HEAVING OF AIRFIELD PAVEMENT AT HONG KONG INTERNATIONAL AIRPORT

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Abstract

The new Hong Kong International Airport, with two parallel runways, was opened in 1998. Soon after the opening of the North Runway in July 1999, a strange phenomenon occurred on the asphalt pavement. Pavement damage associated with the heave of the wearing course was observed at various locations on the taxiway shoulder after heavy rainfall of long duration. At some locations, the wearing course layers was temporarily lifted up from the underlying crushed aggregates base course in a dome with a height of up to 400 mm and a diameter up to approximately 10 m. Remaining locations of damage were in the form of cracking and localized bulging of the wearing course. In the later part of the year, the problem extended to the aircraft movement areas in a taxiway and on a runway and on one occasion caused the closure of the runway for an emergency repair. This paper describes the investigation carried out by the Airport Authority Hong Kong to identify the cause of the heaving. It also describes the temporary measures taken to mitigate the problem as well as the development and implementation of a long-term solution.

1 Background

Pavement structures

The runways and taxiways of the Hong Kong International Airport (HKIA) are constructed on reclaimed land. To cater for the ground settlement, a flexible pavement design was adopted. The flexible pavement layers comprise of a Marshall Asphalt Wearing Course and a Base Course (MAWC & MABC) on a compacted Crushed Aggregate Base Course (CABC) and a Crushed Aggregates Sub-Base (CASB). A typical cross section of the runway / taxiway pavement is shown on Figure 1.

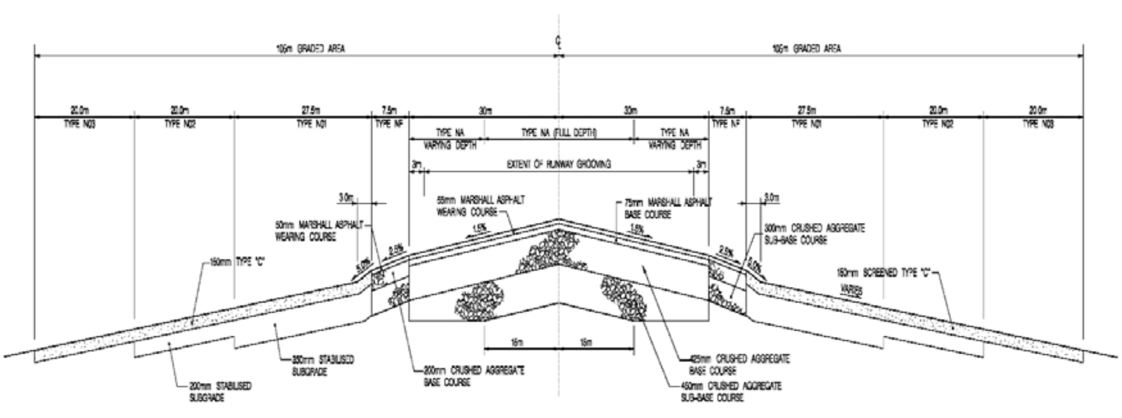

Figure 1 - Typical Runway Cross Section

Subgrade and Fill

Prior to the reclamation, the soft marine clay, which blankets most of the seabed, was removed by dredging. The reclamation in the area of the runway and taxiways are comprised of a 2-4 meter thick marine sand capping layer overlaying 13 meters rock fill which in turn is underlain by 5-10 meters of marine sand to dredge level. A horizontal geotextile filter fabric was installed between the marine capping sand and rock fill to prevent the wash out of the capping sand into the underlying rock fill. The subgrade sand fill below the CASB was compacted to 98% of maximum dry density.

2 Problem of Pavement Heaving

Pavement damage associated with the heave of the wearing course was first observed on the taxiway shoulders within the North Runway Area between July and September 1999. At some of these locations the wearing course was observed to be temporarily lifted away from the underlying crushed aggregate base course forming a dome with height of up to 400 mm and a diameter up to approximately 10m. At the remaining locations the damage was observed in the form of cracking and localized bulging of the wearing course. (See Figure 2). It was noticed that the heaving phenomena occurred only after prolonged heavy rainfall during the summer months. Air bubbles were also observed at the locations of the damaged pavement surfaces during the heaving occurrence. The duration of each heaving occurrence was also very short, about one or two hours, after which, the dome disappeared.

