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Canadian Airfield Manual

Pavements for airfield aprons and taxiways

• *Design* • *Specifications* • *Construction* • *Maintenance*

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CANADIAN AIRFIELD PAVEMENT DESIGN WITH CONCRETE PAVERS

November 1993
Updated May 2020

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ACKNOWLEDGMENTS

The author would like to thank Roy D. McQueen, P.E. of Roy D. McQueen & Associates Ltd. and David R. Smith, Technical Director of the Interlocking Concrete Pavement Institute, for their valuable contributions to the development of this manual. Thanks also go to John Emery of the United Kingdom in updating the list of airports with interlocking concrete pavements in Chapter 1. Mr. Emery was the first to introduce interlocking concrete pavements into airport use.

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CHAPTER 1
INTRODUCTION

1.1 GENERAL

Segmental paving has been used as a pavement surface for over 2000 years. Recently engineers and designers have recognized the benefits of interlocking concrete pavements for airport applications. Pavements surfaced with concrete pavers exhibit many desirable properties of conventional concrete pavements such as resistance to fuel spills and static indentations while having similar or lower construction and maintenance costs.

1.2 SCOPE OF THE MANUAL

This manual presents guidelines for the structural design and construction of interlocking concrete airfield pavements. Concrete pavers are for use for apron and low speed taxiways and are not recommended for areas subjected to aircraft traveling at speeds greater than about 50 km/hr. This manual is intended to compliment Public Works Canada Architecture and Engineering, "Manual of Pavement Structural Design" (ASG-19/AK-68-12) [1].

1.3 AIRPORTS WITH INTERLOCKING CONCRETE PAVEMENTS

The following is a list of airfields with concrete pavers in use as of 2012. A history of the technical evolution of the pavement system is provided in “Evolution of Interlocking Concrete Pavements for Airfields” [20].

LOCATION (m) = military	APPLICATION	APPROXIMATE AREA ft^2	m^2
Australia			
Sydney International	Taxiway Widening & Apron Parking	129,170	12,000
RAAF Base Pearce – RSAF (m)	Apron Parking	427,330	39,700
RAAF Base Tindal (m)	Apron Parking and Maritime OLAs	227,206	21,108
RAAF Base Scherger (m)	General Purpose Apron Parking	302,468	28,100
RAAF Base Albatross (m)	Apron Parking	387,500	36,000
Cairns	Aircraft Apron	645,840	60,000
Thevenard Island – W. Australia	Runway & Apron Parking	279,860	26,000
Bangladesh			
Hazrat Shajalal Airport	Cargo Handling Area	188,370	17,500
British West Indies			
Cayman Brac	Aircraft Parking	9,690	900
Grand Cayman	Aircraft Apron	105,490	9,800
Hong Kong, China			
Chek Lap Kok International Airport	Aircraft Parking	5,382,000	500,000
Israel			
Ben Gurion Int'l, Israel	Aircraft Parking	430,560	40,000
Israel Aircraft Industries	Aircraft Parking	75,350	7,000

Kenya			
Jomo Kenyatta,	Aircraft Parking	608,812	56,650
Malaysia			
Subang	Aircraft Apron	731,950	68,000
Tanjong Manis	Aircraft Apron	80,730	7,500
New Zealand			
Christchurch	Aircraft Apron	42,195	3,920
Wellington	Aircraft Apron	16,150	1,500
Norway			
Krisiansand – Kjevic	Aircraft Parking	71,580	6,650
Oslo – Fornebu	Aircraft Parking	13,455	1,250
Stavanger/Sola	Aircraft Parking and Taxiway	139,930	13,000
Trondheim – Vaerens	Aircraft Parking	292,780	27,200
Oman			
Muscat International Airport	Aircraft Parking	306,775	28,500
United Arab Emirates			
Fujairah	Apron Taxiway and Fuel Area	602,780	56,000
Shahjah	Aircraft Parking	376,740	35,000
Sheik Zayed Airport, Abu Dhabi	Aircraft Parking	107,400	10,000
United Kingdom			
Abingdon (m)	Aircraft Fueling Bay	150,700	14,000
Benson RAF (m)	Helicopter Landing Pads	204,520	19,000
Blackpool	Helicopter Pad and Aircraft Parking	56,620	5,260
Brize Norton (m)	Aircraft Parking	398,270	37,000
Coventry	Runway End	32,300	3,000
Dishforth (m)	Helicopter Pads	376,740	35,000
Dunsfold (m)	Runway End & Helicopter Pads	53,820	5,000
Eastleigh	Apron Taxiway	96,880	9,000
Gatwick	Aircraft Safety Areas	329,380	30,600
Glasgow	Aircraft Parking	452,090	42,000
Heathrow	Aircraft Parking	495,140	46,000
Luton	Aircraft Parking	150,700	14,000
Lyneham (m)	Aircraft Parking	69,970	6,500
Manchester	Aircraft Parking	45,209	4,200
Newquay (m) + commercial	Aircraft Parking	48,440	4,500
Northolt (m)	Aircraft Parking	678,130	63,000
Oban	Aircraft Parking	37,670	3,500
Scampton (m)	Aircraft Parking	35,520	3,300
Scilly Isles	Aircraft Parking	26,910	2,500
Southhampton	Aircraft Parking	322,920	30,000
Stanstead	Aircraft Parking	301,390	28,000
Stornaway (m)	Aircraft Parking	150,700	14,000

Valley (m)	Helicopter Pads	204,520	19,000
Wood Vale (m)	Aircraft Parking	49,514	4,600
United States			
St. Augustine, Florida	Aircraft Parking	49,514	4,600
TOTAL USED ON AIRCAFT PAVEMENTS		**16,800,000 ft^2**	**1,556,200 m^2**

Note: There is an unspecified area of interlocking concrete pavement at Amsterdam's Schiphol Airport in The Netherlands.

CHAPTER 2
PRINCIPLE COMPONENTS OF INTERLOCKING CONCRETE PAVER SYSTEMS

The principle components of interlocking concrete paver pavements are shown in Appendix B. They include pavers, bedding sand, jointing sand, sealer, geotextile and edge restraints. Pavers are fabricated with Portland cement concrete (PCC) and have a nominal size of 100 mm wide, 200 mm long by 80 mm thick. Although concrete pavers can be produced in different shapes, rectangular pavers are the most common shape for airports. The pavers are generally bedded on 25 to 30 mm of high-quality bedding sand. A fine, high quality sand is used for filling the joints between pavers to interlock them together. This allows for the paver/sand surface to structurally function as one durable layer [2,3,4,5].

