PERFORMANCE REVIEWS OF HONG KONG INTERNATIONAL AIRPORT AND YANTIAN INTERNATIONAL CONTAINER TERMINALS

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SUMMARY

This paper reviews the current performance of concrete block pavement at both Hong Kong International Airport (HKIA) and Yantian International Container Terminals (YICT), in the People's Republic of China. They are large international projects and geographically close to each other. When the current construction of Phase III expansion at YICT is completed, the combined area of concrete block pavement will be over 3 million m^2.

Unlike in-situ concrete pavement, concrete block pavement has the benefit of being able to tolerate large settlements and differential settlements. Unlike asphalt pavement, concrete block paving is resistant to punching loads and resistant to fuel and oil spills and deposits. HKIA and YICT were built on reclaimed land where high and differential settlements were predicted. As well as being able to tolerate differential settlement, concrete block pavement was chosen because they are easier and more economical to maintain.

After approximately 8 years of use, the block pavements are still performing and meeting the design criteria and only nominal maintenance is required. The findings from this investigation demonstrate that concrete block pavement can provide long term, cost-effective solutions on very large and heavily loaded pavement for these types of applications.

A brief review of the design, construction and maintenance is also given in this paper and some feedback from the users is also provided. The dissemination of experience and knowledge gained from these projects will be a benefit for the future users of concrete block pavement.

1. INTRODUCTION

Approximately 50 harbors and commercial and military airports worldwide have utilized concrete block pavement. Hong Kong International Airport (HKIA) and Yantian International Container Terminals (YICT) are two projects using concrete block pavement, implementing what was perceived at the time to be best practice in design, specifications and workmanship. The concrete block pavement at HKIA also represents the largest single installation in an airfield and is regarded by many observers as the state-of-the-art in design and construction. Both of these projects were constructed on filled land, subject to high and differential settlement. They are probably the busiest terminals of their type currently operating in the world. Therefore, their successful performance over the years will benchmark the development of accepted practices in design, specification and construction of block pavement in these types of applications. Their success will hopefully convince other project owners of the benefits of concrete block pavement.

I was employed as a site engineer for the Phase II project of YICT, involved in the construction of block pavement and associated works. As part of my continuing professional development I had the opportunity to view the ongoing construction at HKIA and meet the head of the design team, Larry Mujai and members of the contractor's team responsible for the pavement construction to discuss aspects of the design and construction.

In September 2006, I visited both HKIA and YICT to review the performance of the block pavement to date, and discuss maintenance and construction issues with the personnel involved in these projects, with the object of disseminating any lessons learnt and experiences to a wider audience so that the designers, owners and operators of future projects can benefit and learn from this information.

1.1 Hong Kong International Airport

HKIA took six years to build and was claimed by its builders to be the biggest civil engineering project in history. It was built on a vast man-made island. The airport opened in July 1998 and consists of two runways and associated taxiways leading to parking aprons for passenger aircraft, cargo operations, maintenance area and business aviation. It is among the world's five busiest airports in terms of international traffic. In 2005, it handled 40.74 million passengers and up to 3.4 million tonnes of cargo. The airport aprons and service areas built on filled areas were constructed as concrete block pavement with a total area of approximately 500,000m^2.

1.2 Yantian International Container Terminals

YICT is located in Shenzhen, People's Republic of China, and is a joint venture between Hutchison Port Holdings (HPH) and the Shenzhen Yantian Port Group. It currently has nine berths with another three additional berths expected to come on line in the near future. It is one of the fastest growing container ports in the world. In terms of throughput, the facilities handled 7.6 million TEU (twenty foot equivalent units) in 2005, serving over 35 of world's top shipping companies. Phase II, completed in 1999, consisted of 500,000m^2 of concrete block pavement (CBP). Phase III, completed in 2005 consists of 800,000m^2 of CBP. Phase III expansion is under construction and consists of 1.3 million m^2.

