Sensor Design and Layout for Airport Asphalt Pavement Instrumentation to Test for Delamination

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Abstract

The constant improvement of airport pavement design standards is very important for maintaining high levels of performance, protection and efficiency in air transportation. Numerous distress types can be found in asphalt pavements at airports. Interlayer delamination, caused by a poor bond between the two layers of paving, is a serious concern in runway and taxiway surfaces. However, preventing this problem has proven to be a difficult issue. The use of sensors to monitor the condition of pavements shows several advantages and benefits since it monitors the pavement in real time and collects practical data, which facilitates the analysis to produce predictive models. Nonetheless, it is a relatively new concept within the transportation industry. The purpose of this paper is to present different types of sensors, their infrastructure, as well as the positioning and spacing. While the types of sensors available in various industries are abundant, there are only a few types that are appropriate for use in pavements. Although, the amount and types of sensors can vary depending on the particular objective, the basic types include strain gages, temperature gages, pressure sensors, as well as the collection of environmental data. The behaviors of transversal and longitudinal sensors arrangements are also discussed.

Keywords
DAQ, strain gages, milling, longitudinal sensors, transverse sensors, solar array.

1. Introduction

The use of sensors to monitor the condition of pavements is a relatively new concept within the transportation industry. Pavement management systems (PMS) that utilize these methods only do so in order to rate the condition of pavements. There are various tests to essentially measure the same properties or characteristics of pavements, which provide useful information of current conditions that gives the management team a better idea of how to prioritize maintenance, reconstruction or rehabilitation, and subsequently allocate funds appropriately.

Even though sensor instrumentation is still basically in the research stage and only utilized in a handful of large-scale pavement projects, the advantages and benefits in using sensors in pavements are numerous and mainly facilitate the analysis to produce predictive models that correlate observed distresses and the current condition of the pavement. The utilization of these sensors can provide Transportation Departments with a way to actually monitor the pavement in real time and collect practical data.

The Federal Aviation Administration's (FAA) National Airport Pavement Test Facility (NAPTF) has extended their pavement sensor research out to the field by instrumenting a handful of different runways at International airports, including Denver International Airport, John F. Kennedy Airport, Newark International Airport. In addition to

NAPTF, the Hawaii Department of Transportation is working on installing sensors at their Honolulu airport to measure the intensity of delamination at a taxiway. Collecting information on a taxiway prior to departure is useful because the aircraft is the most heavily loaded at that time, and pavement stresses are at the highest, even higher than while landing. This will be the first asphalt pavement instrumentation project in Hawaii. The main aim of pavement instrumentation is to "conserve airport development funds and reduce the downtime of airfield pavements for construction and maintenance activities" (Garg *et al.* 2010).

2. Sensors

2.1. Stress Measuring Sensors

Sensors for pavement instrumentation for measuring stresses are primarily dynamic sensors that "measure the effects in the pavement during heavy wheel loading from all aircraft landings". They are engaged only when an aircraft is detected on the runway. The common dynamic sensors used in airport pavements include the following (Weinmann *et al.* 2004):

- Linear Variable Displacement Transducer (LVDT) – measures vertical displacements
- H-Bar Strain Gages – measure strain response due to aircraft loading
- Carlson Strain Gages – measure strain response due to aircraft loading
- Position Strain Gages – detect aircraft locations
- Optical Fiber Sensors – measure joint movement with temperature changes
- Pressure Sensors – measure in-situ stresses

All of these sensors ultimately determine the stresses present within the pavement (i.e. internal stresses) at various depths and locations. The type of sensors used on the projects analyzed is limited to strain gages.

2.2 Strain Gages

The strain gages used in asphalt and concrete differ due to the fact that there are different requirements and installation processes for a flexible (asphalt) pavement and for a rigid (concrete) pavement. Asphalt strain gages (ASG) are designed specifically to withstand the high temperatures of the hot-mix asphalt as well as the vibratory and rolling impact from the pavers. Typically, ASG's are embedded in two layers of asphalt. This is so that one can monitor stress changes at various depths. When runways require a repaving of the surface layer, an asphalt overlay project is usually initialized. The gages are placed at the milled surface as well as about one inch below the bottom of the asphalt overlay (Refer section 4 on Instrumentation Installation). As for concrete, strain gages are usually much more robust and are typically attached to the rebar before the concrete is poured. The Geokon model 3900 or the CTL CSG has been used in the past as a strain gage for concrete pavement instrumentation (Timm *et al.* 2004). A typical strain gage used for asphalt, such as used in the Newark airport project is shown in Figure 1.