2.1 PAVERS

The manufacturing of high-quality concrete pavers involves combining Portland cement, coarse and fine aggregate to produce a "no slump" concrete which in turn is moulded in manufacturing equipment under vibration and extreme pressure. Admixtures may be used to increase various engineering properties (strength, density) and reduce the likelihood of efflorescence. Normally, the paver units are constructed with 1.5 - 2 mm thick spacer bars to ensure uniform, properly spaced joints and with chamfered edges to prevent chipping and spalling. Rectangular or dentated units may be used. In Canada, pavers are manufactured to specifications outlined in CSA-A231.2, "Precast Concrete Pavers." This standard requires:

- minimum average compressive strength of 50 MPa
- minimum individual compressive strength of 45 MPa
- freeze-thaw durability
- close dimensional tolerances

2.2 BEDDING SAND

High quality bedding sand is used to resist high compressive forces associated with high load and high tire pressure aircraft. A clean (i.e. less than 1 percent passing the 75 μm sieve size), hard, natural or manufactured sand is normally required. Gradation analysis and degradation testing are performed for approval purposes. In many locations, locally available clean concrete sands will meet the necessary requirements for bedding sand. The bedding sand layer should be drained.

2.3 JOINTING SAND

Finer graded (100 percent passing the 1.18 mm sieve size), high quality sand is required to fill joints (typically 3 to 5 mm) between the pavers. The jointing sand among the individual paver units provides interlocking thus transmitting aircraft loads to surrounding pavers by shear forces. This enables the pavers and bedding sand to structurally function as a distinct layer allowing distribution of loads in a manner similar to a hot mix asphalt concrete layer.

2.4 SEALER

Although not normally required to enhance the surface durability of the paver units, a sealer is necessary on airport pavements to prevent loss of the joint sand from the effects of repeated jet blast and propeller wash. The sealer will also prevent the ingress of water, oils, and fuel through the joint sand into the bedding sand. Several commercially available sealers have been used for airport projects, such as elastomeric urethanes.

2.5 GEOTEXTILE

Geotextile are normally not required with an aggregate or hot mix asphalt base. However, for a cement treated base, a woven geotextile fabric is recommended to prevent migration of bedding sand through shrinkage cracks which normally develop as the cement treated base cures. With concrete paver inlays or overlays on existing asphalt or concrete surfaces, a geotextile is also recommended. The fabric should be turned up against edge restraints to prevent sand from migrating into the joint between the pavement and the edge restraint.

2.6 EDGE RESTRAINTS

Edge restraints are used to prevent the lateral movement of pavers at pavement edges or at interfaces with asphalt or concrete pavements. Portland cement concrete or steel angle is typically used for restraints. Further details on edge restraint construction are provided in Appendix B.

2.7 INSTALLATION

After construction, inspection and acceptance of the pavement base, the bedding sand is spread and screeded to a consistent thickness (typically 25 to 40 mm). The moisture content of the sand should remain as consistent as possible to ensure uniform compaction during installation.

The paver units can be placed by hand or mechanically. The 45- and 90-degree herringbone patterns, as shown in Figures 1 and 2 (Appendix B), are the most common laying pattern used to minimize movement and maximize interlock between the paver units. A single or double string (sailor) course (one or two rows) of pavers is usually placed beside the edge restraint. The herringbone pattern abuts this string course resulting in a more stable surface at the edge and transition area to other pavements.

Paver units are vibrated with a minimum 22 kN force plate compactor to compact the bedding sand. Jointing sand is swept into the paver joints and is re-vibrated. This procedure is repeated until the joints are filled with sand. In order to ensure proper bedding of the paver units into the bedding sand, the surface is rolled with a 70-90 kN pneumatic tire roller.

2.8 GUIDE SPECIFICATIONS

A guide specification, "Interlocking Concrete Pavement Construction for Airport Pavement," is included in Appendix A. The specification outlines detailed requirements for paver production and installation.

CHAPTER 3
SELECTION CRITERIA AND CONCRETE PAVER MERITS

The pavement designer requires a working knowledge of different pavement materials to select an appropriate pavement system. The selection should be based upon the following parameters:

- safety and reliability (i.e. operational requirements)
- environmental and climatic considerations
- constructability and operational disruption during the construction process
- structural requirements (i.e. aircraft loading)
- construction budget
- maintenance requirements
- cost-effectiveness

This chapter outlines the merits of concrete pavers, to ensure that an informed decision is made by the pavement designer as to the appropriateness of concrete pavers for a particular application. The life-cycle cost procedures outlined in AK-76-06-000 are applied to concrete pavers in Chapter 6.

3.1 SAFETY AND RELIABILITY

Special attention must be given to the following properties in the design of a safe and reliable airport pavement:

- surface stability
- resistance to fuels, hydraulic oils, and de-icing chemicals
- resistance to static loading
- skid resistance
- roughness
- surface operational markings

3.1.1 Surface Stability

Foreign object damage (FOD) refers to the ingestion of materials, birds, etc. into jet engines or damage to the airframe. In this regard, it is crucial that a pavement surface remains intact with low FOD potential. Chamfered edges and uniform joint spacing with concrete pavers will reduce the potential for FOD. The interlock and stability of pavers depend on the joint sand. To eliminate the uptake of this joint sand, a sealer is used for stabilization [6].

Concrete pavers are not recommended in certain situations. Concrete pavers have been exposed to high velocity jet exhaust in tests conducted by the British Ministry of Defense, British Aerospace, PLC and the U.S. Air Force [6,7,8,9] and although the results of these experiments were favourable, concrete pavers are not recommended in airport locations subjected to full power or reverse thrust. These locations include runways or apron areas where aircraft "power-back" operations are conducted.

Based on past performance and the results of testing by the military, pavers should be considered for:

- static parking positions with "tug-in/tug-out" or "power-in/power out" operations
- low speed taxiways and taxilanes

As mentioned above, a sealant should be used to stabilize the joint sand and prevent erosion by occasional high levels of jet blast.

3.1.2 Resistance to Fuels, Hydraulic Oils and Deicing Chemicals

Aircraft parking areas constructed with an asphalt concrete surface are subject to deterioration by spilled jet fuels, aviation gas, and hydraulic oils. Although hot mix asphalt concrete surfaces can be protected by applying jet fuel resistant slurry sealers, such sealers have a finite life and typically require re-application every 5 years. Consequently, Portland cement concrete (PCC) has been the material of choice for aircraft parking positions and apron areas. However, while PCC has been found to resist deterioration by aviation fuels and hydraulic oils, these fluids have been found to have deleterious effects on some joint sealant materials.

