On October 29, 2007, a new section of taxiway was poured at O’Hare International Airport, and sensors were installed into the pavement to measure temperature, relative humidity, lift-off of slab corners, and joint-opening displacement.

One result of interest to pavement engineers trying to understand the concrete volume change and cracking has been the persistently high relative humidity observed through the thickness of the concrete slab. RH at any location in the slab thickness stays relatively high, although there is a modest gradient of RH that ranges from 95%+ near the bottom of the slab to mid-80% near the top of the slab. The data suggests that moisture gradients play a relatively small role in curling stresses, while temperature swings may induce greater stresses.

The attached report has been prepared to summarize the results of the experiments collected to date.
Pavement sensor data 10L on the south airfield at the Chicago O’Hare International Airport

David Lange, John Popovics, and Yi-Shi Liu

Department of Civil and Environmental Engineering
University of Illinois at Urbana-Champaign

January 12, 2009
**Introduction**

On October 29, 2007, a new section of taxiway was poured at O'Hare, and sensors were installed into the pavement to measure temperature, relative humidity, lift-off of slab corners, and joint-opening displacements. Powered by the solar panels, the sensors and data collection system are designed to be self-sustaining in off-grid or remote areas. The temperature and relative humidity sensors were assembled as sensor trees, installed prior to the pouring of concrete, to provide the environmental response profiles inside the pavement. Internal lift-off sensors, also installed before pouring, were placed next to the dowels to monitor the vertical displacement or curling deformation at the corners. Joint-opening sensors were installed after saw-cutting to capture the opening initiation and displacement afterwards. External lift-off sensors were attached in place near the potential opening posterior to the removal of the side forms. The purpose of these measurements is to analyze the deformation of the slab under early age volume changes and environmental changes.

**Project location and sensor layout**

The instrumentation was installed at the designated location on taxiway ZD near taxiway L (Figure ). The pavements were constructed as part of the south airfield runway 10L-28R extension project. Each concrete slab sizes 20ft by 20ft and 17in thick. The instrumented sensoring system includes environmental profiling sensors, joint opening gauges, and corner lift-off gauges (Figure 2).

**Environmental profiling sensors**

The sensor unit used for environmental profiling in concrete was developed at University of Illinois at Urbana Champaign. Each unit consists of Sensirion SHT75 digital sensor enclosed by plastic tube and Gore-Tex as shown in Figure 3. Arrays of sensor units were placed at 0.5, 1, 2, 3, 6, 10, and 16 inches below the slab surface.
**Corner lift-off gauges**

The embedded corner lift-off gauges were designed to meet the following two challenges: 1) slip-form placement of concrete, and 2) water intrusion and moisture exposure in concrete. The lift-off sensor packages consist of Macro Sensors GHSA 750 spring-loaded LVDT with housing and bellows to improve the ruggedness and water-resistant as shown in Figure 4.

**Joint opening gauges**

The Joint opening gauges also use the GHSA 750 LVDT to measure the displacement. The units were placed after the placement of concrete and sawing of joints (Figure 5). Two gauges were placed on the north-south joint and one gauge on the east-west joint to measure the opening behavior of different direction on the pavements.

**Data collection station**

The data acquisition station, as shown in Figure 6, was placed next to the instrumented slab. Two types of data loggers were assembled for the instrumentation. A Campbell Scientific CR10X data logger and AM16/32 multiplexer, connected to the LVDTs through signal conditioners Macro Sensors LPC-2000, gathers displacement data hourly. The other measurement system is the field-ready multiplexer developed at UIUC in which the relative humidity and temperature data were recorded from the time of concrete placement and collected hourly.

Although the instrumentation locates in the airfield, the access to power is limited at this location. A self-contained power supply was assembled, which includes solar panels (total rated power 40W, nominal voltage 24V), a charging regulator, and a battery bank consisting of six 12V deep-cycle battery in serial-parallel connection, designed for 5 days operation life if not charging. The solar panels were replaced later with a 190W 24V high power solar panel to better withstand severe weather condition in winter.
Environmental profiles

The environmental sensor trees provided the internal profile of temperature and relative humidity. These gradients are the main causes of slab volume instability under climate changes. Figure 7 demonstrated the early age temperature profile in the slab. Before the placement of concrete (before 10/29), all sensors recorded the same value of temperature. After the placement of concrete, the temperature profile displayed a distinct gradient, in which the high internal temperature occurred due to hydration, and the amount of daily fluctuation varied along the slab depth. The early age gradient often contributes the built-in permanent curling of concrete pavements. The long term temperature profile was plotted in Figure 8. Overall temperature trends were similar across the sensors, but near surface temperature fluctuated more than the inner sections.

The early age relative humidity data was plotted in Figure 9. Unlike the temperature data which showed a distinct gradient, early age relative humidity remained nearly saturated in the slab as the moisture was still retained in concrete. Because the sensors were installed two days prior to the placement of concrete, the initial RH readings equaled to the ambient relative humidity. The internal relative humidity soon reached saturation after the placement of concrete, and remained high humidity through winter as shown in Figure 10 as a result of curing compound and seasonal snow cover. The prolong coverage under snow at early age acted like a long-term curing practice which prevents surface cracking and ensures low permeability in concrete. The internal RH started to show variations after spring, but only lost a small amount of moisture as a well-cured concrete would perform.

Pavement responses

The joint opening gauges provided information related to joint crack initiation. As shown in Figure 11, the sudden jump in the displacement data captured by the sensors indicated the time when the crack occurred, which was verified by visual inspection on the same day. Knowing that the north-south joint cracking did not take place until two
weeks after construction, and knowing that the east-west opening was still intact, we can infer that the amount of drying shrinkage in concrete pavement in this period of time was low, which conforms with the relative humidity data mentioned above.

The corner lift-off data in Figure 12 showed diversion between internal and external gauges. The external data showed settlement or creep between concrete slab and asphalt base. These deformations would not be captured by the internal gauges since the sensors were embedded in the slab and anchored while the concrete slab and asphalt base were intact. Both the internal and external sensors showed vertical displacement after March, while the temperature rose above zero degrees Celsius. Although the bond breaker was applied on the asphalt base before the placement of concrete to ensure debonding between layers, the value of vertical displacement was relatively low since the relative humidity gradient was not very obvious throughout the year.
Figure 1 Instrumented slab location (Taxiway L/ZD)

Figure 2 Sensor layout
Figure 3 Environmental profiling sensors.

Figure 4 Corner lift-off gauges.

Figure 5 Joint opening gauges.
Figure 6 Data acquisition station.

Figure 7 Temperature profile (1st month data)
Figure 8 Temperature profile (1 year data)

Figure 9 Relative humidity (1st month data)
Figure 10(a) Relative humidity (1 year data)

Figure 10(b) Internal relative humidity (1 year data less ambient RH)
Figure 11 Joint opening displacement (JtOp1-across N-S joint, edge; JtOp2-across N-S joint, center; JtOp3-across E-W joint)

Figure 12 Corner lift-off vertical displacement