3. Inferring and Detecting Delamination

The theory behind being able to infer delamination in airport asphalt pavements is that the overlay layer and base layer depict contrary strain responses in contrast to that of a homogenous layer which should depict identical or near-identical responses at the interface. As soon as there is evidence that the upper and lower parts of the pavement are behaving independently, there is reason to believe that delamination has taken place. Figure 2 shows an example of delamination where the pavement shows slippage.

The phenomenon of varied response is demonstrated by Figure 3. In a homogenous system, where there is full bonding, the stress-strain diagram acts over the entire thickness of the bonded layer. In contrast, once there is slippage or delamination between the upper layer and lower layer, the two layers begin to act and behave independently, registering their own tension and compression profiles (Cook and Singh, 2014). Thus, detecting this shift in the pavement is a non-destructive technique of determining delamination. This is especially important, since non-destructive tests involving shutting down the runway or taxiway, which is quite impossible in busy airports.

4. Instrumentation Installation

Asphalt strain gages embedded in airport pavements consist of longitudinal and transverse gages, thermocouples to relate response to temperature, and a data acquisition system from where data can be sent by wireless for logging in remotely. The longitudinal and transverse sensors must be installed at a reasonable distance apart to ensure that the data of each can be registered and read independently, without interference. Figure 4 shows the layout of gages as proposed for Honolulu. The circular dots on Figure 4 show the landing gear configuration of various aircraft –