Figure 2 - Heaving at Shoulder

During the summer months of 2000, the heaving at the shoulder area continued. In 2001, the heaving problem extended to the aircraft traffic area in a taxiway and a runway. On 7 June 2001, after 5 days of heavy rainfall, an area of taxiway pavement at Rapid Exit Taxiway (RET) A5 heaved and fractured the pavement along a construction joint. (See figure 3). On the following day, heaving damage was also observed on the runway along the centerline paving joint. Although no dome was observed. it was clear that the MAWC had been separated from the MABC.(See Figure 4) The taxiway and runway had to be closed for several hours to facilitate the emergency repair.

Figure 3 - Heaving at Taxiway

Figure 4 - Heaving at Runway

3 Investigation and Cause of Heaving

Following the initial heaving problem in 1999, a task force was set up to undertake a thorough investigation of the phenomena. The investigation included a review the as-built drawings of the reclamation, construction and the underground utilities and correlation of heave occurrences with rainfall events, ambient temperature, tide level and sunshine hours.

One possible cause of the surface heave considered was vaporization of moisture trapped beneath the wearing course as a result of high pavement temperature (in excess of 60^{o}C) during sunny days, as experienced by some other airports. However, the heaving occurrence data on rainy days indicated that temperature was not a direct cause of the heaving.

The most obvious correlation of the heaving damage phenomenon was with rainfall. However, based on the porosity of the sand capping layer and the rainfall data during the heaving incidents, the rise of water table did not exceed 0.5m. It was therefore unlikely that the heave was associated directly with water pressure lifting the wearing course, as the perched water table would remain well below the underside of the pavement. The rainfall acted as a trigger for the heave damage rather than being directly responsible.

A detailed review of the tidal record indicated that all of the heaving incidents occurred during a rapidly rising " Spring" tide and after continuous heavy rainfall for a few days. Spring tides are associated with either a full moon or new moon and are the highest tides of the monthly cycle. A high tide is associated with a rapid rate of rise tide approximately 3 hours before the actual high tide. Site measurement revealed that the water level during a rising tide was almost 5 meters below the pavement surface, the heaving caused by direct tidal water force was also ruled out. After review of the combined tide and rainfall record, followed by site measurement and laboratory soil testing, the investigation concluded that the pavement heaving was caused by the build-up of air pressure underneath the pavement due to the rising tide and blockage of free air flow in the saturated capping sand layer. Under dry weather, a rising tide would push the air in the void below the geotextile up through the relatively permeable sand capping and this air would escape slowly through the pavement layers or through the landscaped areas. (Figure 5) During periods of heavy rain a perched water table built up within the sand capping layer directly above the geotextile and the soil in the landscape area was saturated with rainwater. The air permeability in the saturated soil was reduced. [1]

The wetting of the surface of the MAWC also reduced the air permeability of the asphalt pavement and its ability to dissipate air pressure. The rapidly rising tide pressurized the trapped air in the air voids in the granular layer beneath the pavement and caused the heaving. (Figure 6) Calculations indicated that a pressure of 3 kPa would lift a 125 mm full thickness pavement (wearing course and base course) and a pressure of 1.2 kPa would lift a 55 mm pavement. (debonded wearing course or shoulder pavement)