Fears of the accumulation of aviation fuel in the sand layer underneath the concrete pavers appear to be unfounded. Tests conducted at London Luton Airport under the supervision of the County Petroleum Officer indicated that no explosive vapours were present when sample pavers were removed from an area heavily contaminated with aviation fuel [11]. Nevertheless, concrete pavers used for airfield pavements are typically sealed to help prevent intrusion of aviation fuel.

Urea, an anti-icing agent, and glycol, a deicing agent, are two of the chemicals most commonly used in winter for aircraft safety. These two materials have been known to have damaging effects upon concrete, due to the very rapid cooling effect within the surface of the pavement, which can freeze any moisture present. A rapid volume increase of approximately 9 percent in the pores holding water can lead to an almost immediate disintegration of some concrete surfaces, particularly if the concrete is saturated.

The freeze-thaw deicing test procedures outlined in the Canadian Standards Association (CSA) specifications for "Precast Concrete Pavers" (CSA-A231.2) is recommended for concrete pavers exposed to freeze-thaw cycles or deicing agents. This standard requires a maximum mass loss not to exceed 225 g/m^2 of paver surface area after 28 freeze-thaw cycles or 500 g/m^2 after 49 freeze-thaw cycles while submerged in a 3 percent salt (sodium chloride) solution. This test method is more severe and exposes concrete pavers to higher stresses and damage than that of airport deicers. Therefore, an added measure of safety and durability from deteriorating concrete is provided.

3.1.3 Resistance to Static Loading

Static indentation is frequently a problem when aircraft with high tire pressures are parked on hot mix asphalt concrete surfaces. During hot weather, the stiffness of the asphalt concrete decreases. Consequently, the aircraft wheels deform the surface. Over time, these depressions in the surface will collect water forming "bird baths" resulting in localized ice patches in the winter. ASG-19 requires that for new construction, aircraft pavements subjected to turning movements, such as aprons, holding areas, etc., should be surfaced with PCC if the traffic consists of aircraft with tire pressures exceeding 1.0 MPa. Concrete pavers provide the same resistance to static indentation of the pavement surface as conventional poured concrete pavements.

3.1.4 Skid Resistance

Skid resistance is measured in terms of the coefficient of friction developed between a braking tire and the pavement surface. Frictional test results have shown that concrete pavers provide superior skid resistance over Portland cement concrete pavement [13,14,15,16,17].

3.1.5 Roughness

This criterion is not considered essential for apron and low speed taxi areas, which are generally subjected to slow moving traffic only, i.e. aircraft speeds of under 50 km/hr. However, little is known about the roughness performance of concrete pavers under aircraft traveling at high speeds.

3.1.6 Surface Operational Markings

Concrete pavers can be integrally coloured to form pavement markings for gear locations, lead-in lines, gate numbers, equipment, parking areas, and airline identification. Entire bays can be coloured to compliment the architecture of the airport terminal buildings. The units can also be painted with lines and numbers used for airport pavement operation. Paint markings should be placed prior to sealing.

3.2 CONSTRUCTABILITY

Compared to conventional concrete, interlocking concrete pavements can be constructed quickly. In some situations, low speed taxiways may need to be constructed adjacent to active runways, or aircraft aprons may require rehabilitation on a gate by gate basis. Concrete pavers can reduce the down time associated with such facility closures thereby saving airlines/airports from interruptions to operating schedules and their associated costs.

Mechanical installation of interlocking concrete pavements can be used to significantly accelerate construction. Knowledgeable and experienced contractors can use mechanical equipment to accurately place interlocking concrete pavements while maintaining a high quality of construction, conformance to specified tolerances for surface elevations and consistent paver joint widths. Daily productivity per machine and crew ranges between 400 and 600 m^2.

3.3 MAINTENANCE AND REINSTATEMENT

Pavements at busier airports may need to be repaired rapidly due to air operations limiting access time for construction. When repairs to utilities or the base layers are needed, concrete pavers can be removed and reinstated. They can also be rapidly reinstated in freezing temperatures; however, the bedding sand and aggregate base materials should not be frozen. Once placed and compacted, they can be put into immediate use. Unlike asphalt or poured concrete, the continuity of the pavement is not damaged by cuts for access to utilities. Generally, interlocking concrete pavements can be reinstated at approximately 25 percent less cost than concrete pavements in a fraction of the time. A procedure for inspection and maintaining concrete pavers is included in Appendix C.

3.4 REMOVAL OF SURFACE WATER AND SNOW

Concrete pavers with chamfered edges are capable of rapid removal of surface water. Observations have shown that after wetting, concrete pavers can dry faster than asphalt surfaces. Concrete pavers can be coloured to absorb more of the sun's radiant energy to accelerate snow and ice melting.

Snowplow blades will not catch on concrete pavers, provided that each paver unit has a consistent thickness and that a smooth surface is achieved when installed. Smoothness is achieved by ensuring an even surface for the base material and bedding sand. Surface smoothness is further achieved during construction with compaction and final static proof rolling with a 70 to 90 kN pneumatic tired roller.

Interlocking concrete pavements are usually sealed to stabilize the sand in the joints to reduce FOD potential. Sealing also prevents water from seeping into the bedding sand. Should water infiltrate and saturate the bedding sand, the water, when frozen, does not cause the pavers to heave. While there is movement in a saturated bedding sand layer when it freezes, it is minimal. Movement is typically a fraction of a millimetre. The sealer in the joints should be able to accommodate this small amount of movement without breaking its bond with the sand or sides of the pavers.

The amount of movement in a frozen, saturated bedding sand layer of 25 mm can be estimated. When compacted, bedding sand may have a void space of 5 percent to 7 percent. If water expands 9 percent when frozen, then the potential for heaving is 0.07 x 0.09 x 25 mm = 0.16 mm. Therefore, movement from freezing saturated bedding sand is small. The negligible amount of movement will not allow paving units to protrude above the pavement surface and be damaged by a passing snowplow blade.

3.5 CLIMATIC CONSIDERATIONS

3.5.1 Durability

Concrete pavers can be utilized under a wide variety of climatic conditions. Freeze-thaw resistant pavers typically can be achieved by using cement contents of 17 to 19 percent, absorption less than 4 percent, densities exceeding 2,300 kg/m^3, a low water cement ratio, and durable aggregates. If concrete pavers will be exposed to consistent freeze-thaw cycles, a test for freeze-thaw by the Canadian Standards Association is recommended for assessing durability. The Canadian freeze-thaw test can be found in the Canadian Standards Association Specification CSA-A231.2-06, "Pre-cast Concrete Pavers".