Figure 1. Typical strain gage for pavements

Figure 2. Example of delamination

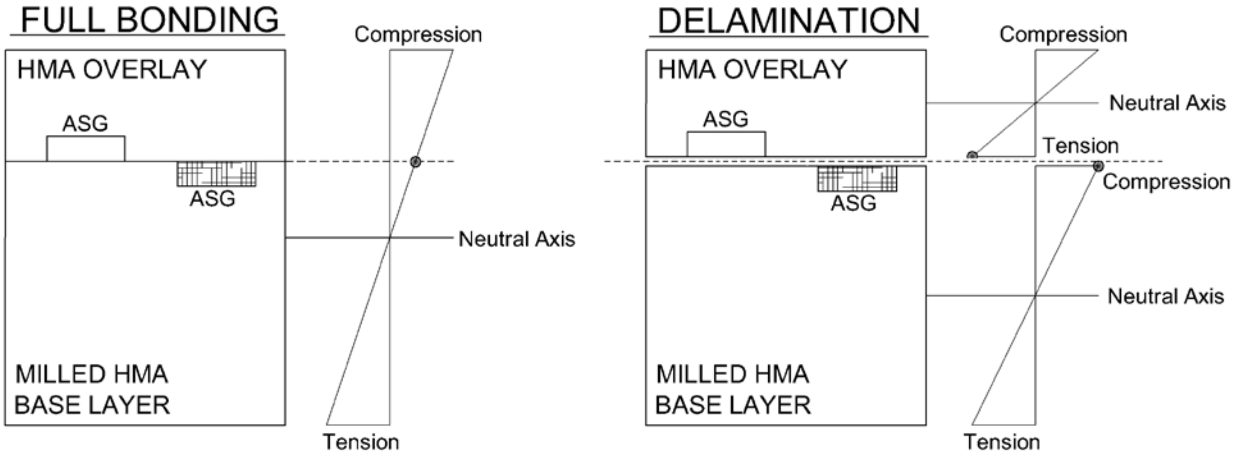


Figure 3. Changes in stress response between the bonded and delaminated cases

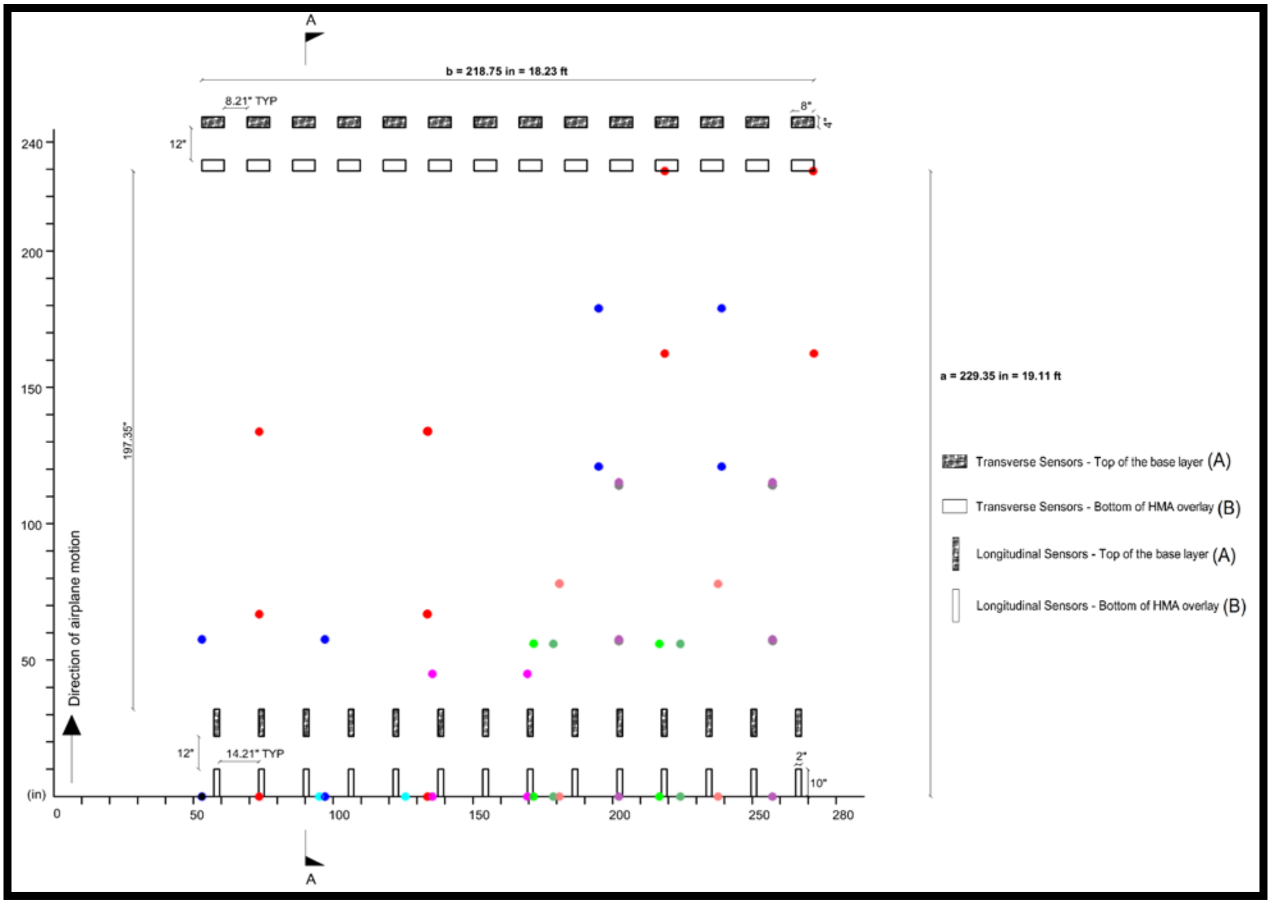


Figure 4. Proposed layout of gages at Honolulu airport – 56 sensors

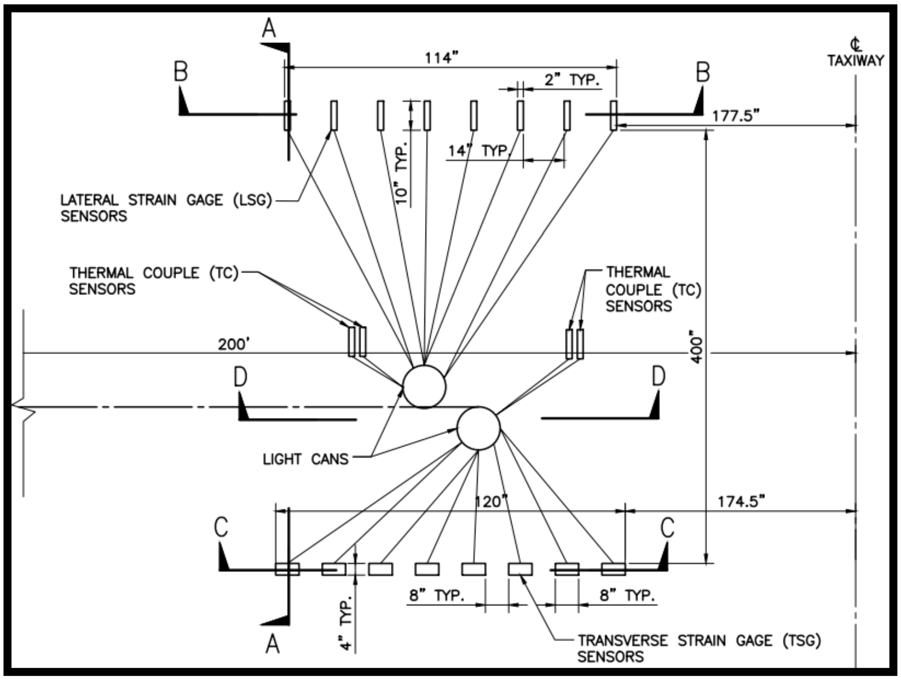


Figure 5. Layout with 16 sensors

Boeing 737-300, 747-300, 757-300, 767-300, 767-300 ER, 777-300 B, 777-300 ER, A330-300 and A380-800. All aircraft have different landing gear, so if a particular aircraft type is to be targeted at any airport, then the spacing between the sensors can be different, accordingly.

The number of sensors to use depends upon the aircraft configuration being targeted, and on the money available for the instrumentation project. At the lowest, this project conceived to use 16 sensors for a proposed project at Kahului airport, Maui – eight transverse sensors and eight longitudinal sensors (Figure 5). For Honolulu, where nine types of major aircraft land and take-off, it was found fit to use 56 sensors in total per Figure 4.