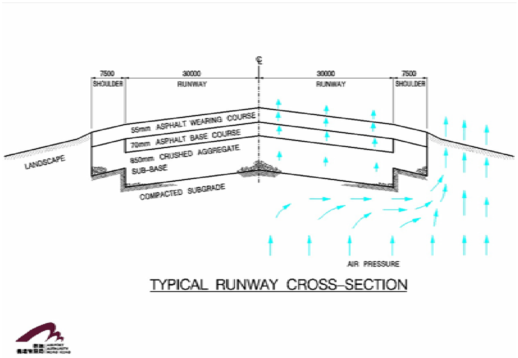

Figure 5 - Air flow during Dry Weather

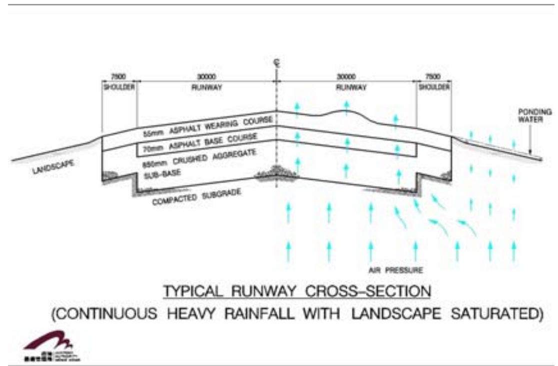

Figure 6 - Air flow during Wet Weather

In order to identify the extent of the heaving problem, pressure sensors were installed along the centre of the North Runway and its associated taxiways to measure the air pressure build up underneath the pavement during dry and wet weather and under rising tide conditions. Based on the collected data, the entire length of the runway was classified into high-pressure, medium-pressure or low-pressure zones. High-pressure zones (pressure build up to 3 kPa) indicated that the likelihood of pavement heaving occurrence was high when there were continuous heavy rainfall and a rapidly rising tide.

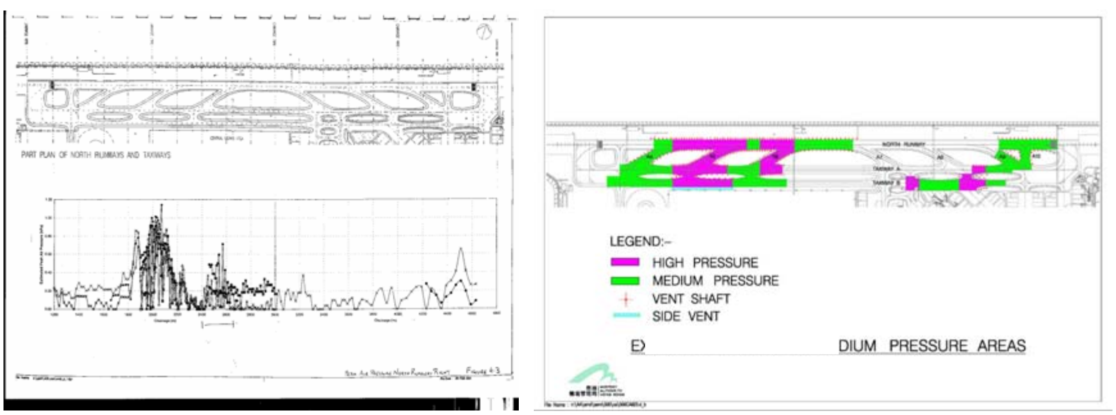

Figure 7 - Pressure zone plan

4. Short Term Solution

The inspections on the North Runway and associated taxiways, particularly the high pressure zone, by the Airfield Operation staff were immediately stepped up during high tide periods when the rate of rising tide exceeded 0.3m/hr and there was heavy rain fall for a couple of days. Maintenance staff were geared up with electrical hand-drill tools and 12mm diameter pressure relief holes were drilled on the pavement once heaving was observed.

As a short term preventive measure, 160,000 of 12 mm diameter x 130 mm deep air pressure relief holes were drilled through the asphalt pavement in the high and medium pressure zones. One meter spacing was provided in aircraft wheel path areas, two meter spacing was provided outside aircraft wheel path area and 3 meters spacing was used in medium pressure zones.

A ground penetration radar survey was also carried out on the pavement to check the bonding condition between the wearing course and base course. Confirmation coring was conducted on suspected debonded areas and followed up by patch repair when debonding was confirmed.

5. Long Term Solution

The following options were considered:

(i) Permanently retain the pressure relief holes through the asphalt pavement.

(ii) Install extensive cut-off barriers to eliminate tidal movement in the fill.

(iii) Overlay the pavement to increase thickness and weight to resist the uplift air pressure.

(iv) Anchor the asphalt surfacing down to the underlying subgrade to prevent the formation of domes.

(v) Introduce a vent system to release the air pressure. (e.g. vent pipe down to the rock fill; side vent trenches along pavement edges)

Scheme designs were carried out for each option and evaluated against the following criteria: complexity, risk of failure, construction cost, operational impact and residual maintenance. Option (v) was considered to be the most preferable solution followed by Option (iii). The design concept for Option (v) is shown in Figure 9.