3.5.2 Resistance to High Temperatures

Field testing has shown that concrete pavers are capable of withstanding temperatures up to 520°C [8]. Further, unlike thermo-viscous materials such as hot mix asphalt, the structural properties of pavers will not change with increasing temperatures, thereby preventing static indentation at parking positions. Since concrete paver units are small, rapid increases in temperature do not cause `shock' stresses in the units that could cause shrinkage and spalling. This is an advantage over rigid Portland cement concrete which can spall and cause FOD as a result of a rapid increase in surface temperatures from jet blasts.

3.5.3 Resistance to Thermal Movements

Minor differential thermal movements in the underlying pavement base layers will not produce visible movement in the concrete pavers. This is due to the fact that the pavers and sand act as a flexible surface and individual pavers articulate without significant opening of the joints.

3.6 STRUCTURAL PROPERTIES

Concrete pavers provide a high strength operational surface. Typically, 80 mm thick pavers achieve a compressive strength of 60 MPa to 75 MPa after 28 days. Concrete pavers are bedded on a coarse sand, and both the pavers and sand are compacted to refusal. The use of joint sand and the confinement by edge restrains provides interlock, enabling the pavers/sand to function as a distinct structural layer. Nondestructive tests have shown that the pavers and bedding sand act as a structural layer with an elastic modulus of 3000 MPa. This exceeds the hot weather (i.e. 35°C) modulus of hot mix asphalt, which is typically 1500 to 2500 MPa.

3.7 COST-EFFECTIVENESS

For areas where conventional concrete pavements have been the material of choice, concrete pavers can provide a viable, cost-effective alternative pavement structure. Areas include aircraft parking aprons and taxiways where resistance to fuel spills, static indentation, and to rutting is required. These are areas where significant economies in initial construction and life-cycle costs are achievable. Savings in initial construction costs of 10 to 15 percent can be realized when an interlocking concrete pavement is compared to a conventionally poured concrete pavement. Life cycle cost analysis methods are given in AK-76-06-000 "Life Cycle Costing Procedures." An example life cycle comparative cost analysis is given in Chapter 6.

CHAPTER 4
STRUCTURAL DESIGN

4.1 DESIGN PROCEDURE OVERVIEW

The structural design procedures for pavements subjected to aircraft loadings are discussed in detail in the Public Works Canada Architecture and Engineering Services "Manual of Pavement Structural Design" (ASG-19).

The pavement structural design procedure for concrete pavers will provide a pavement system at least as strong as a flexible pavement designed using the current procedure outlined in ASG-19. The design method for concrete pavers uses a procedure similar to that used for the design of a flexible pavement including:

- determination of the design aircraft load rating (ALR)
- confirmation of subgrade bearing strength (from plate load tests)
- calculation of the required equivalent granular thickness
- conversion of the equivalent granular thickness to the design pavement structure
- verification of frost protection requirements
- verification that minimum layer thicknesses for tire pressure have been satisfied

As Public Works Canada (PWC) is committed to the continued support of their pavement design methods, this manual will not attempt to duplicate the design curves, etc., contained in their structural design manuals.

4.2 BASIS OF DESIGN PROCEDURE

Information on the design of concrete interlocking concrete pavements has been presented by Knapton [13,14], Rollings [15] and Anderton [16]. This research established that concrete pavers and bedding sand have load spreading characteristics greater than that of an equivalent thickness of asphalt. Analyses of falling weight deflectometer (FWD) test results [18] have confirmed that the resistance of the pavement system to tensile strains is superior to that of a traditional asphalt concrete flexible pavement system.

Knapton also developed the British Ports Association Heavy Duty Pavement Design Manual [14]. This manual allows designers to proportion layer thicknesses for interlocking concrete pavements subjected to container handling equipment with wheel loads of up to 30 tonnes. In Europe and North America, concrete pavers have been used to surface port pavements for many years.

Emery [2,3,4,5], as part of a concrete paver installation, completed plate bearing tests on an asphalt concrete surfaced aircraft pavement at Luton Airport in England. Field test results indicated a 14 percent increase in overall pavement strength when the asphalt concrete layer was replaced by concrete pavers. In this manual, this strength increase has been ignored so that the PWC design procedure can be used conservatively.

Pavements designed in accordance with this method are intended to provide a structural life of 20 years, requiring little maintenance provided design aircraft loadings are not exceeded. Experience with interlocking concrete pavements indicates that only minimal surface maintenance will be required during this period.

Application of the research work referred to above, allows the current PWC design procedure to be modified to accommodate concrete pavers. The PWC design procedure requires that thickness of pavement layers be proportioned based on minimum standards. By substituting the concrete pavers and sand bedding layer for the asphalt concrete surface layer, the resulting pavement will be at least as strong as a traditional asphalt concrete surfaced flexible pavement.

4.3 DESIGN EXAMPLE

An airport apron area is to be designed to accommodate a Boeing 737 design aircraft, given a tire pressure of 1.25 MPa, freezing index of 500 and a lower quartile spring reduced bearing strength of 85 kN.

From Table 3.2.1 of ASG-19, the B737 aircraft would be classified as ALR = 9. From Figure 3.4.1 for an overload ratio of 1.0 and subgrade bearing strength of 85 kN, the required pavement equivalent granular thickness is 80 cm. From Table 3.4.1 for a design aircraft with a tire pressure of greater than 1.0 MPa, a minimum asphalt concrete layer thickness of 10 cm and granular base thickness of 30 cm would be required in addition to selected granular subbase to satisfy the total pavement equivalent granular thickness and the total pavement depth required for frost protection. By using the granular equivalency factors given in Table 3.2.5 and allowing a granular equivalency factor of 2.0 for the 8 cm concrete pavers and 3 cm bedding sand layer, the following pavement structure would result.

Layer	Granular Equivalency Factor		Equivalent Granular Thickness (cm)
8 cm concrete pavers and 3 cm bedding sand	2		22
30 cm crushed stone base	1		30
28 cm selected subbase	1		28
Total equivalent granular thickness		=	80 cm
Actual pavement thickness		=	69 cm

From Figure 3.3.1, the minimum pavement thickness for frost protection would be 67 cm and as an overall thickness of 69 cm is being provided, the frost criteria are satisfied.

