PULLOUT TESTS IN CONCRETE BLOCK PAVEMENTS FOR EVALUATING THE RESISTANCE TO AIRCRAFT JET ENGINE THRUST

Ilan Ishai, Boris Fix and Nehemia Masuri
Prof. Ilan Ishai, Dept. of Civil & Environmental Engineering, Technion, Haifa 32000, Israel
Tel: 972-52-2539668, Fax: 972-9-7714198, E-mail: iishai@013.net
Dr. Boris Fix, Testing Expert, ISOTOP Ltd., P.O.Box 2, Gedera 70700, Israel
Tel: 972-8-8533915, Fax: 972-8-8533915, E-mail: isotop@zahav.co.il
Nehemia Masuri, Civil Engineer, Ackerstein Industries, P.O.Box 337, Herzlia 46103, Israel
Tel: 972-9-9596666, Fax: 972-9-9543130, E-mail: nehemiam@ackerstein.co.il

SUMMARY

Among the many applications of Concrete Block Pavements (CBP), its use in airport facilities is recently gaining a vast momentum. Airport projects like the Chek Lap Kok - Hong Kong International Airport, Heathrow London Airport, and many other civil and military airports around the world, show the major engineering and economical advantages of the successful use of CBP for heavy loaded apron, aircraft stands, taxiways and other low-thrust facilities. Despite this proven success, many agencies and officials are still reluctant to use CBP in airports serving jet aircraft. This reluctance is mainly due to the fear of the detrimental effect of the jet engine thrust on the small element paved surface. The major concern is the pulling out of paver blocks that might be caused by the jet engine thrust.

The Israeli Concrete Pavers Industry is now promoting the use of CBP in the design and construction of several new airport facilities in the country. Among the different engineering parameters to be demonstrated, an emphasis is given to the resistance of the concrete block surface to aircraft jet thrust. For this task, a series of pullout tests were performed on actual old industrial and airport CBP surfaces. The tests were performed by a specially-designed system that provide continuous and accurate measurements of the pullout force on a single paving block, together with the vertical lift surface deflections in the center and in four offset points. Several pullout tests were conducted in each site on a 10/20 rectangular blocks and a "Uni-Coloc" blocks, all with a 100 mm thickness. The testing parameters were the development of the pullout force in each measuring point up to the final failure pullout force, and the development of the "negative" pullout deflection basin around the center measuring point.

The results have shown that the final failure pullout forces ranges between 1300-1600 kgf for a single paving block, and the maximum deflection in the center between 10-17 mm. A comparison between the lift forces generated by breakaway and ground-idle jet thrust velocities and the pullout forces measured, indicated that pullout resistance of the interlocking blocks are much higher, providing a large factor of safety for taxiing and idle aircraft.

1. CONCRETE BLOCK PAVING IN AIRPORTS

Concrete Block Pavements (CBP) have been used worldwide for many categories of aircraft pavements since the beginning of the eighties of the 20th century. This technology utilization is recently gaining a vast momentum, driven by several successful airport projects. It is estimated that several million square meters of pavers are now in service in many civil and military airports around the world. Airport projects like the Chek Lap Kok - Hong Kong International Airport, Heathrow London Airport, Dallas - Fort Worth International Airport, and many other civil and military airports around the world, show the major engineering and economical advantages of the successful use of CBP for heavy loaded apron, aircraft stands, taxiways and other low-thrust facilities.

The use of CBP in airport infrastructures was widely reported in the technical literature. A comprehensive report by Knapton and Emery (1996) summarizes this technology by providing a historical review as well as guidelines and recommendations for the reliable application of this technology for aircraft facilities. The authors also present a frank and thorough analysis of the CBP failure on the turning areas at Luton Airport in the UK due to engine thrust of jet aircraft. Emery (1998) presents the experience and the many factors involved in utilizing CBP for military airports. Many papers on the successful use of CBP in airports were presented and reported in the International Conferences on Concrete Block Paving held in many countries around the world during the last 25 years. Several major agencies, like the USA Air Force (1991), FAA (1993), ICPI (1993), UK Ministry of Defence (2005) and others, approved this technology and have published guidelines, specifications and pavement design methods for airport facilities using CBP.