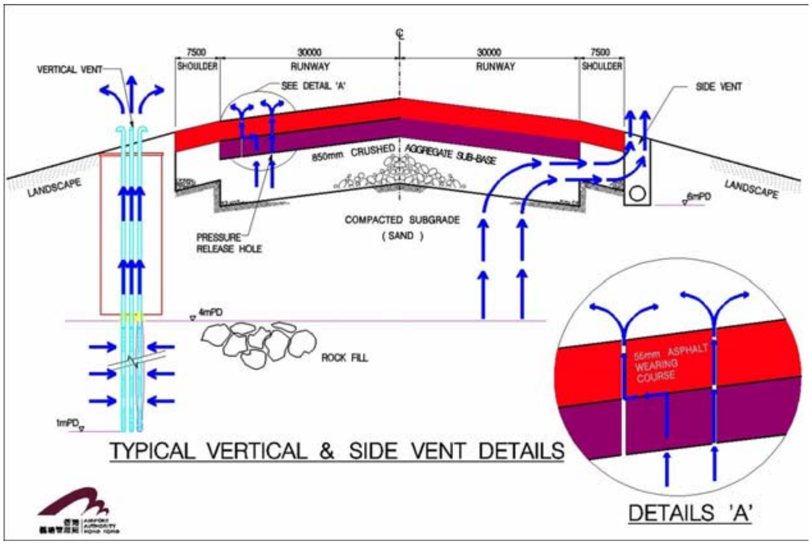

Figure 8 - Venting System

Additional testing was carried out to determine the air permeability of the underlying capping sand and rock fill under dry and wet condition. A mathematical model of the air flow condition through the ground and pavement was established. Using finite element analysis [2], different combinations of vent pipe size and spacing were simulated and the air-release efficiency was compared. The vertical vent pipe system was found to be more effective than the side trench venting system. The model indicated that a group of five 150 mm diameter pipe penetrating the rock fill by 2.5 m at intervals of 20 m along the landscape area outside the runway /taxiway pavement edge would be capable of releasing the trapped air underneath the pavement and preventing the air pressure beneath the pavement exceeding 1kPa.

The main challenge, at the time, was to develop an installation method that would not disturb the existing geotextile at the rock fill /capping sand interface which is 3 meter below ground level. The construction sequence should also not affect the normal runway operation (i.e. work could only be carried out during the runway closure between 0000-0800).

Finally, an innovative design /construction detail was developed as shown in Figure 9. The construction sequence for one vertical vent shaft (comprising five 150 mm diameter UPVC vent pipes) took place over 4 night-time closures and was as follow:

Night 1: Excavate a 3-meter deep pit (to expose the geotextile) and install a 1600 mm diameter precast concrete pipe. A removable steel covering plate was placed on top of the concrete pipe and the adjacent ground was backfilled. Tack coat was applied to stabilize the reinstated soil surface and the work area returned to normal runway operation.

Night 2: The thin soil cover above the steel plate was removed and a drilling rig was set up on top the concrete pipe & cover steel plate. 175 mm diameter holes were drilled through the ground and into the rock fill to depth of 3 meters. The 150 mm diameter UPVC vent pipes were then installed. The annulus between the pipe and drilled hole was backfilled with single size gravels while the steel casing was slowly withdrawn. The drilling and installation operation was repeated for the 2nd or 3rd UPVC vent pipe if time allowed.

Night 3: The operation for Night 2 was repeated to install the remaining two or three UPVC vent pipes. After all five vent pipes were installed, workers inside the concrete pipe repaired the damaged geotextile manually. The steel plate was re-installed, adjacent ground was re-instated and area returned to normal runway operation.

Night 4: The steel plate was removed and the concrete pipe was backfilled. The removable cover to the 5 nos UPV vent pipe was installed. The adjacent ground was re-instated and the runway was returned to normal operation.