For larger projects at international airports, the granular base for pavements serving heavy aircraft should be cement stabilized. Transforming the above pavement structure, the following pavement structure would result:

Layer	Granular Equivalency Factor	Equivalent Granular Thickness (cm)
8 cm concrete pavers and 3 cm bedding sand	2	22
20 cm cement stabilized base and geotextile	2	40
18 cm selected subbase	1	18
Total equivalent granular thickness	=	80 cm
Actual pavement thickness	=	49 cm

As the minimum pavement thickness for frost protection would be 67 cm, an additional 18 cm of selected subbase would be required to satisfy the frost criteria.

4.4 LAYERED ELASTIC DESIGN

The current PWC design method is based on plate load testing and the McLeod model [17]. Some pavement engineers are also using layered elastic analysis to model the response of pavements to aircraft loads and to predict structural performance. When conducting design analyses, the layered elastic results may be compared to the PWC design results. Although the layered elastic model will more closely represent the actual response of the pavement structure, the elastic models will have some deficiencies when applied to plate load testing because the pavement deflection measured under a plate load test will have a plastic as well as elastic component.

Layered elastic design methods for airfield pavements are based on the theory that the pavement structure reacts to loads as a multi-layered elastic system. Each layer is characterized by its elastic modulus and Poisson's ratio. Critical strains in the layers are computed for the range of predicted loads and subgrade conditions. For flexible pavements, these are normally horizontal tensile strain at the bottom of the asphalt or stabilized base layer(s) and the vertical compressive strain at the top of the subgrade layer. The computed strains are compared to limiting strain criteria, which are normally a function of layer strength and the number of strain repetitions (i.e. coverages). Since the strength of the pavement materials are known, pavement layer thicknesses are then selected that will yield strains that are less than or equal to the limiting strains.

An elastic modulus of 3000 MPa and a Poisson's ratio of 0.3 should be used to model the composite paver/bedding sand layer when conducting layered elastic designs. This is based on research conducted by the Interlocking Concrete Pavement Institute and other literature on the design of heavy-duty pavements with interlocking concrete pavers [14,18]. Further research and adoption of layered elastic design methods may show that some decrease in total pavement section thickness is possible with the use of a concrete paver surface as compared to an asphalt concrete surface.

CHAPTER 5
PAVEMENT REHABILITATION WITH CONCRETE PAVERS

Most airport pavements in use today were designed and constructed 20 years or more ago. In many cases, they have been subjected to increased aircraft weights and frequencies of operation which often exceeded the original design assumptions. In these situations, the pavement may require strengthening to accommodate the traffic forecast over the next design period.

In other cases, although the pavement may be structurally adequate, surface conditions may have deteriorated to the point where debris is generated creating a potential FOD hazard. In these situations, rehabilitation would be required to provide a safe, reliable and functional surface.

Concrete pavers can be used for either structural (i.e. strengthening) or functional (i.e. non-structural) surface rehabilitation of airport pavements. As with new construction, the pavers are modeled as hot mix asphalt concrete material when performing structural overlay computations using the procedures outlined in the Public Works Canada Publication ASG-19. Pavers are appropriate for rehabilitating both flexible and rigid pavements.

The computational sequence involves:

- evaluation of existing pavement conditions
- determination as to whether structural or functional rehabilitation is required
- design of the overlay thickness for structural rehabilitation (i.e. strengthening)
- determination of the amount and type of pre-requisite base pavement repairs required prior to construction of the overlay.

5.1 STRUCTURAL REHABILITATION

If structural rehabilitation and strengthening is required, the designer should use the flexible overlay procedures outlined in ASG-19. Required inputs include:

- design aircraft
- freezing index
- lower quartile spring reduced subgrade bearing strength
- layer equivalencies for the flexible pavement layers based on the condition of each layer

5.1.1 Overlay of a Flexible Pavement

The overlay procedure for flexible pavements is based on the structural deficiency approach. The existing deficient pavement is compared to the requirements for a new pavement and the difference is the required overlay thickness.

If the surface of the asphalt concrete layer is significantly deteriorated, localized repairs such as crack sealing, patch and base repairs, etc. should be completed. If the overlay requirement is 11 cm or less, and grades permit, concrete pavers and sand can be directly substituted for the asphalt concrete layer. If the overlay thickness required is greater than 11 cm, the additional thickness can be made up using hot mix asphalt concrete. In general, the minimum practical thickness of asphalt concrete is 5 cm. For concrete pavers and sand placed on top of a cracked or broken asphalt concrete layer, a geotextile fabric should be placed prior to installing the bedding sand to prevent the migration of the sand into cracks in the pavement. If a thick overlay of 20 cm of equivalent granular thickness or greater is required for strengthening or grade purposes, consideration may be given to a sandwich overlay (granular lift followed by geotextile bedding sand and concrete pavers).

5.1.2 Overlay of a Rigid Pavement

A flexible overlay on a rigid slab is assumed to result in a rigid pavement structure if the depth of overlay does not exceed the thickness of the slab, or 25 cm. For this case, the thickness of the flexible overlay required is computed as follows:

$$t = 1.67\,(F \times h_d - h)$$

where
- t = thickness of the flexible overlay (cm) with a granular equivalency factor of 2.0
- F = a factor dependent on the bearing modulus of the existing slab as given in Figure 3.2.2 of ASG-19
- h_d = thickness of slab required for a new concrete pavement given in Figure 3.4.2 of ASG-19 (cm)
- h = existing slab thickness (cm)

As with overlays on flexible pavement, if the required thickness of asphalt concrete is greater than 11 cm, the difference between the required thickness and the thickness of the concrete paver/sand layer can be made up with asphalt concrete.

The designer of a concrete paver/sand overlay on a concrete pavement is cautioned that some special treatments may be required, such as:

- use of a geotextile to prevent the loss of bedding sand into the concrete joints or cracks
- possible jointing of the pavers over underlying slab
- improvement of joint efficiency (i.e. load transfer), of the concrete slabs prior to placement of the concrete pavers/sand by using methods such as slab jacking, installation of load transfer devices or by slab cracking and seating
- localized repairs of severely deteriorated slabs, etc.

5.2 NON-STRUCTURAL OVERLAY

In some instances, a pavement may be structurally adequate for the forecasted traffic, but its surface condition may have deteriorated to the point where operational safety or reliability is compromised. In these instances, an overlay, or inlay, with concrete pavers may be an appropriate rehabilitation option. An example would be a low speed taxiway in need of functional surface improvement, or an existing asphalt apron in need of a hard surface to eliminate static indentation and fuel spill damage.