2. PROJECT REVIEWS

2.1 Design

The design life of concrete block pavement at both HKIA and YICT is 20 years, which means the concrete block pavement will remain serviceable throughout this design life. However, proper maintenance will be necessary during this time. These two projects are similar in some aspects, such as sites subject to high and differential settlement, but the traffic loading and frequency are different.

2.1.1 Hong Kong International Airport

The concrete block pavement at HKIA is designed to accommodate aircraft weighing up to 770 tonnes with wheel loads in the order of 33 tonnes. In general, the wheel loads imposed by the aircraft and aircraft tugs on the aprons are very high, but the frequency and speed of movements are low, whereas the access roads around the terminal endure relatively light loads except when aircraft tugs use these roads, but the frequency and speed are high compared to the aprons.

The layer thicknesses of the pavement structure were determined using proven existing airfield design methods for asphalt pavement. A one-for-one substitution of the concrete blocks and bedding sand was then made for the thin asphalt surfacing. Immediately below the bedding sand, 175mm crushed rock base with 3% cement added was designed to reduce elastic deformation. To avoid the bedding sand washing or migrating downwards due to cracks or shrinkage which will inevitably occur in the cement-bound base over time, a geotextile layer was installed over the base course and secured with a bitumen tack coat. Learnt from past experience, the compacted thickness of bedding sand was 20mm. The joints were sealed to ensure that the joint sand was not eroded by jet engine blasts. A typical pavement cross section is shown in Figure 1.

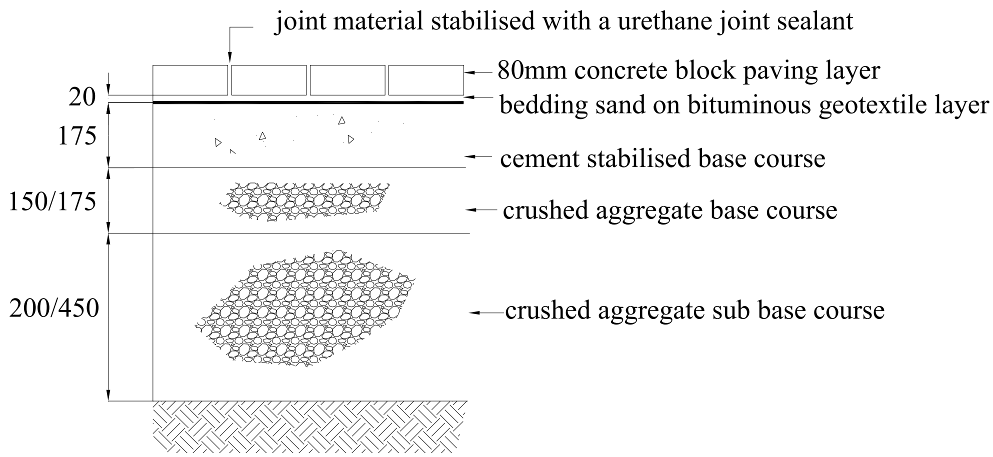

Figure 1. Typical Pavement Cross Section (HKIA)

2.1.2 Yantian International Container Terminals

The concrete block pavement at YICT is designed to accommodate stacked containers five high with point loads of up to 24 tonnes at each bottom corner casting. The container handling equipment, used for moving empty containers and transporting containers for repair, can result in axle loads of 90 tonnes although the vast majority of container movements are undertaken by eight wheeled rubber tired gantry cranes (RTGC) weighing up to 220 tonnes with wheel loads of 27 tonnes/wheel. These regularly run and turn on the block pavement when traversing between RTGC reinforced concrete runways. The remaining traffic is conventional road semi trailers and terminal container trucks with solid tires. With the exception of the container fork lifts and the RTGC crossover points, in general the wheel loads imposed by the yard trucks are relatively light (for a heavy duty pavement) but the frequency is extremely high.

The design of the concrete block pavement was referred to Harboring Engineering Design Code in China but incorporating some Western technologies in concrete block pavement. The thickness of the blocks is 100mm instead of 80mm as specified in HKIA. The thickness of bedding sand is 25mm after compaction and 500mm thick lean mix concrete with a compressive strength of 10-20 MPa was specified as a base course. The typical pavement cross section is as shown in Figure 2.