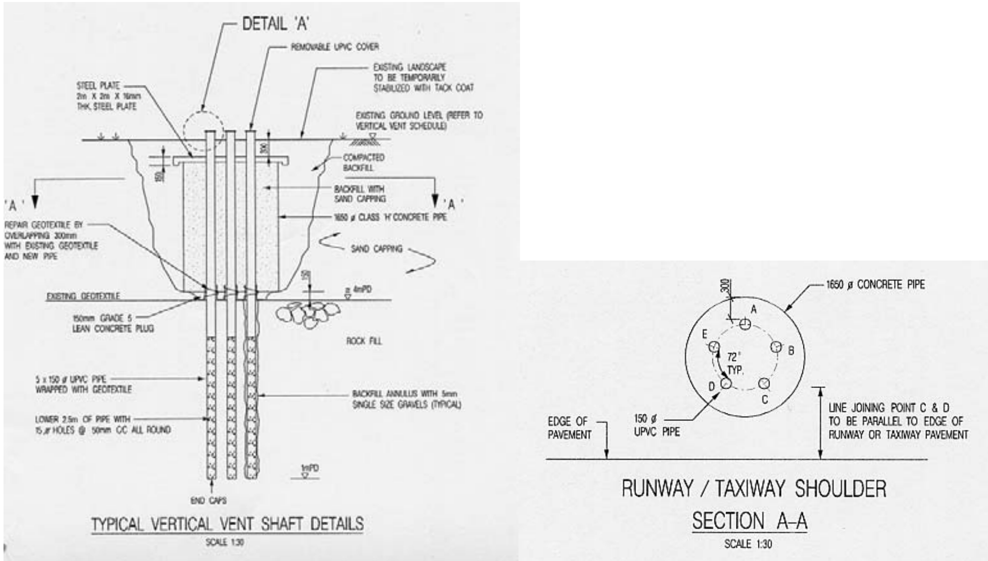

Figure 9 - Vertical Vent Shaft Detail

On the south side of the Taxiway B, the vertical vent shaft option could not be used due a sloping interface between the rockfill and capping sand which resulted in no rock fill at this location. The side trench vent system as shown in Figure 10 had to be adopted.

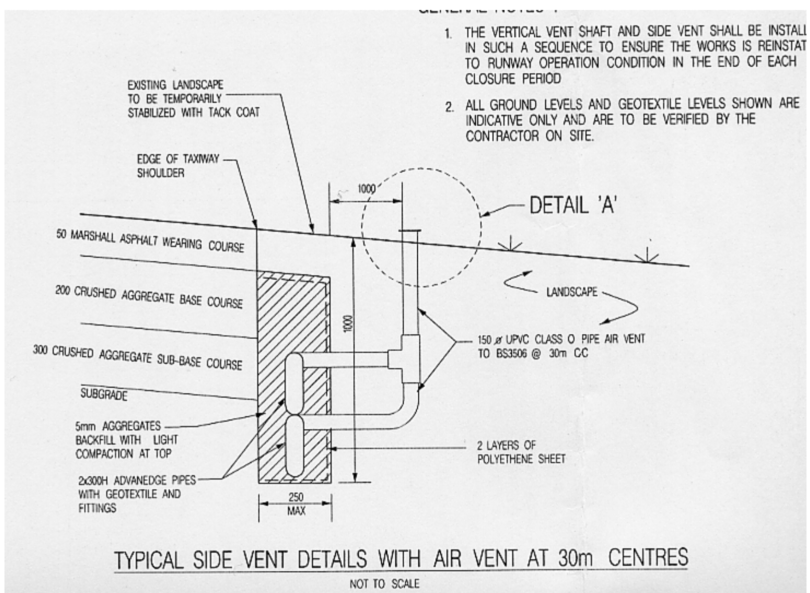

Figure 10 - Side Vent Detail

6. Implementation of Long Term Solution

Site Trial

Based on the developed design/construction detail, eight of vent shafts and a section of side vent were installed in a high-pressure zone area. The air pressure underneath the pavement was closely monitored and compared with previous records and record of areas without vent shaft during the wet event. The data collected confirmed the effectiveness of the vent shaft design with a significant reduction in air pressure and also helped to optimize the layout.

Full Scheme

A total of 282 vertical vent shafts were installed over a 10 month period during the normal runway night closure period between 0000-0800. (Figure 11) The spacing of the vent shaft in the high and medium pressure zone areas was 20 meter and 30 meter respectively.