Figure 6 shows the section across the gages at Honolulu airport and to illustrate that the gages A and B are at different elevations – A at the bottom of the overlay layer, and B at the top of the base layer. Thermocouples can be installed at any height, so long as they aren't too deep or too shallow: they simply have to be around the interface layer so that the temperatures that affect delamination can be measured.

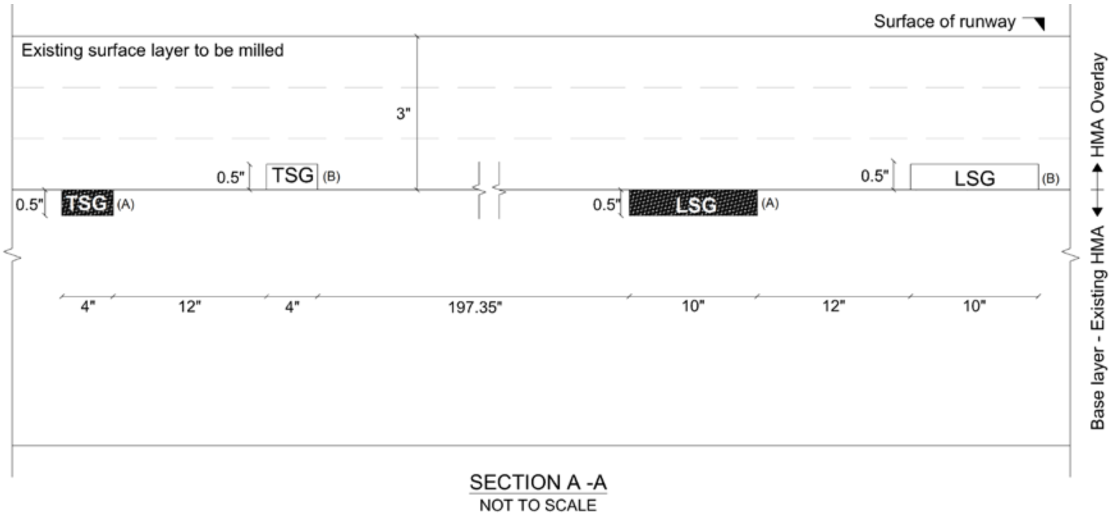


Figure 6. Representative cross-sectional illustration of ASGs (refer figure 4)

Figure 7 shows how the sensors are installed on the milled surface: for the ASG that is at the top of the base layer, grooves are cut into the asphalt to position the H-shape sensor configuration. The sensors that are at the bottom of the overlay layer are simply placed on the milled surface and covered with asphalt prior to paving of the overlay layer.

Figure 7. ASG installation at Newark Airport

Figures 8 and 9 illustrate where the sensors were placed in relation to the larger airport at Newark International airport, thus giving perspective to the management and coordination requirements for even a small job such as this at a busy airport.

