

# Evaluation of Runway Distress and Repair Strategy at Hobby Airport, Houston, Texas

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**A** team of professional engineers with expertise in soils stabilization, forensic analysis, construction, and rehabilitation recently investigated the runway distress at Hobby Airport in Houston. Their findings and recommendations for repair are presented in this article.

## Introduction

During the summer of 1998, Houston Hobby Airport Operations and the airlines identified ride quality problems at the transition points between the asphalt-concrete pavement of Runway 12R-30L and the concrete pavement in the intersection with Runway 4-22; specifically, a distinct “bump” at these locations was reported. In fact, there was even one incidence of minor structural damage to an aircraft—loss of hydraulic pressure in the landing gear, attributed to the runway defects. Although the asphalt hump was ground off on several occasions, it continued to reappear, and the Touchdown Zone Light circuit failed. Airport personnel discovered that the circuit’s cable had been severed in one of the light bases within the runway intersection. Upon further inspection, many of the Touchdown Zone Light bases within the intersection were observed to have been damaged by shearing.

Runway 4-22 was totally demolished and reconstructed in 1989 using 15-inch continuously reinforced concrete pavement (CRCP), 8-inch cement-stabilized crushed concrete base, 2-inch asphalt bond breaker, and 8-inch lime fly ash stabilized subgrade. It is 7,600 feet long and 150 feet wide. Runway 12-30L, of the same dimensions as 4-22, is approximately 50 years old. It is an asphalt runway, rehabilitated with asphalt overlays at regular intervals.

The intersection of Runways 12R-30L and 4-22 receives nearly 95% of the total air traffic at Hobby Airport because these are the only two Instrument Landing System (ILS) runways. With the steady growth in air traffic at this airport from 127,000 air carrier operations in 1995 to an anticipated 151,000 in the year 2000, the intersection pavement needed to be a heavy-duty pavement. It was constructed in 1995 on a super fast-track basis that enabled opening of this intersection within 16 days (Godiwalla 1977). Accelerators and high Type III cement content were used to provide rapid strength development to minimize downtime in the intersection construction. Proprietary very high-early-strength or Type III high-early-strength cement was specified. The contractor elected to use a Type III cement. The mixture proportions of the concrete used by the contractor are presented in Table 1.

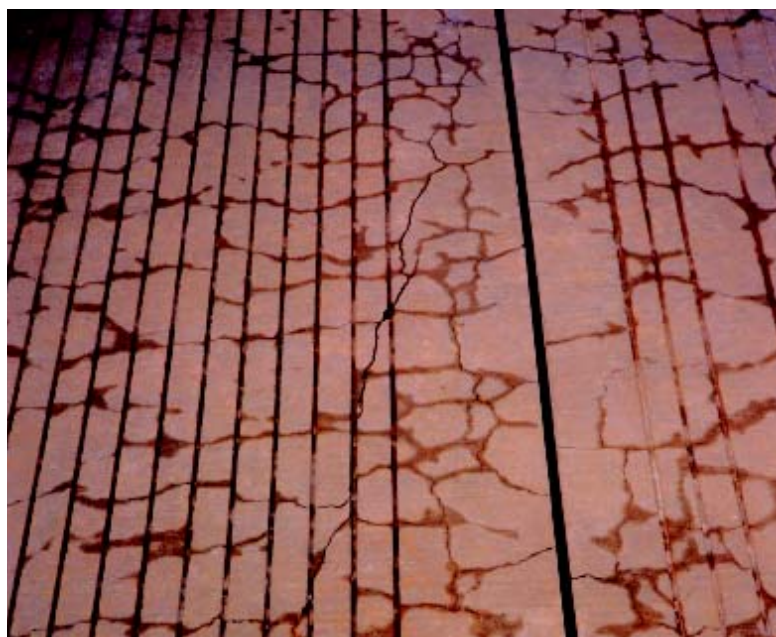


Fig. 1: Profuse map cracking on the concrete surface of Runway 4-22

**TABLE 1: HIGH-EARLY-STRENGTH CONCRETE MIXTURE PROPORTIONS**

ASTM Type III cement	705 lb/yd <sup>3</sup>
Fly ash	140 lb/yd <sup>3</sup>
Total cementitious content	845 lb/yd <sup>3</sup>
Coarse aggregate (1½ inch crushed limestone)	1,788 lb/yd <sup>3</sup>
Fine aggregate	954 lb/yd <sup>3</sup>
Air-entraining admixture	8.5 oz/yd <sup>3</sup>
High-range water-reducing admixture	126 oz/yd <sup>3</sup>
Accelerator	126 oz/yd <sup>3</sup>