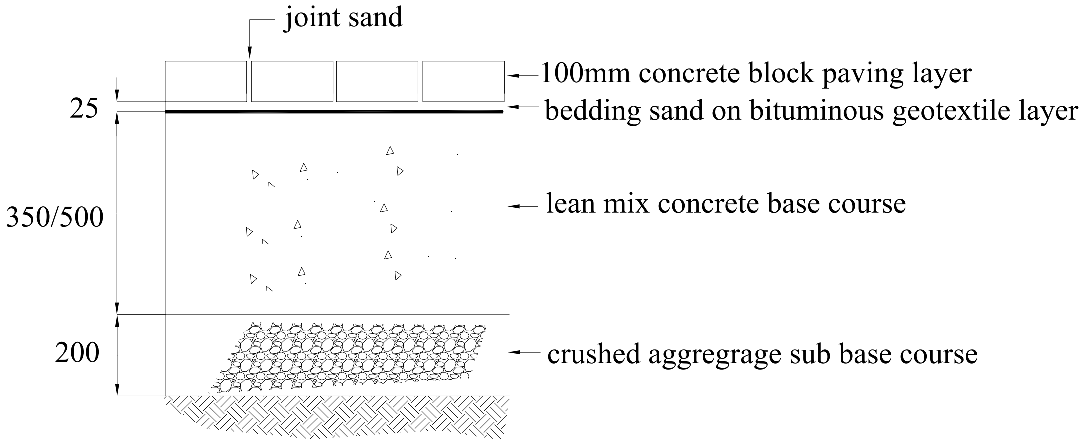

Figure 2. Typical Pavement Cross Section (YICT)

2.2 Specifications

For both HKIA and YICT, designers have implemented rigorous specifications to assist construction. Table 1 summarizes the pavement structure of the two projects for comparison.

Table 1. Comparative summary of designs

	HKIA	YICT
Concrete Block	80mm thick 16-sided fully dedented blocks manufactured to British Standard BS 6717: part 1 1986, except dimensional tolerances. Special requirement for surface texture (to minimize the potential of foreign object damage).	100mm thick 16-sided fully dedented blocks manufactured to requirements for the HKIA, although this was not an original specification requirement.
Laying	Herringbone pattern, machine-laid, joints sealed.	Herringbone pattern, hand-laid, joints not sealed.
Bedding Sand	Well graded with max. 3% fines (0.075mm), max. 2% increase of fines after Micro Deval test.	Well graded with max. 3% fines (0.075mm), max. 2% increase of fines after Micro Deval test.
Geotextile	Non-Woven with 450g/sqm, impregnated with K1-40 bitumen emulsion.	Non-Woven with 450g/sqm impregnated with the Chinese equivalent of K1-40 bitumen emulsion. See comments below.
Base Course	175mm cement stabilized crushed rocks with 3% cement added compacted to 100% MDD. 150/175mm crushed aggregates base course compacted to 98% MDD.	500mm lean mix concrete with 10-20MPa, placed in layers and compacted to 95% MDD.
Sub-base	200/450mm crushed aggregate sub-base course compacted to 98% MDD.	200mm crushed aggregates sub-base compacted to 98% MDD.
Sub-grade	CBR 10%	Allowable bearing capacity of 180kPa
Foundation	Hydraulic fill and compacted by high energy impact roller compaction.	Dynamic compaction for most areas, sur-charge/wick drains at mud pond locations

Geotextile note: Phase II of YICT was constructed in stages, and when each stage was completed it was immediately handed over to Operations for use. It became evident after a certain period of time and traffic that the pavement surface was showing evidence of distress. Extensive investigations determined that the geotextile was breaking down. It was deleted from the remainder of the works and all subsequent stages, and in the defective areas it was removed during ongoing maintenance. From then on, only bitumen emulsion was applied to assist in curing and waterproofing the lean mix.