Despite this proven success, many agencies and officials are still reluctant to use CBP in airports serving jet aircraft. This reluctance is mainly due to the fear of the detrimental effect of the jet engine thrust on the small element paved surface. The major concern is the pulling out of paver blocks that might be caused by the jet engine thrust.

2. CHARACTERIZATION OF JET ENGINE THRUST

Jet aircraft operation produces different level of engine exhaust thrust. This thrust affects the rear space of the aircraft in three dimensions, thus also affects the pavement surface in term of velocity and temperature. The magnitude of the thrust is mainly depended on the aircraft type, and also on the type of operation. Technically, three level of jet engine thrust are defined:

- **Ground Idle Thrust –** Parking operations
- **Breakaway Thrust** – Taxiing operations
- **Takeoff Thrust** – Takeoff and engine acceleration operations.

An example of the three levels predicted contours of jet engine exhaust velocity, for different models of Boeing 737 aircraft, are presented in Figure 1 (Boeing 2005). It can be seen that the critical thrust velocities affecting the pavement surface are 56 km/hr for idle, 80 km/hr for breakaway, and as high as 322 km/hr for takeoff thrust.

Following the failure of CBP in Luton Airport due to jet engine thrust (Knapton and Emery 1996), as will be discussed later, it was clearly realized that CBP are not suitable for airport pavements exposed to takeoff thrust. On the other hand, it was found that CBP are suitable for breakaway thrust and lower. In the research on Innovative Paver System –IPS, Emery et al. (2005) present the breakaway thrust characteristics of typical commercial aircrafts, as seen in Table 1.

