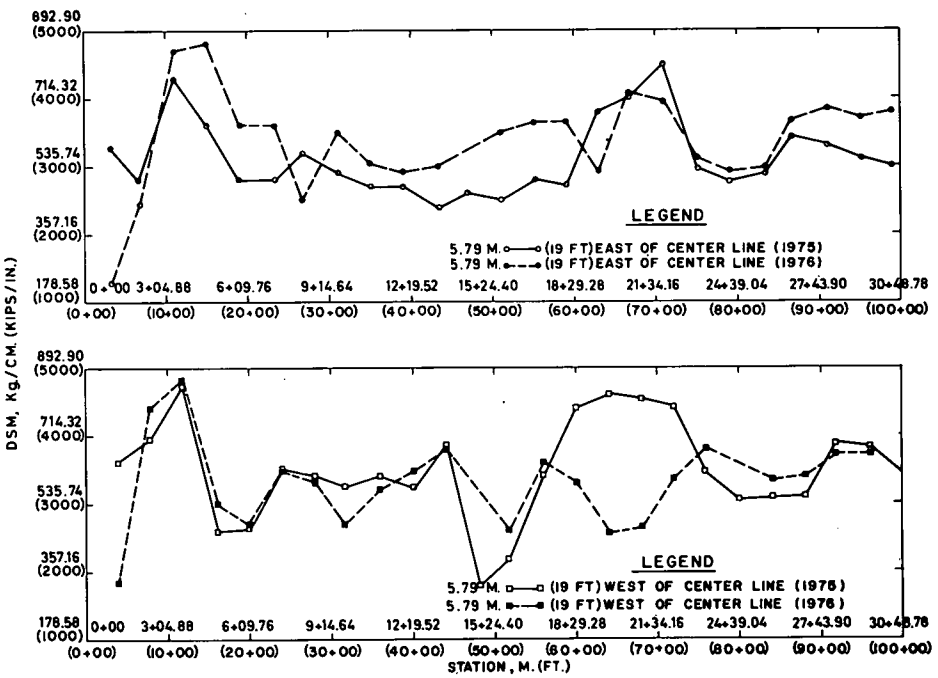
In conjunction with the annual nondestructive testing program being implemented at O'Hare, the Corps of Engineers was also requested to make design recommendations for runways 4L-22R and 9L-27R. To achieve compatibility with the FAA procedures, the tests were made adjacent to the test pits on both runways. The results were correlated, and design recommendations were prepared.

These design recommendations are shown in Figure 3. The actual overlays were less than the design because stage construction is being used, and additional overlays estimated to be 76 mm (3 in) in thickness at approximately 5-year intervals are planned.

The repeat tests showed the stiffness of the pavements very clearly, but it became apparent in the 1976 tests that temperature corrections would be necessary to make the various yearly tests compatible. Curves for design overlays and allowable loads were also prepared by the Corps of Engineers (3).

As more information and records are accumulated, it should be possible to compare the various types of pavements and empirically determine their load-carrying capacities. From these observations, standards for future construction at O'Hare could be developed. It may

Figure 2. Dynamic stiffness modulus (DSM) profiles of runway 14L-32R.



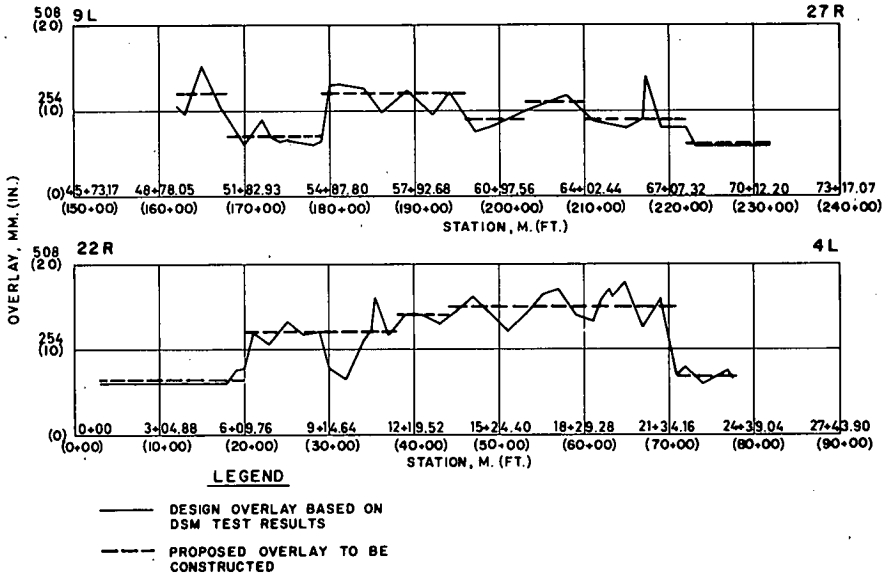


Figure 3. Overlay design for runways 9L-27R and 4L-22R.

be possible to develop a minimum strength for various types of pavements in terms of the dynamic stiffness modulus, which ranges from 1000 to 6000. However, these programs will take time, and correlation through FAA and the Corps of Engineers on pavements at other airports should be studied.

Decisions about the construction and maintenance of runways are also affected by operational and environmental considerations. Consequently, the rehabilitation of existing pavements, rather than the construction of new, may be necessary. This requires that all the available information be obtained about such factors as traffic, existing pavements, and soils. New methodologies such as nondestructive testing should be investigated to supplement present technologies, so that rational decisions supported by facts about how to most economically maintain airport pavements can be made.

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Aircraft-Pavement Compatibility Study

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An economic analysis is summarized that was performed to relate the cost of upgrading airport pavements to the penalty cost associated with adding gears and wheels to aircraft to provide adequate flotation for present-day pavement design criteria. A basic assumption was made that the wide-body jets and a 680-Mg (1.5-million lb) aircraft (categories 1 and 2 aircraft respectively) would use the 26 projected major hub airports by 1985. Three types of gear were designed for categories 1 and 2 aircraft: (a) current, i.e., flotation that is compatible with present pavement criteria; (b) median, a compromise design that considers both present pavement criteria and the optimal gear for aircraft structure; and (c) optimal, a gear optimized for the aircraft structure with no regard for the pavement flotation requirements. Costs were based on each type of gear for both categories of aircraft. Pavement data were surveyed for all 26 projected 1985 major hub airports. Thicknesses for rigid and flexible pavements were determined for categories 1 and 2 aircraft for both new construction and for overlay of selected pavement areas where the aircraft might operate. Aircraft costs were developed as associated with carrying landing-gear masses and volumes in excess of the optimal gear. Pavement-upgrading costs were determined, and cost comparisons were made. Recommendations were presented relative to policy decisions on pavement criteria.

An economic analysis relating the cost of pavement upgrading to the penalty cost associated with adding gears and wheels to aircraft to provide adequate flotation for present-day pavement design criteria has been performed. Adequate flotation as used here implies distributing the total mass of the aircraft over a larger area to keep pavement stresses within acceptable limits. Specifically, the question to be answered was, Should the Federal Aviation Administration (FAA) policy on pavement strength—i.e., that the maximum pavement strength for which Federal-Aid Airport Program (FAAP) [which has been superseded by the Airport Development Aid Program (ADAP)] funds may be applied at any airport may not exceed that required for a 1560 kN (350 000 lbf) dual tandem gear airplane—be changed due to the advent of wide-body jets (the B-747, DC-10, and L-1011) and the possible addition of an aircraft weighing up to 680 Mg (1.5 million lb) to air carrier