Figure 8. Location of instrumentation on runway (Imagery © 2016 Google, Map data ©2016 Google)

Figure 9. Location of instrumentation at EWR (Imagery © 2016 Google, Map data ©2016 Google)

5. Strain Gage Responses

Figure 8 shows strain responses for transverse gages for the bonded and delaminated cases, while Figure 9 does the same for longitudinal gages. Transverse gages are affected by lateral wheel traffic, while the LSGs are not so influenced. This is because the gages only register strains along their longer axis. As evident, in the bonded cases, the strain responses are all in the same direction and pattern, while the pattern is reversed in delaminated cases.

Gages will only collect data along their longer axis, because that's how the gage is oriented. Pressure waves perpendicular to their main axis are unlikely to be registered in any significant way. In addition, there are two conditions to be evaluated – bonded pavements and delaminated pavements. This plays an important role in interpreting the results that follow.

5.1 TSG Sensor Behavior

While the aircraft wheel is approaching the TSG sensor, no reading is recorded because the sensor is oriented perpendicular to the direction of the compression wave being generated by the oncoming aircraft. However, as soon as the wheel is directly on top of the sensor, a sharp tensile force is experienced by the sensor in bonded pavements. The upper left part of Fig 10 shows this phenomenon.

TSGs will also pick up compression waves from wheels positioned laterally. In this case, the TSG will only register a compressive force. Because the wheel is not traveling directly above the sensor, no sharp tensile force will be recorded. The lower left part of Fig. 10 shows this phenomenon.

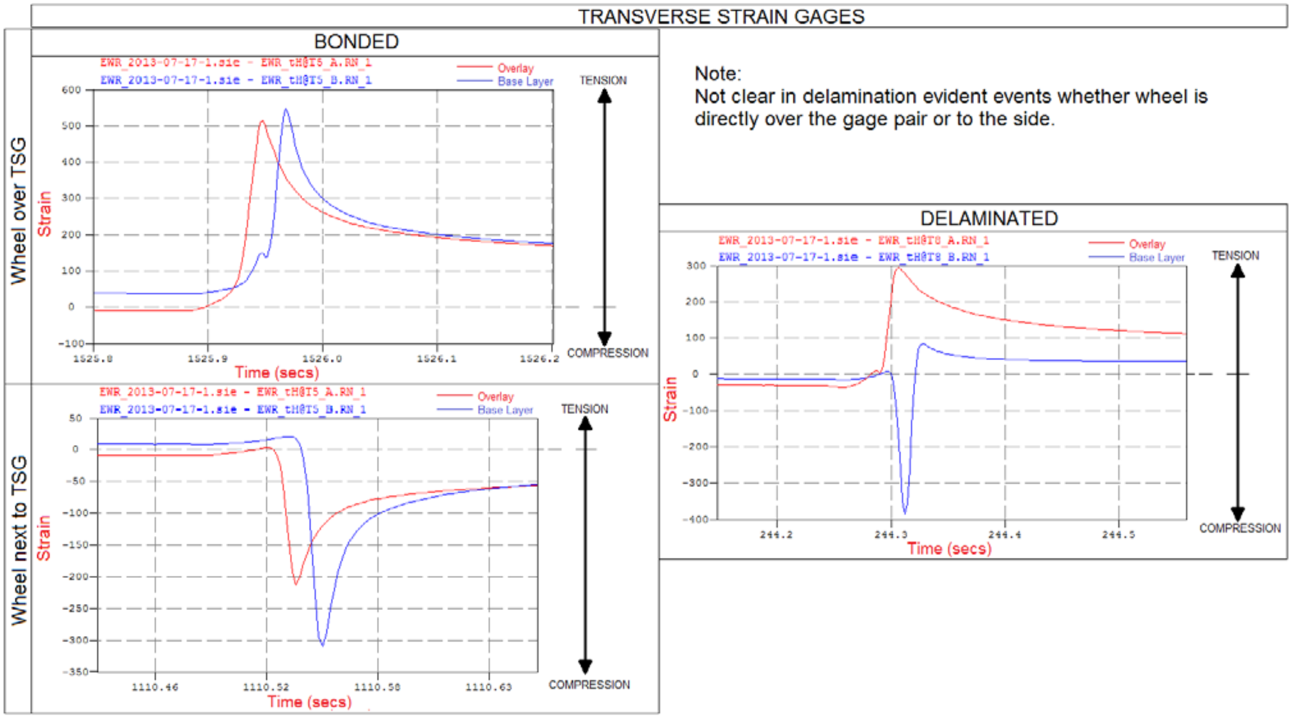
However, in delaminated cases, the stress response is totally in contrast to homogenous cases, as evidenced in the right side of Figure 10.