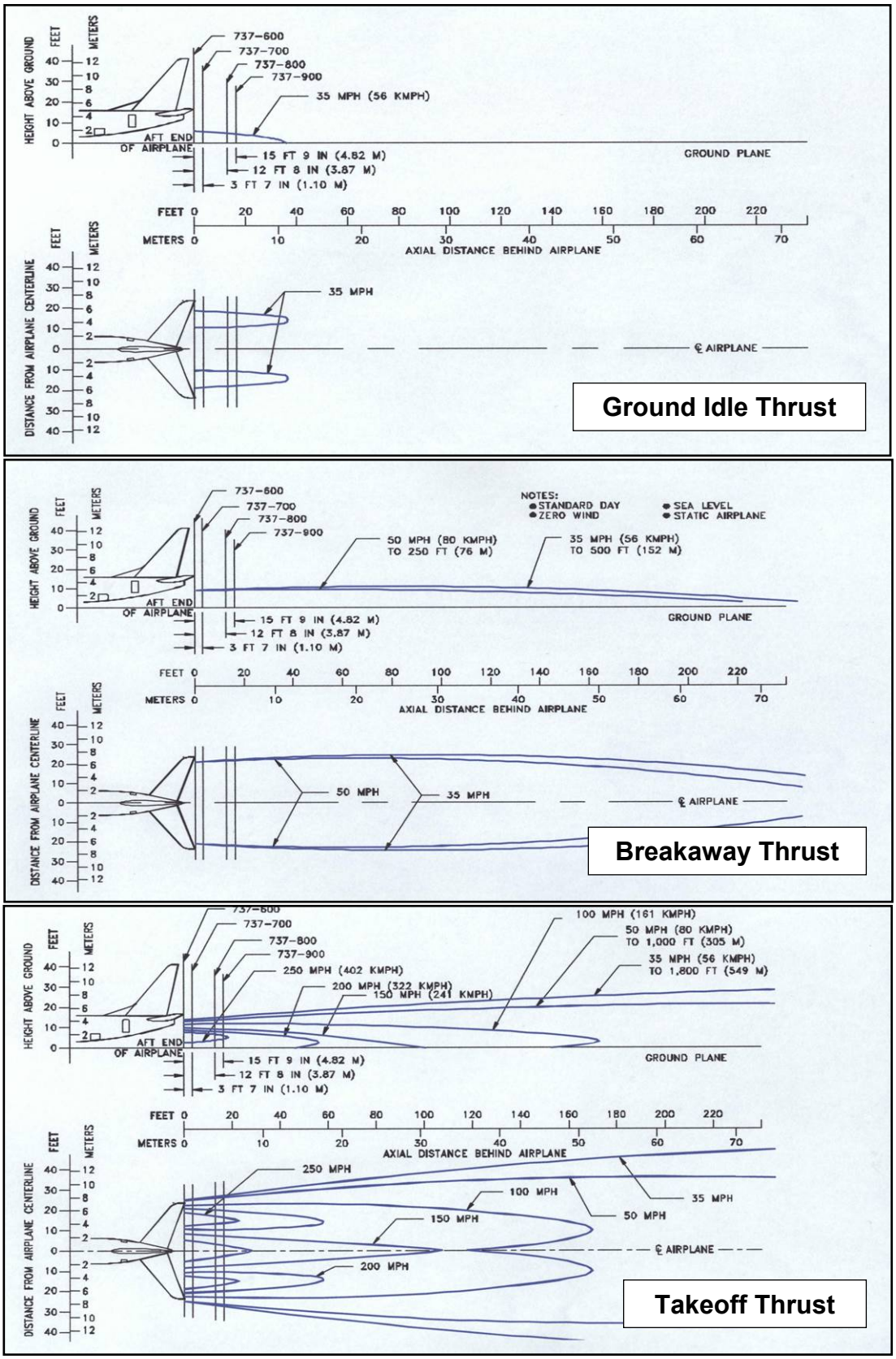


Figure 1. Predicted jet engine exhaust velocity contours of all models of Boeing 737 Aircraft (BOEING 2005)

Table 1. Breakaway Thrust Characteristics of Typical Commercial Aircraft (EMERY et al. 2005)

Aircraft	Breakaway Temperature, ^{o}C	Breakaway Velocity	
		m/sec	km/hr
Airbus A380	38	40	144
Boeing 707	52	22	79
Boeing 737	<30	22	79
Boeing 747	27	59	212
Boeing 777	<38	22	79

It can be seen that the breakaway velocity for the most common air carriers, that may affect the pavement surface, ranges between 79 to 212 km/hr. The breakaway temperatures are relatively low, not acceding 52^{o} C.

3. PAVEMENT FAILURES ASSOCIATED WITH JET ENGINE THRUST

The major failure of concrete block pavement due to jet blast occurred in Luton Airport near London (Knapton and Emery 1996). The success of the application of CBP in aircraft stands in that airport, led to the use of pavers on the turning circles at each end of Luton main runway, as a part of a strengthening project (during 1983 to 1984). These turning circles were directly exposed to takeoff thrust velocities. From 1987 to 1992 several cases of paver displacement were occurred in both turning circles. One typical displacement incident started with progressive erosion of jointing sand due to the jet blast. Then a local area bulged upwards to a height of approximately 10 cm when one of the 10 cm thick rectangular pavers was discovered beneath its neighbors, presumably having been forced there by the exhaust blast from the engine of an aircraft taking off. Several cases of displacement occur periodically and corrected. One of the turning circles was repaved twice with different type of pavers, but finally, in 1992 all pavers were removed from both turning circles. The major conclusion from the Luton CBP failure is the inadequacy of CBP in airport facilities exposed to direct takeoff jet thrust.