Figure 11 - Construction of vertical vent shaft

Long term monitoring

In order to ensure the effectiveness of the entire venting system, an online monitoring system was also installed. Two rain gauges and two atmospheric sensors were installed to record the precise rainfall and atmospheric pressure on the North Runway area. Water level sensors were installed in each vent shaft to measure the tide level in the rock fill and 47 sub-pavement sensors were installed along the centerline of the runway and taxiways to measure the build up air pressure under the pavement. All these devices were linked and connected to a computer in the Maintenance Service Control Centre.(Figure 12) Special software was developed to analyze the collected data and generate a warning alarm if the preset safety threshold pressure was exceeded. Maintenance staff would then check whether the vent pipe were blocked and carry out cleaning/repairs as required.

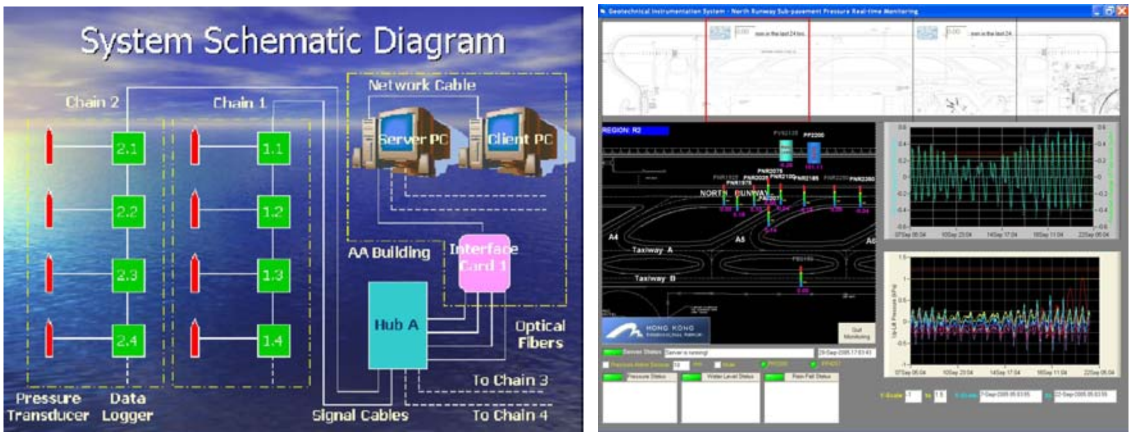

Figure 12 - Long term air pressure monitoring system

Filling up of the temporary air pressure relief hole through pavement

The temporary air pressure relief holes in one section of the high-pressure zone were filled up and the monitoring data indicated that there was no significant change of air pressure underneath the pavement. This confirmed that the temporary air pressure relief holes were no longer contributing to the pressure reduction. All of the 160,000 of temporary pressure relief holes were then filled with sealant to avoid weakening of the subgrade due to the penetration of rainwater via the drill holes.

7. Conclusion

The pavement-heaving problem exhibited at HKIA was both un-usual and, as far as the authors are aware, unique. It was caused by a combined tidal and wet weather effect. The rising tide in the rock fill beneath the runway and taxiways displaces air in the voids in the ground. The airflow underneath the pavement was blocked by the saturated soil and reduced air permeability of the pavement after prolonged heavy rain. During a rising "Spring" tide, the pressurized trapped air lifted the thin asphalt pavement at the shoulder and also the debonded wearing course in the aircraft movement area. The problem was temporarily resolved by installing small diameter pressure relief holes through the asphalt pavement, which allowed time to develop a permanent solution. The interception of abnormal air pressure by installing vertical deep ventilation pipes was an effective, cost efficient and innovative solution. A real time monitoring system was also installed to continuously monitor the air pressure underneath the pavement and the condition of the vent shafts.

Reference :

1. Stylianou C and DeVantier B. A., (1995), “Relative air permeability as function of saturation in soil venting”. Proc. Journal of Environmental Engineering, Vol. 121, Issue 4, pp 337-347.

2. Itasca (1999), “Fast lagrangian analysis of continua”. Itasca Consulting Group Inc., Minneapolis, USA.