2.3 Construction

The contractor responsible for the pavement construction at HKIA was required to implement a Quality Assurance Scheme to ensure that the works were constructed in compliance with the contractual requirements. This also extended to the manufacturing and testing of all the materials including the blocks that were manufactured in China and delivered by barge to site.

The contract at YICT was a traditional "design and tender" contract where the inspection of the works was undertaken by the client's representatives. As the Chinese Mainland contractor had no experience in the construction of the concrete block pavement, it was necessary to partner with them to help develop quality control procedures to ensure that the work was compliant and to a continuous high quality. The senior management at YICT had the foresight to form its own on-site testing facility and site supervisory team to supervise and assist the contractor.

The blocks were manufactured by the same manufacturer used by HKIA and the same manufacturing quality control procedures were adopted.

A major difference between the two projects was the method of undertaking the work. Labor is cheap and readily available in Mainland China, as opposed to Hong Kong, therefore much of the construction for YICT project was undertaken by manual labor, not by machines. For example, the sub-base aggregates were delivered and dumped in the areas where they were to be laid and mixed and blended in-situ by manual labor. Laying course and jointing materials were screened manually prior to use, by a team of one man and three women. The blocks were laid manually.

At HKIA as much as possible of the work was undertaken by machines, including the drying and screening of bedding and jointing sand, screeding the bedding sand with an asphalt paver, and mechanically laying the blocks and applying the joint sand sealant.

3. PERFORMANCE OF BLOCK PAVEMENT

3.1 Visual Assessment

Only visual inspections of the pavement surface were conducted on both projects as it wasn't feasible to undertake inspections of the underlying pavement layers or carry out any testing, although discussions were held with personnel involved in the construction and maintenance of both projects.

3.1.1 Hong Kong International Airport

Passenger Aircraft Apron, Cargo Apron, and Aviation Apron

It was observed that the concrete block pavement at the aircraft aprons is generally performing well, with no evidence of any significant pavement distress. There was evidence of oil spillages from service vehicles and possibly from aircrafts, but the surface of the blocks appeared unaffected with no evidence of any significant surface wear or defects. The surface flatness and smoothness of the pavement appeared to be good. There were isolated broken blocks, possibly caused by impact loads from aircraft loading equipment. The joints were full and appeared to be sealed with no evidence of erosion of jointing material. Figures 3, 4 & 5 show the aprons at different locations.

Figure 3. Passenger Aircraft Apron (HKIA)

Figure 4. Cargo Apron (HKIA)

Figure 5. Aviation Apron (HKIA)

Figure 6. Defective Areas (HKIA)

Traffic Areas Adjacent to the Terminal Building

In the traffic areas adjacent to the terminal building and aprons, some minor deformations were found. The defective areas are less than 1m^2 in size and typically 10-20mm deep. They are randomly spread on the road surface as shown in Figure 6.

The defective pavement at some service pits has been brought back to the correct level, as shown in Figure 7.

In general, no continual longitudinal traffic rutting was found in the block pavement. It is possible that settlement might have occurred in areas that have undergone repairs.

Figure 7. Maintenance at Service Pits (HKIA)

Figure 8. Container Yard (YICT)

3.1.2 Yantian International Container Terminals

Container yards

In general, the block pavement are performing well (refer to Figure 8). No deformation and surface wear were found in this area except for some broken blocks at container corners possibly caused by impact load. Debris and detritus were found to be ground into the joints and the surface of block pavement as shown in Figure 9. Judging from their appearance, blocks at the location of some of the container corners appeared to have been broken for some time but they didn't appear to adversely affect the structural integrity of the pavement.

Figure 9. Container Corner (YICT)

Figure 10. Defective Area (YICT)

Access ways

There are isolated areas of minor longitudinal and to a lesser extent transversal ruts on access ways as shown in Figure10. Typically these ruts are 300mm wide by 20mm deep and may indicate localised failures at locations of the joints between the lean mix paver runs.