Where grade considerations are not a factor, an overlay with pavers may be considered. However, where grade constraints make an overlay impractical, such as an apron area, either surface reconstruction with pavers or an inlay (i.e. remove sufficient surface thickness to allow for the paver/sand layer) may be considered depending on the thickness of the surface layer.

As with structural overlays, pre-requisite pavement repairs should be accomplished and a geotextile fabric should be placed prior to constructing the paver/sand layer.

Typical construction details for pavement rehabilitation using concrete pavers are included in Appendix B. The designer should carefully review each applicable detail and make any modifications necessary to meet site specific design and construction requirements.

CHAPTER 6
LIFE CYCLE COST ANALYSIS

Cost analysis for the comparison of pavement design alternatives should be performed in accordance with AK-76-06-000 "Life Cycle Costing Procedures" [19]. For a comparison of relative costs, a present value is calculated for each design alternative according to the following equation:

$$P_v = C + \sum_{i=1}^{n} \frac{R_i}{(1 + r)^i} - \frac{V_n}{(1 + r)^i}$$

where
P_v = present value of the facility ($)
n = analysis period (years)
C = initial construction cost ($)
R_i = restoration or maintenance cost in year, i
V_n = residual value of the facility at the end of the analysis period
r = discount rate applied to future costs or values

An analysis period of 30 years is normally used for pavement construction projects. With an analysis period of this duration, the residual value discounted to a present value is small and can be assumed equal for all alternatives. This is considered to be a reasonable assumption when comparing concrete paver pavement with conventional concrete pavements as the concrete pavement can continue to contribute structurally to the pavement if overlaid and the concrete pavers can be re-used. Under these circumstances, AK-76-06-000 indicates that the residual value can be eliminated when P_v is being calculated only for relative comparison purposes.

All costs are calculated in terms of present-day dollar value. The application of a discount rate to these costs when they are expended in the future reflects the advantages of delaying expenditures. These advantages include the average difference between interest and inflation rates, possible productivity gains in the future, and more accurate assessments of future requirements as time progresses. In accordance with AK-76-06-004, the discount rate normally applied to future expenditures and values is 10 percent. Additional calculations at 5 and 15 percent may be made to determine the sensitivity of the decision process to this factor.

The present value of design alternatives bears little relationship to the actual costs of the facility over its life cycle; present value is simply a relative measure for comparison purposes.

6.1 PAVEMENT DESIGN EXAMPLES

Typical concrete paver/bedding sand and Portland cement concrete pavements should be designed in accordance with the procedures outlined in ASG-19. The concrete paver/bedding sand pavement structure is designed using the approach outlined in Section 5.3 and the concrete pavement using a maximum slab flexural stress of 2.75 MPa.

The following equivalent design alternatives are compared using the example shown in Section 4.3:

Alternative A - Concrete Pavers
8 cm concrete pavers
3 cm bedding sand
30 cm crushed stone base
28 cm selected subbase

Alternative B - Portland Cement Concrete
27 cm Portland cement concrete
20 cm cement stabilized base
20 cm selected subbase

6.2 INITIAL CONSTRUCTION COSTS

Using typical construction cost data (in 1992 dollars), the initial construction cost of each alternative is computed as follows:

Alternative A - Concrete Pavers	
Pavers/bedding sand and edge restraints	$ 22.00/m^2
Surface sealer	1.35
30 cm crushed stone base	7.50
28 cm selected subbase	4.50
	$ 35.35
Alternative B	
Portland cement concrete	$ 35.00/m^2
Joint sealer	1.75
20 cm cement stabilized base	7.50
20 cm selected subbase	3.20
	$ 47.45/m^2

The construction costs are based on contractor estimates for airport projects. Actual costs may vary depending on geographic location, project size and site-specific conditions. However, the costs presented are considered to be reasonable for relative comparison purposes.

6.3 MAINTENANCE COSTS

As pavement maintenance costs are normally included in the overall operation and maintenance budget of an airport, it is often difficult to identify specific annual and periodic maintenance costs for airport pavements. The following assumptions on periodic maintenance have been made for each alternative:

Alternative A - Concrete Pavers

Activity	Frequency	Cost ($/m^2)
Reapply surface sealer	5 years	0.15
Replace damaged pavers	5 years	0.45

Provided that damaged pavers are replaced, the service life of the concrete paver flexible pavement system is expected to be the same as that for a conventional concrete pavement.

Alternative B - Portland Cement Concrete

Activity	Frequency	Cost ($/m^2)
Reseal joints	5 years	0.30
Patching and local slab replacement	5 years	0.45

By using the present value function given at the beginning of this chapter and assuming an analysis period of 30 years, discount rate of 10 percent and similar residual values for both types of pavement, the present worth of the two alternatives were computed to be:

Alternative A – Interlocking Concrete Pavement

Activity	Year	Cost	Present Value
Initial Construction	2020	35.35	35.35
Reapply Sealer	2025	0.15	0.09
Replace Pavers	2025	0.45	0.28
Reapply Sealer	2030	0.15	0.06
Replace Pavers	2030	0.45	0.17
Reapply Sealer	2035	0.15	0.04
Replace Pavers	2035	0.45	0.11
Reapply Sealer	2040	0.15	0.02
Replace Pavers	2040	0.45	0.07
Reapply Sealer	2045	0.15	0.01
Replace Pavers	2045	0.45	0.04
Reapply Sealer	2050	0.15	0.01
Replace Pavers	2050	0.45	0.03
	Total Present Value		**$36.28**

Alternative B - Portland Cement Concrete

Activity	Year	Cost	Present Value
Initial Construction	2020	47.45	47.45
Reseal Joints	2025	0.30	0.19
Patching and Slab Replacement	2025	0.45	0.28
Reseal Joints	2030	0.30	0.12
Patching and Slab Replacement	2030	0.45	0.17
Reseal Joints	2035	0.30	0.07
Patching and Slab Replacement	2035	0.45	0.11
Reseal Joints	2040	0.30	0.05
Patching and Slab Replacement	2040	0.45	0.07
Reseal Joints	2045	0.30	0.03
Patching and Slab Replacement	2045	0.45	0.04
Reseal Joints	2050	0.30	0.02
Patching and Slab Replacement	2050	0.45	0.03
	Total Present Value		**$48.63**

Therefore, on a life cycle basis, the pavement constructed with concrete pavers is approximately 30 percent less expensive than the Portland cement concrete pavement.