In the years 1989 to 1990 the Israeli Aircraft Industry (IAI) erected two new hangars for the maintenance of Boeing 747 and other aircrafts. They include two external CBP aprons of about 13,000 m^2 area (ISHAI et al. 1994). In the course of operation, parts of the CBP aprons, and also of adjacent asphaltic pavement, were assigned for running and acceleration of Jet aircraft engines. Incidents of displacement, bulging and disintegration of CBP areas, as well as of the asphaltic top layers, occurred. The running and acceleration of jet engines produce takeoff thrust velocities, and even higher. In the report, investigating a major disintegration incident occurred in asphaltic pavement due to the acceleration of Boeing 737 aircraft (IAI 2004); calculations of the lift forces produced by the exhaust thrust velocities were made. The thickness of the asphaltic layers or the concrete slabs that are required to withstand the lift forces were also calculated (see Table 2). It should be stressed that the calculated required thickness is very conservative since it is valid for the weight a free area only. In reality, the horizontal and vertical continuity of pavements produce much higher resistance to the lift forces, as compared to the unit weight alone.

Table 2. Calculated Lift Forces and Required Pavement Thicknesses due to Exhaust Thrust Velocities (IAI 2004)

Jet Thrust Velocity at Pavement Surface, km/hr (mi/hr)	Lift Force at Pavement Surface, kg/m^2	Minimum Required Asphalt/Concrete Thickness, cm
80 (50)	46	2
160 (100)	185	8
240 (150)	417	17
320 (200)	741	31
400 (250)	1157	48
480 (300)	1667	70

4. CBP TESTING ASSOCIATED WITH JET ENGINE THRUST

Only limited number of CBP testing, associated with the effect of jet engine thrust, are reported in the technical literature. These testing are related to the jointing sand erosion phenomenon, and to the resistance of pavers to pullout forces.

Emery (1992) and Knapton and Emery (1996) found that joint erosion has been a crucial factor in paver failures in an aircraft pavement. Accordingly, they reported about erosion testing made on CPB sections as performed by British Aerospace Hot Gas Laboratory. Tests were carried out under full scale jet pressure and temperature values, as characterized by Vertical Short Takeoff and Landing (VSTOL) aircrafts under takeoff conditions. Although the individual blocks were generally found to be resilient to jet blast, dependent on temperature, the jointing sand was found to be easily removed by the pressure of the jet. This occurred at jet pressure ratio well below the VSTOL operating conditions. Also, it was observed that the loss of jointing sand allowed air to penetrate under the blocks, creating 'ballooning' of the block pavement surface, thus destroying the integrity of the pavement and causing serious Foreign Object Damage (FOD) risk in operational applications. Substantial improvement was achieved when the block paving was treated and sealed with polymers. The results indicated that considerable erosion resistance is provided by the polymer. Polymer treated block paved panels were unaffected by high pressure ambient jet, up to 2 times higher than the VSTOL condition, when subjected to run up to 60 seconds duration.

Recent erosion tests on CBP samples were made in the laboratory by Emery et al. (2005) in Cranfield University, UK. Polymer sealed and unsealed IPS block paved panels were tested under simulated breakaway thrust conditions, up to 215 km/hr. Each panel was exposed to jet efflux of 60 seconds in a series of ten tests. The unsealed test units exhibited immediate sand erosion after the first exposure to jet efflux. However, no spalling or lifting of the units was noted during the complete testing program. The sealed panels were unaffected during the entire jet efflux test.