5.2 LSG Sensor Behavior

When the aircraft wheels approach the sensor, they push a compression wave in front of them. This means that the sensor will record compression till as long as they receive the compression wave. But, as soon as the wheel goes above the sensor, there is a sharp vertical load on the sensors, and a tensile wave is recorded. Once the wheel passes, the sensor returns to its zero reading (Garg and Hayhoe 2001). All this happens in microseconds. The behavior is depicted in the left side of Figure 11.

Responses on LSGs are not significantly affected by wheels passing laterally because the sensors direction is parallel to the direction of air traffic. Minor readings, however, may be registered because the visco-elastic pavement will transmit some forces in a radial direction, but these are insignificant.

In the delaminated case, the stress response is in stark contrast to the bonded case, as seen on the right side of Figure 11. The two layers perform in opposing ways, demonstrating that the layers are not homogenous.



Note:
Not clear in delamination evident events whether wheel is directly over the gage pair or to the side.

Figure 10. Response of transverse strain gages for bonded and delaminated cases

Cook *et al.* (2016) carries information on results of an experiment undertaken at Newark Liberty International Airport. The results convincingly reveal that delamination can be detected with statistical confidence, as well as visual corroboration.

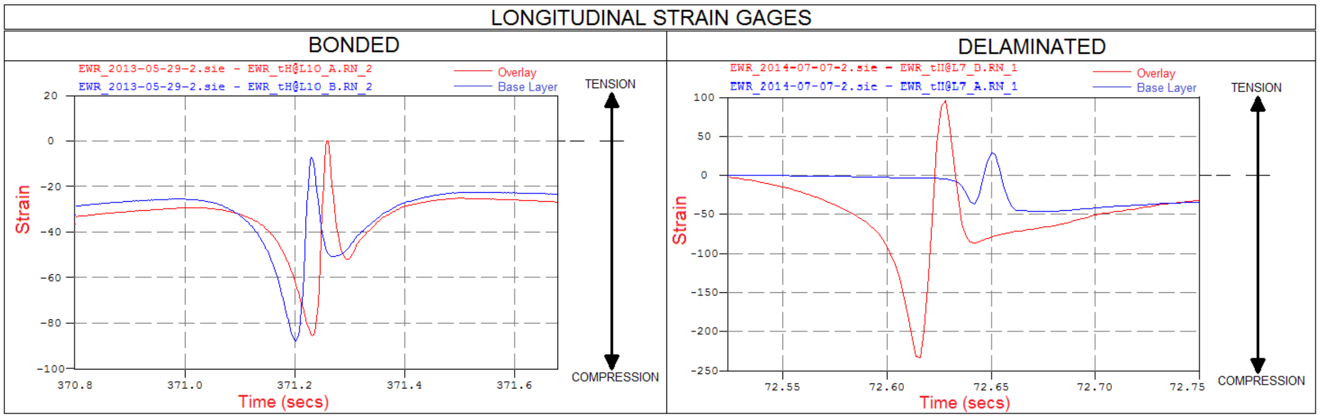


Figure 11. Response of longitudinal strain gages for bonded and delaminated cases

6. Data Collection Methods and Infrastructure

To collect the data involves an elaborate infrastructure procurement that includes milling the pavement, trenching anywhere from 200 to 500 ft. away from taxiway centerline to locate the data acquisition unit on a slab at grade (Singh and Cook, 2015). The trench usually needs to be more than 18" deep to adhere to airport standards to prevent waterlogging; a pullbox has to be capable of withstanding traffic loads, since it is not expected that any aircraft will veer off course while on the taxiway at 15 mph; Figure 12 shows the larger overview and elevation view of the project, while Figure 13 shows a data acquisition cabinet that needs to be placed on a concrete slab, along with a solar array; Figure 14 gives a close up view of the solar array.