A study was initiated in May of 2000 to investigate the cause of the distress and to provide recommendations for repair. At the time of the first site visit by the investigation team under the direction of Brown & Root Services, at least three of the light bases in the intersection had been severely damaged by shearing, there was a pronounced bump on both

sides of the intersection of Runway 12R-30L at the joint between the concrete in the intersection and the asphalt pavement on the remainder of the runway, there was severe cracking and heaving of the asphalt comprising the shoulders in all four “corners” of the intersection, and significant spalling had occurred at the joint between the intersection concrete and the CRCP of Runway 4-22.

Figure 1 illustrates the map cracking that had developed on the concrete surface of Runway 4-22. The asphalt distortion at the intersection on Runway 12R-30L is shown in Figure 2, and Figure 3 illustrates one of the affected light bases in the runway in which the Touchdown Zone Light circuit cable had severed.

Microstructural analysis of concrete core samples collected from different parts of the distressed runway intersections was carried out. Use of other conventional evaluation methods would have required a major shutdown of the runways.

## Microstructural Analysis

Optical microscopy is an effective method for evaluating the nature and extent of damage in concrete (Sarkar 1994; Sarkar and Little 1999). In this method, the microscope provides visual characterization of deterioration of the paste, aggregate, or both. Supplementary analyses of the damaged concrete were carried out using scanning electron microscopy-energy dispersive X-ray analysis (SEM-EDXA) to identify any deterioration product(s). The SEM allows direct observation of surface topography of the affected concrete, and by probing the matrix and interfacial zones with the EDXA, the composition of any secondary product formed as a result of chemical deterioration mechanism can be determined simultaneously.

Figure 4 is an optical micrograph of the damaged concrete showing a multitude of microcracks in the paste. Furthermore, these microcracks are filled with a foreign mineral. Though microcracking of concrete is a rule rather than an exception, the frequency and width of microcracks, in this particular instance, were exceptionally high and suggest damage due to some secondary chemical reaction that must have occurred later in the service life of the concrete than its curing period. A significant amount of this foreign mineral is also present at the paste-aggregate interface, normally occupied by hydrated lime or  $\text{Ca}(\text{OH})_2$ . Figure 5 is a scanning electron micrograph illustrating profusion of needle-like crystal growth around an aggregate particle. Its EDX spectrum (Figure 6) typically displays a peak ratio of  $\text{Ca}:\text{S}:\text{Al} = 3:2:1$ , confirming the foreign mineral to be ettringite.

## Mechanism of Distress

Recent investigations have pointed to delayed ettringite formation (DEF) as a cause of significant damage in concrete structures (Thaulow et al. 1996; Tepponon and Erickson 1987). Delayed ettringite formation is different from primary



Fig. 2: Asphalt distortion at Runway 12R-30L

ettringite in that primary ettringite formation is associated with controlled growth of ettringite to interrupt the very rapid early hydration (“flash set”) of tricalcium aluminate ( $\text{C}_3\text{A}$ ) in the general hydration process of portland cement concrete.

Delayed ettringite formation, on the other hand, refers to reformation of ettringite in an uncontrolled manner (Sarkar 1999). It must also be clearly differentiated from secondary ettringite formation in which an external source of sulfate ions is involved. Converse to external sulfate attack, DEF occurs when internal sources of sulfates tip the balance of the chemical composition and ion ratios in favor of excessive ettringite development and



Fig. 3: An affected light base in the runway in which the Touchdown Zone Light circuit cable had severed