In the same Research, Emery et al. (2005) tested the pullout resistance of conventional and IPS rectangular blocks. The Innovative Paver System – IPS is a new paver concept with unique tongue and

groove feature which provides a special mechanical interlock**.** In the tests, which were performed on a single middle block within the testing panel, the maximum sustained force and the related deformation at pullout were measured. The comparative results are presented in Table 3:

Table 3. Pullout Test Results Performed by Emery et al. (2006)

Block Type	Maximum Sustained Load, kN (kgf)	Maximum Pullout Movement, mm	Mode of Failure
IPS – 'Tongue and Groove'	22 (2,248)	6.73	Fracture of block at female lug end
Conventional Rectangular	3 (306)	0.7	Pullout of block with no visual signs of cracking or other distress

5. PULLOUT TEST ON ACTUAL OLD CONCRETE BLOCK PAVEMENTS

5.1 General Description

The Israeli Concrete Pavers Industry is now promoting the use of CBP in the design and construction of several new airport facilities in the country. As stated above, despite this proven success, many agencies and officials are still reluctant to use CBP in airports serving jet aircraft. This reluctance is mainly due to the fear of the detrimental effect of the jet engine thrust on the small element paved surface. The major concern is the pulling out of paver blocks that might be caused by the jet engine thrust.

Therefore, a series of pullout tests were performed on actual old industrial and airport CBP surfaces. The tests were carried out by a specially-designed system that provide continuous and accurate measurements of the pullout force on a single paving block, together with the vertical lift surface deflections in the center and in four offset points. Several pullout tests were conducted in each site on rectangular blocks and "Uni-Coloc" blocks. The testing parameters were the development of the pullout force in each measuring point up to the final failure pullout force, and the development of the "negative" pullout deflection basin around the center measuring point.

5.2 Testing Details

The following are the pullout testing details:

- **Blocks and Locations:** 225/225 mm, 100 mm thickness UNI COLOC shaped blocks in industrial apron (dairy products), Pardesia. 100/200, 100 mm thickness Rectangular blocks in Hangars 10 and 11 aprons, Israeli Aircraft Industry (IAI), Ben Gurion Airport (see Ishai et al. 1994).
- **Testing Setup:** Application of vertical pullout force (with no eccentricity) through a testing structure composed of: 2 bridge beams and 2 reaction beams, pullout rod with electronic deformation gauge, deflection measurement beam with 4 deflection gauges, hydraulic force actuator with 60 tons capacity, and data logger. This testing setup is described in Figures 1 through 3.

- **Preparatory Actions:** For each pullout test, a special metal testing plate was glued by epoxy to the single test block 3 days in advance.

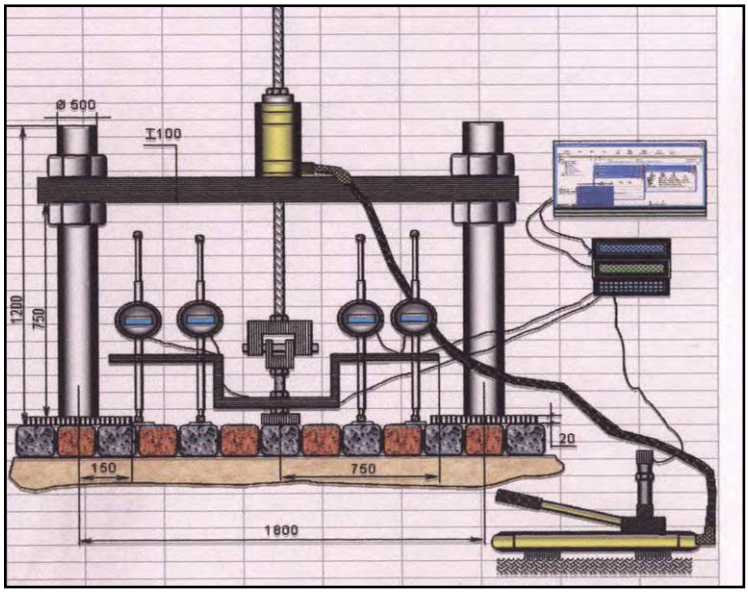


Figure 1. Schematic description of the Pullout Test on old pavements



Figure 2. Pullout Test setup as carried out in the aprons of Hangars 10 & 11 at the Israeli Aircraft Industry (notice the excellent condition of the CBP after 16 years of intensive service without any maintenance)



Figure 3. Carrying out a Pullout Test in the aprons of Hangars 10 & 11 at the Israeli Aircraft Industry (IAI) facilities

5.2 Presentation of Test Results and Discussion

Figure 4 presents a typical output of a pullout test carried out on rectangular block in the IAI facilities. Each graph in the figure reflects the "negative deflection," within the bulging-up deflection basin, as developed with the increase of the pullout force while pulling out the center block. In this test the maximum pullout force was 1,500 kgf, and the deflection of the center block at pullout condition was 12 mm. Figure 5, present the negative deflection basins as they developed during the increase of the pullout force in the same test.