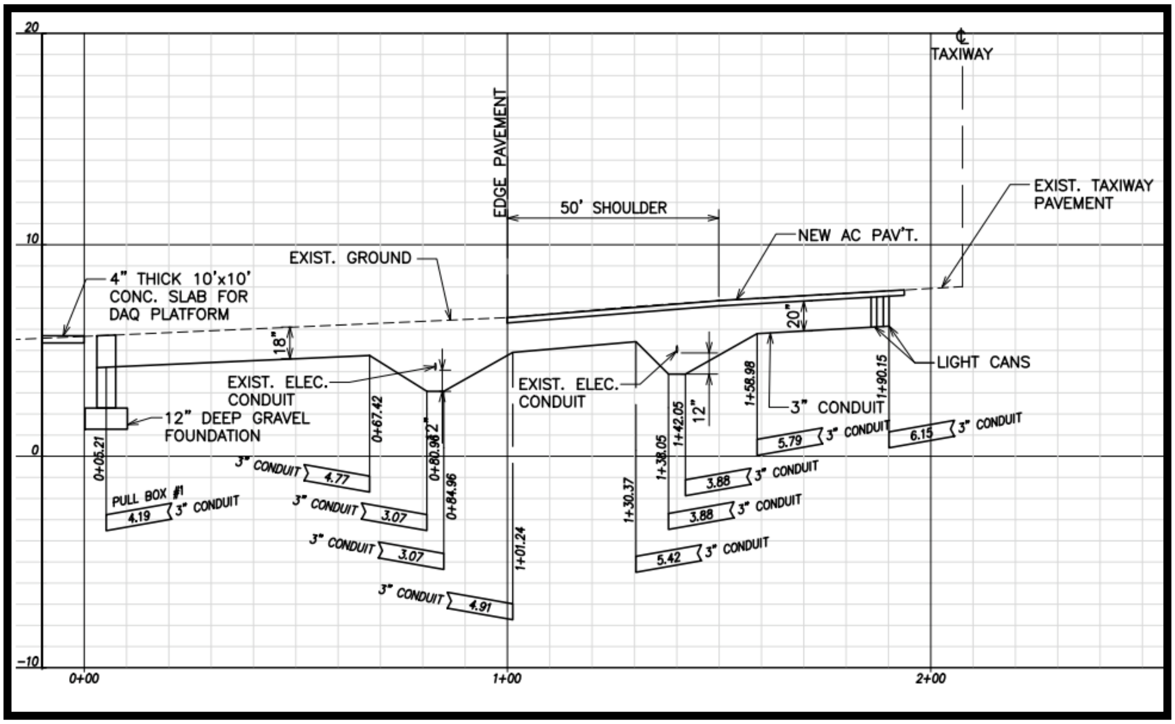


Fig. 12. Side view of infrastructure works for sensor

Figure 13. DAQ and small solar array

Figure 14. Close up view of small solar array for DAQ

7. Conclusions

The aim of this article is to cover the basic concepts of sensors and the types that are used in pavement instrumentation. While the types of sensors available in various industries are numerous, there are only a few types that are used or necessary for use in pavements. Both dynamic and static sensors are embedded in either asphalt or concrete pavements in order to gather data that can be used to help correlate research data and confirm predictive models developed by research institutions. The article illustrates how the strain gages are read and how the responses are recorded.

The article gave various layout patterns of sensor configuration, which depends upon the landing gear configuration of aircraft, the number of aircraft targeted for observation and measurement, and the funding available for the project.

Considerable infrastructure needs to be installed to ensure that data from the runway/taxiway can be collected by a data acquisition cabinet (DAQ). Typically, the DAQ is positioned 200 ft. to 500 ft. away from the center line of the runway/taxiway, owing to safety and needs and the specific positioning of the sensors at any particular airport.

Whenever there is delamination in an asphalt pavement, the upper overlay layer separates away from the base layer, resulting in each layer acting independently rather than homogenously. Hence, each layer exhibits its own tension and compression profile rather than being part of homogenous whole. The sensors are able to pick up the discrepancy in tension and compression at the different layers, thus enabling the detection of delamination without destructive testing, and without having to close down the runway/taxiway for any alternate non-destructive testing method.

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Biography

Amarjit Singh is a professor in the Department of Civil Engineering at the University of Hawai'i. He has a B.Tech. in Civil Engineering from I.I.T. Delhi, an M.Eng. in Civil Engineering from Texas A&M University, and a Ph.D. in Civil Engineering from Purdue University.

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