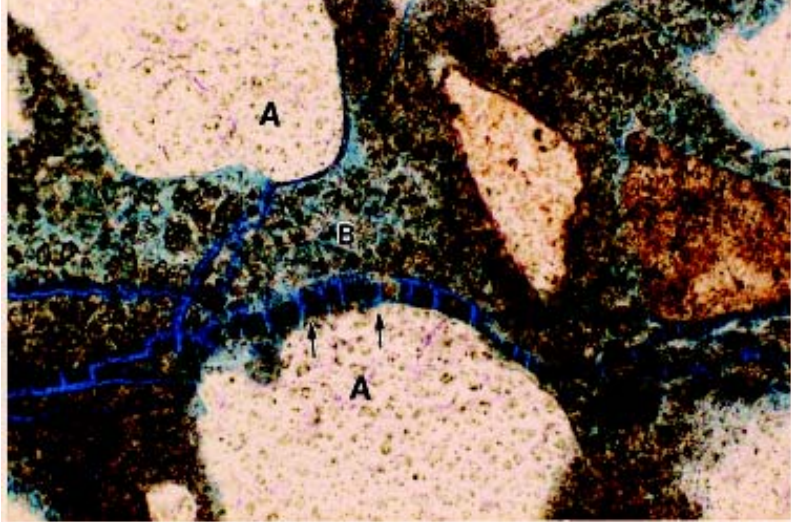


Fig. 4: An optical micrograph of the damaged concrete showing a multitude of microcracks filled with a foreign mineral in the paste

concomitant expansion. It follows the breakdown of primary ettringite and its reformation as delayed ettringite at a later stage of the service life of the concrete that had experienced an elevated temperature, either during its placement, fabrication, or at some stage of its service life (Lawrence 1995; Taylor 1994). The deterioration process is described as ettringite preferentially crystallizing in pre-existing cracks, causing them to open wider. Damage to the paste occurs, and the cracks open further. The high-early-strength mixture design used for the intersection most likely caused considerable drying-shrinkage cracking that developed the polygonal microcracking pattern. This pre-cracking most likely provided a “catalyst” for DEF.

The kinetics and thermodynamics of delayed ettringite reactions are complex and not completely understood (Taylor 1994). Certainly, a precise prognostication of the probability of continued damage due to ettringite growth in the cracks and voids of the concrete intersection is beyond the scope of this evaluation. This is especially true since the exact mixture constituents and proportions are not known. Time monitoring the soluble sulfate quantity in the concrete, however, will provide an indication of the potential for further distress because the reaction is driven by a sulfate source internal to the concrete.

From microstructural analysis, DEF was diagnosed as the primary cause of the distress in the intersection pavements. The high cement content used to achieve high early strength in concrete is likely to have generated excess heat, which is considered an essential condition for DEF. The most plausible source of the other prerequisites (sulfate and aluminum ions) for DEF to occur is the cement. As a Type III cement was used, its  $C_3A$  content could be expected to be much higher than in a Type I cement. The high heat caused thermal cracks to appear in the concrete earlier and more densely than usual, then these cracks increased both in frequency and dimensions as DEF progressed. Finally, as the concrete surface is horizontal, penetration of water through the microcracks occurred with relative ease. The net result was expansion of

the concrete, followed by partial disintegration in parts of the upper exposed surface.

## Recommendations for Repair

The first recommendation made for repair is to seal the fine cracks that exist in the surface of the intersection, using a low-viscosity polymer grout injection. These materials are capable of flowing/seeping into the tortuous cracks and effectively sealing them as they form a solid matrix after injection. The most effective way to protect the slab from significant further damage is to prevent the ingress of water, especially through the surficial cracks.

Additionally, a joint repair scheme that provides new expansion joints on each side of the concrete intersection between the asphalt pavement and the intersection concrete pavement has been recommended. These joints provide for an additional 12 cm (5 inches) of expansion, which is anticipated to be adequate for the remaining 15 years of the present design life. Also recommended is the installation of a set of full-depth (of the “new concrete”) expansion joints on Runway 4-22 on each side of the intersection at the joint with the existing continuously reinforced concrete pavement. It has been further proposed that the added expansion joint capacity should be 10 to 12 cm (4.5 to 5 inches), and should be sawn when the air temperature is approximately 70° F.

Out of the three options initially proposed for the light base repair, only recoring of the distressed base holes to a depth of the 42 cm (17-inch) pavement has been recommended. The 15 cm (6-inch) thick concrete pavement that pre-existed the 42 cm (17-inch) overlay will not be penetrated in this option. This option is recommended because additional differential movement between the two concrete slabs may occur, and the light base can move with the surface layer without damage due to that movement. A bond breaker should be placed between the bottom of each light base and the pre-existing 15 cm (6-inch) concrete slab at a depth of approximately 42 cm (17 inches). This bond breaker should consist of a 1.25 cm (½-inch) layer of a mixture of AC-5 grade asphalt cement and TxDOT Grade 4 aggregate.

It will be prudent to visually monitor the performance of the pavement for evidence of further reaction and slab movement. If significant additional movement or deterioration is noted, cores may need to be obtained for additional analysis.