It can be seen that due to the interlocking effect of the concrete block surface, the whole paved area surrounding the pulled center block (within a radius of about 1 meter) resist the pulling out of the center block. This provides quite an impressive evidence of the effective locking and interlocking capacity of concrete block pavements.

The summary of the results of the different pullout tests are presented in Table 4. For each test the table specifies the maximum pullout force, as well as the associated lift deflection of the center block at pullout condition.

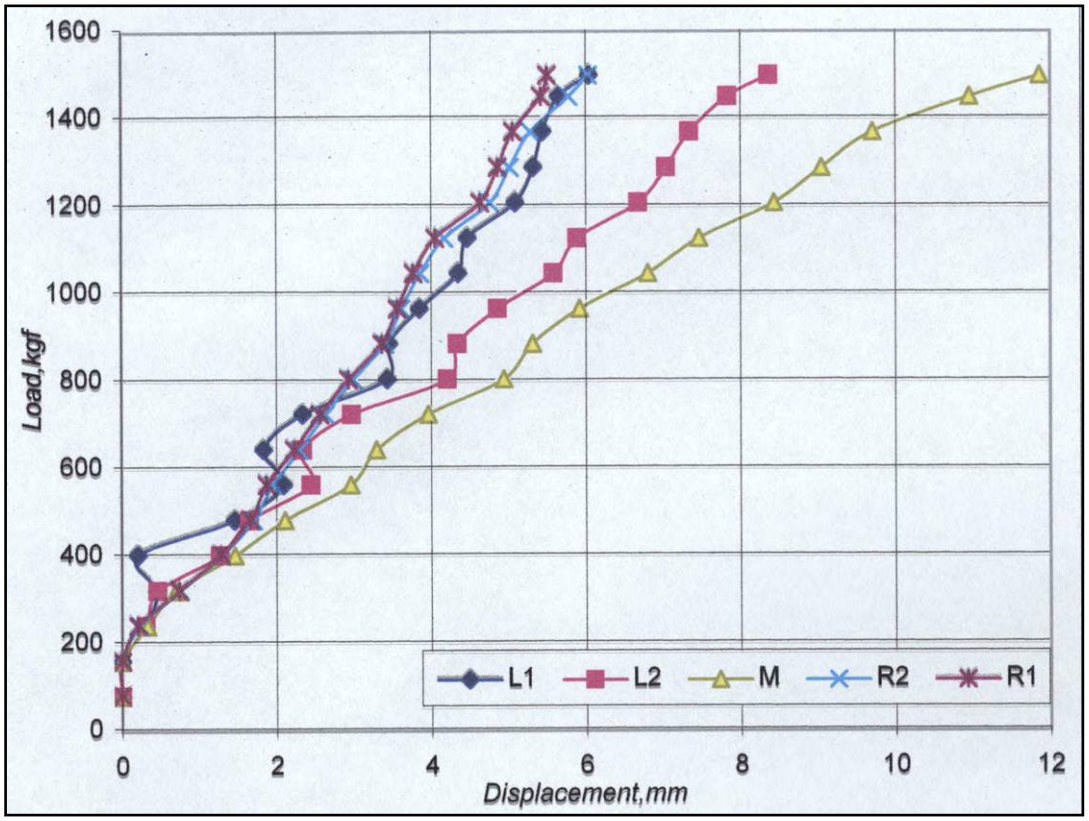


Figure 4. Block upward deflection as developed with the increase of pullout force, measured at the center and at 4 offset locations (rectangular blocks, IAI point 1)