There is minor settlement around service pits and against structures such as drainage channels and the reinforced RTGC runways.

3.2 Maintenance

3.2.1 Hong Kong International Airport

Any maintenance required is undertaken by maintenance contractors. The personnel responsible for overseeing the maintenance expressed that they and the operatives carrying out the work found it difficult to remove the blocks from the pavement. They also found it was very difficult to replace the blocks back to achieve the same quality on lines and levels by manual labor as was achieved using machines during the original construction work.

3.2.2 Yantian International Container Terminals

YICT have taken a pro-active approach to maintenance with a dedicated, trained in-house team of six men set up with the appropriate equipment to undertake continuing minor repairs as soon as they become apparent. This interventionist action results in repairs undertaken efficiently with minimal disruption to the port's operations.

When they removed blocks in defective areas, maintenance personnel found that:

1. Most of the jointing and bedding sand had been washed away.
2. If geotextile was present, it was breaking down.
3. Base course material was cracked or crumbled and loose and easily removed by hand.

When they repaired these defective areas, they normally jack-hammer out the top one-third of base and use C20 concrete to fill back to the correct levels, then reinstate the block layer. However, in some areas this practice has created an additional problem in that at the location of the joint between the new C20 and existing base some further failures occur after a certain period of traffic.

4. DISCUSSION

4.1 Hong Kong International Airport

The pavement around the terminal building and passenger & cargo aprons was designed as "transition pavement" between piled structures that shouldn't settle and adjacent in-situ concrete pavement that may settle. The concrete block pavement contains a significant number of service trenches, service pits, and manholes. These areas were recognized from the outset that they would endure the most differential settlement and the most traffic from service vehicles and aircraft tugs, the latter having significant axle loads and would require a high maintenance level. As anticipated, most defects and repairs were concentrated on these areas.

However, the defects at these locations should be fully investigated to establish the cause or causes.

4.2 Yantian International Container Terminals

Whilst I was still working on site at YICT as part of the supervising team, the problem of blocks breaking at locations of the container feet occurred shortly after the first stage of Phase II was handed over to Operations for use. Working with the Senior Resident Engineer, I was given the task of developing a solution to this problem. Experiments were undertaken to manufacture and test different types of fiber-reinforced blocks and half blocks. It was concluded that the solution to the problem would be to replace full blocks with half blocks at the corner locations only. YICT Operations were advised that if the broken blocks did affect the structural integrity and pavement performance, then they could be replaced with half blocks. To date blocks at these locations have not been replaced.

The formation contained mud ponds and was built up with uncontrolled fill. This combined with the intensive continuous volume of traffic, non-stop for 24 hours, 365 days of the year, would lead to ongoing settlement.

Experience has shown that significant settlement can occur adjacent to structures within the pavement, such as manhole and service pits, but the minor settlement witnessed may be attributed to the very stringent construction and supervision procedures developed and implemented by the YICT supervisory team during construction.

To solve the problem of failures of C20 repaired areas it maybe desirable to investigate the cause of this. It would be important that the repair concrete is full depth over the entire area of the repair and is not tapered down which may result in weakness. Perhaps the perimeter of the repaired base should be saw-cut full depth to ensure a constant thickness of the repaired base.

5. CONCLUSIONS

HKIA opened in 1998 and the first stage of block pavement at YICT was completed in 1998 and subsequent stages have been completed and put into operation since then until the present.

The concrete block pavement at both of these projects is performing as intended by the designers, except the performance of the geotextile layer at YICT.

Repairs are necessary to ensure serviceability and maintaining the life of the pavement, as are the repairs that are also undertaken for the asphalt and in-situ concrete pavement. All pavements require some sort of maintenance and the positive, proactive approach demonstrated by YICT is preferable. It is recommended that for similar projects to these, the developments of pro-active maintenance regimes with skilled operatives with the appropriate equipment are implemented.

It is concluded that the physical properties of concrete block pavement are ideal for these types of applications. The fact that YICT continues to use block pavement is testimony to their faith in the suitability of this type of construction.

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