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APPENDIX A
GUIDE CONSTRUCTION SPECIFICATIONS FOR INTERLOCKING CONCRETE PAVEMENT FOR CANADIAN AIPRORTS

Note: The text must be edited by a qualified, licensed design professional to suit specific project requirements. ICPI makes no representations or warranties of any kind, expressed or implied, and disclaims any liability for damages resulting in the use of this guide construction specification.

1.0 DESCRIPTION

This item shall consist of a surface course composed of interlocking concrete pavers set in bedding sand on an approved base course constructed in accordance with the Plans and Specifications. All pavers shall be manufactured for the construction of paved surfaces to be trafficked by jet or propeller driven aircraft. This item shall include pavers, bedding sand, joint sand, edge restraints, and sealer manufactured and installed in accordance with these Specifications. This item shall be required for construction of interlocking concrete pavements in the manner and at the locations shown on the Plans or as directed by the Engineer.

Note: The use of concrete pavers is not recommended for areas subjected to full power or reverse thrust (e.g., runways, high speed taxiways, or apron areas where aircraft "power-back" operations are conducted).

2.0 MATERIALS

2.1 CONCRETE PAVERS

2.1.1 GENERAL

Concrete pavers shall be manufactured in accordance with CSA-A231.2 except as modified by Sections 4.1 and 4.2 of this Specification. Hard face or coated pavers with special finishes shall not be used. Pavers shall have chamfered edges around the top of the paver unit and shall be constructed with spacer bars, i.e. small protrusions on each side of the paver to keep the pavers uniformly spaced so that sand can fill the joints. Chamfers shall have a nominal size of 3 to 6 mm and the spacers shall have a nominal size of 2 mm thickness. Concrete pavers shall be manufactured by a member of the Interlocking Concrete Pavement Institute.

2.1.2 DIMENSIONS

Concrete pavers shall consist of rectangular chamfered units, 100 mm by 200 mm by 80 mm thick, nominal dimensions, or other shapes and sizes as shown on the Plans. All pavers shall have round spacer bars, not exceeding 2 mm in thickness. The minimum thickness of concrete pavers for airport applications is 80 mm.

2.1.3 COLOUR

Colour shall be natural grey, except where indicated on the Plans. Coloured pavers shall use natural or synthetic mineral oxides with proven colorfastness that meet ASTM C979.

2.1.4 FREEZE-THAW DURABILITY

The contractor shall submit test results and certification that the concrete pavers meet the durability requirements of CSA A231.2 Precast Concrete Pavers.

2.1.5 EFFLORESCENCE
Concrete pavers shall be manufactured with additives to reduce efflorescence.

2.1.6 ABRASION RESISTANCE
Abrasion resistance of concrete pavers shall conform to the weight loss requirements of ASTM C936 when tested in accordance with ASTM C418.

2.1.7 ABSORPTION
The Contractor shall submit test results and certification that the concrete pavers meet the absorption test requirements in ASTM C140.

2.1.8 ACCEPTANCE
Concrete pavers shall be accepted by the Engineer at the source of manufacture in accordance with the acceptance requirements contained in Sections 4.1 and 4.2 of this Specification.

2.2 BEDDING SAND
Bedding sand shall be clean, non-plastic and free from deleterious or foreign matter. Bedding sand shall be fine, naturally occurring or manufactured hard sand. Limestone screenings or stone dust shall not be used. The sands shall be as hard as practically available when concrete pavers are subject to aircraft traffic. Grading shall not vary from the high limit on one sieve to the low limit on the next larger sieve. Bedding sand shall conform to the requirements of CSA-A23.1 FA1, except for gradation requirements contained in Table 1 of this Specification. Locally available manufactured sand is acceptable, provided the sand is manufactured from rock having a Los Angeles Abrasion loss of 20 or less, when tested in accordance with CSA-A23.2-16A. Sand must also have a loss no greater than 8 percent when tested according to CSA A23.2-23A Micro-Deval Degradation. Sand shall be washed and meet the grading requirements of Table 1. The sand shall contain no more than 7 percent loss per ASTM C88 using sodium sulfate or magnesium sulfate. Limestone screenings or stone dust shall not be used.

TABLE 1
GRADING REQUIREMENTS FOR BEDDING SAND (CSA-A23.1 FA1)

SIEVE SIZE	PERCENT PASSING
10 mm	100
5 mm	95 - 100
2.5 mm	80 - 100
1.25 mm	50 - 90
630 µm	25 - 65
315 µm	10 - 35
160 µm	2 - 10
80 µm	0 - 1

2.3 JOINT SAND
All sand for joints shall conform to the grading requirements of CSA-A179 as shown in Table 2. Sand blasting sand may be used. Masonry and beach sands shall not be used. Where locally available, bagged silica sand should be specified for joint sand.

TABLE 2
GRADING FOR JOINT SAND (CSA-A179)

SIEVE SIZE	PERCENT PASSING
5 mm	100
2.5 mm	90 - 100
1.25 mm	85 - 100
630 µm	65 - 95
315 µm	15 - 80
160 µm	0 - 35
80 µm	0 - 5

2.4 SEALER
Sealer for stabilizing joint sand shall be a urethane, or approved equal, capable of 100 percent elongation in accordance with ASTM D2370. The sealer shall have demonstrated acceptable performance in similar application for a minimum of one (1) year. The sealer shall be applied in strict accordance with manufacturer's recommendations and shall carry a five (5) year minimum manufacturer's warranty. The sealer shall stabilize the joint sand to resist repeated blasts from jet engines and propeller wash and shall prevent the ingress of water through the joint sand. The sealer shall also be resistant to jet fuels, aviation gasoline, hydraulic fluids, and de-icing chemicals.

2.5 JOINT SEALING FILLER
When shown on the Plans, joint sealing filler shall be applied at edge restraint interfaces. This item is considered incidental to installation of edge restraints.

3.0 INITIAL ACCEPTANCE REQUIREMENTS

3.1 SUBMITTALS
The Contractor shall submit the following for the approval of the Engineer at least 30 days prior to the start of concrete paver installation.

3.1.1 CERTIFICATION
The Contractor shall provide certifications that all materials to be incorporated into the work can meet the requirements of Sections 4.1 and 4.2 of this Specification. Certifications shall be substantiated by data from tests performed within 90 days of the planned start date for installation.