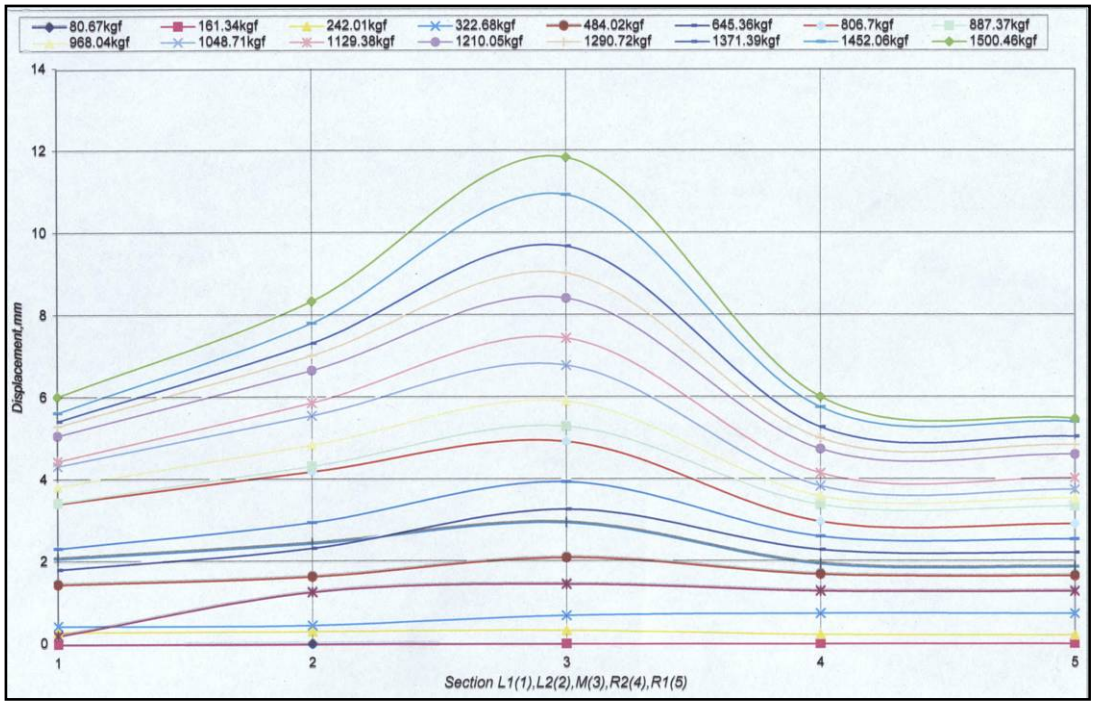


Figure 5. Negative deflection basins as developed during the increase of the pullout force in the test (rectangular blocks, IAI point 1)

Table 4. Summary of Results of the Different Pullout Tests

Location	Industrial Dairy, Pardesia			IAI Hangar Aprons	
Testing Point	**1**	**2**	**3**	**1**	**2**
Maximum Pullout Force, kgf	1,291	1,533	1,371	1,500	1,613
Vertical Upward Deflection at Pullout, mm	16.47	14.48	16.42	11.86	9.64

As can be seen, in order to pull out a single block from the old block paved area, a force in the magnitude of 1.3 to 1.6 ton should be applied. It is also evident that the whole paved area surrounding the pulled center block resist the pulling out of the center block. No significant difference was observed between rectangular and Uni-coloc shaped blocks. The vertical upward deflection associated with the maximum pullout force is in the magnitude of 10-17 mm. By comparing these results with that performed in the laboratory (see Table 3), it can be seen that the pullout forces of conventional rectangular blocks in the actual pavements are about 5 times of that obtained in the laboratory, and the upward deflection at pullout was about 20 times higher. These differences can be explained by the fact that the laboratory paver panels have not yet reached the lockup and interlocking phase that usually obtained in actual old concrete block pavements.