## Conclusions

Petrographic and SEM/EDXA analysis of concrete cores collected from the intersection between Runways 4-22 and 12R-30L at Hobby Airport in Houston revealed the existence of DEF in the concrete. Delayed ettringite formation is the primary cause of the inelastic expansion of the concrete, resulting in distress within the slab and at the interfaces between the intersection concrete and the runway pavements.

The recommended design remedy involves installation of expansion joints that can accommodate approximately 12 cm (5 inches) of total additional movement. This added expansion joint capacity will adequately provide for thermally-initiated and moisture-initiated movements, and also provide a safety factor for some additional movement due to residual sulfate reactions. Such a capricious mechanism as DEF deserves a safety factor.

Coring out the damaged light bases to the depth necessary to install a new "medium-depth" standard light base in the same surface locations has been recommended. In no case should the coring penetrate the "old" concrete which pre-existed the "new" concrete [that is, maximum depth of approximately 42 cm (17 inches)]. This option is anticipated to eliminate problems associated with differential movement between the "old" and "new" slabs.

The "isolation" of the light bases from other pavement layers should prevent any further damage to the runway light system due to expansion of the surface layer differentially from the underlying layer(s).

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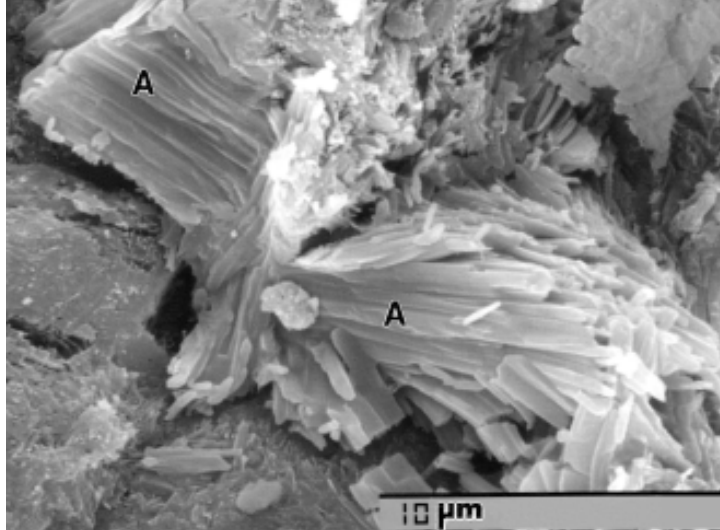


Fig. 5: A scanning electron micrograph illustrating profusion of needle-like crystal growth around an aggregate particle

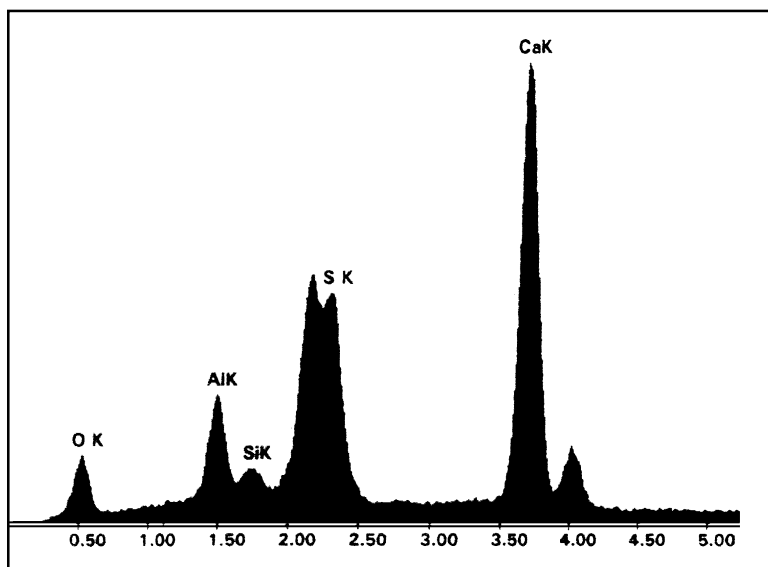


Fig. 6: Its EDX spectrum consisting mainly of Ca, Al, and S peaks confirms the foreign mineral to be ettringite

of ASCE. He received the C. V. Wootan and Trinity Engineering Career Achievement in research leadership for the year 2000 from the Texas Transportation Institute. He has authored approximately 170 papers and significant reports and has served as principal investigator on over \$11 million of grant and contract research in transportation materials.

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