As for relating the pullout force to the lift force produced by the jet thrust velocities, it can be seen from Table 2 that at the maximum breakaway thrust velocity level (212 km/hr, see Table 1), the lift force on the surface of the pavement is about 335 kg/m^2. This lift force is produces a pull force of only 6.7 kgf on a single block, or about 1050 kgf for the entire deflection basin. These forces are much lower than the maximum pullout forces measured on a single block. It should be stressed, however, that this conclusion is valid if the jointing sand or filling are sealed and intact.

6. CONCLUDING REMARKS

As reported and stressed in the technical literature, as validated in actual performance, and as strengthened by the above findings, concrete block pavements are suitable for airport facilities accommodating the operation of jet aircrafts. This suitability is of course limited to facilities in which the jet thrust velocity does not exceed the breakaway levels, and the block pavement is sealed and intact. As recommended ten years ago by Knapton and Emery (1996), and should also be adopted today, pavers can be used to surface the following categories of aircraft pavements:

- Aircraft stands.
- Low speed taxiways not subjected to significant jet blast.
- Aircraft maintenance areas not subjected to significant jet blast.
- Heliport pads.

It is also recommended that pavers should not be used to surface the following categories of aircraft pavements:

- Runways.

- Areas where aircraft engines are run at high thrust values.
- High speed taxiways.

7. REFERENCES

Boeing (2005) "737 Airplane Characteristics for Airport Planning" Report D6-58325-6, Boeing Commercial Airplanes.

Emery, J. (1992) "Erosion of Jointing Sand from Concrete Block Paving" Proceedings, Fourth International Conference on Concrete Block Paving, Auckland, New Zealand, pp. 295-300 .

Emery, J. (1998) "Block Paving for Military Airfields," Proceedings, Third International Workshop on Concrete Block Paving, Colombia.

Emery, J., Lazar, M. and Burrows, G.R. (2005) "A New Paver System for Airfields"

FAA – Federal Aviation Administration (1993) "Airport Pavements – Solutions for Tomorrow Aircraft."

IAI – Israeli Aircraft Industry (2004) "Guidelines for Infrastructure Design for Aircraft Engine Acceleration Facility," Prepared by Hasson Jerushalmi Engineers Consultants and E.L. Engineering.

ICPI – Interlocking Concrete Pavement Institute (1993) "Airfield Pavement Design with Concrete Pavers – A Comprehensive Guide." Prepared by McQueen, R.D., Knapton, J., Emery, J. and Smith, D.R.

Ishai, I., Maurer, U. and Hasson, R. (1994) "Design & Performance of Concrete Block Pavements for Hangar Aprons Serving Heavy Duty Aircrafts", Proceedings, Second International Workshop on Concrete Block Paving, Oslo, Norway.

Knapton, J. and Emery J. (1996). "The use of Pavers for Aircraft Pavements" CAA Paper 96001, UK Civil Aviation Authority, London

UK Ministry of Defence (2005) "Concrete Block Paving for Airfields," Specification 035, Construction Support Team, Defense Estates.

USA Air Force (1991) "Concrete Block Pavement for Airfields" Technical Report GL-91-12, written by G.L. Anderson, Department of the Army, Waterway Experimental Station, Mississippi.

8. ACKNOWLEDGEMENTS

This paper was prepared within the framework of a post research service on "Design and Performance of Concrete Block Pavements for Heavy Loading," financed by Ackerstein Industries Ltd., Herzlia, Israel. The author wishes to thank Ackerstein Company for its sponsorship and help in this project. Acknowledgment is also due to Engr. Yitzhak Adam for his assistance and engineering support. The equipment and tests were designed and performed by ISOTOP Testing Laboratories, Ltd.