3.1.2 SAMPLES
The Contractor shall submit the following samples for preliminary testing and evaluation by the Engineer. Sampling and testing shall be carried out by a concrete testing laboratory, certified in accordance with CSA-A283, by a certification organization accredited by the Standards Council of Canada in the subject area of Building Products and Structures.

a) Pavers
Twenty (20) full sized concrete pavers, cured for 28 days, shall be submitted to the Engineer for testing and evaluation in accordance with Sections 4.1 and 4.2 of this Specification. Ten (10) pavers shall be measured in accordance with CSA-A231.2. Test sampling and frequency shall be in accordance with CSA-A231.2 except for modifications outlined in this Specification.
b) Bedding and Joint Sand

Sieve analyses and samples of bedding and joint sand shall be submitted to the Engineer for evaluation and testing in accordance with Sections 4.1 and 4.2 of this Specification.
c) Sealer
Manufacturer's catalogue cuts shall be submitted for the proposed sealer.
d) Edge restraints
Mill reports and steel detailing showing hole sizes and layout shall be submitted to the Engineer for approval, when steel angle edge restraints are shown on the Plans. When concrete edge restraints are shown on the Plans, the concrete shall conform to Specifications.

3.1.3 STATEMENT OF CONTRACTOR QUALIFICATIONS
The paver Contractor shall have installed at least 30,000 m^2 in commercial, municipal, port or airport projects over the past twelve (12) months. If mechanical installation is to be used, at least 10,000 m^2 of which shall have been mechanically installed. Submit a list to the Engineer of projects with project names, addresses, email addresses, telephone numbers, names of Engineers/Architects and Owners, and dates of construction. The paver Contractor shall hold a current certificate from the Interlocking Concrete Pavement Institute indicating Concrete Paver Installer Certification.

3.2 TEST STRIP
Prior to installation of unit pavers, construct a test strip at least 10 m by 10 m for each form and pattern of unit paver required. Build mock-up(s) using materials, base construction, joints and special features for continuous work, as indicated for final unit of work. The test strip shall also be used to establish "roll down" and sand surcharge requirements for grade control.
a) Locate mock-ups on project site in the location as directed by the Engineer.
b) Notify Engineer in advance of dates when mock-up(s) will be erected.
c) Demonstrate quality of workmanship that will be produced in final unit of work.
d) Obtain Engineer's acceptance of mock-up(s) before start of final unit of work.
e) Retain and maintain mock-up(s) during construction in undisturbed condition as a standard for judging work.
f) Accepted mock-up(s) in undisturbed condition at time of substantial completion may become part of completed unit of work.

3.3 CONCRETE MIX DESIGN
Proportioning requirements for concrete paver manufacture shall be designed for a compressive strength consistent with the acceptance criteria contained in Sections 4.1 and 4.2 of this specification. Prior to the start of paver production and after approval of all material to be used in the concrete, the Contractor shall submit a mix design verification showing the proportions and actual compressive strengths at 28 days of the unit pavers, tested in accordance with Section 4.1 of this Specification. The mix design shall include a complete list of materials including type, brand, source and amount of cement, fly ash or other pozzolans, ground slag, and admixtures, and copies of test reports and certifications. Production shall not begin until the mix design and accompanying test data are reviewed and approved by the Engineer. The mix design shall be submitted at least 15 days prior to the start of paver production.

4.0 MATERIAL ACCEPTANCE

4.1 ACCEPTANCE SAMPLING AND TESTING
All testing for acceptance of concrete pavers, and bedding and joint sand, will be performed by the Engineer without cost to the Contractor. Concrete pavers will be sampled at the location of

manufacture and tested by the Engineer for acceptance before shipment to the job site. Bedding and joint sand will be sampled from the stockpiles maintained by the Contractor at the job site for testing by the Engineer.

4.1.1 CONCRETE PAVERS
Concrete pavers shall be sampled, tested and accepted by the Engineer on a lot basis. A lot shall consist of one tenth of the total area to be paved or 50,000 units, whichever is smaller except for the last lot which shall consist of the number of units required for completion of paving. Each lot shall be divided into five (5) equal sublots. Three (3) full size units shall be randomly located by the Engineer within each sublot in accordance with ASTM D3665. Each specimen selected shall be suitably marked so that it can be identified according to lot, sublot, and sample number at any time. The tests indicated below are required.

4.1.1a COMPRESSIVE STRENGTH
Compressive strength testing in accordance with CSA A231.2 shall be performed on samples at 28 days. Five representative pavers shall be tested.

4.1.1b ABSORPTION
Five (5) full units shall be randomly selected and tested by the Engineer for absorption in accordance with ASTM C140.

4.1.1c ABRASION RESISTANCE
Three units shall be sampled out of every 500,000 units produced and abrasion resistance shall be measured in accordance with ASTM C418.

4.1.1d FREEZE-THAW DURABILITY
Three units shall be tested for freeze-thaw durability in accordance with CSA-A231.2. Weight loss shall be reported at twenty-eight (28) and, if necessary, at forty-nine (49) cycles.

4.1.2 BEDDING SAND
Bedding sand shall be sampled, tested and accepted by the Engineer on a lot basis. A lot shall consist of the lesser of 2000 m^2 or ten percent of the total paved area. The minimum lot size shall be 1000 m^2, except for the last lot, which shall consist of the number of square metres required for completion of paving. Each lot shall be subjected to the following tests for acceptance.

4.1.2a GRADATION
Each lot will be divided into two equal sublots. One (1) sample shall be randomly located by the Engineer within the sublot in accordance with CSA-A23.2-7B. The Engineer shall test each sample for grading in accordance with CSA-A23.2-2A (dry sieve).

4.1.2b MICRO-DEVAL DEGRADATION
One 1.5 kg sample shall be randomly located within each lot in accordance with ASTM D3665. Test according to CSA 23.2-23A Micro-Deval Degradation.

4.1.3 JOINT SAND
Joint sand shall be sampled, tested and accepted by the Engineer on a lot basis. A lot shall consist of the lesser of 2000 m^2 or ten percent of the total paved area. The minimum lot size shall be 1000 m^2, except for the last lot, which shall consist of the number of square metres required for completion of

paving. One (1) sample will be randomly selected for each lot. The Engineer shall test the sample for gradation in accordance with CSA-A23.2-2A (dry sieve). The joint sand shall satisfy the physical requirements for concrete fine aggregate.

4.2 ACCEPTANCE CRITERIA

4.2.1 CONCRETE PAVERS

Concrete pavers shall be evaluated on a lot basis by the Engineer. All acceptance requirements must be fully met as described below for a lot of concrete pavers to be considered acceptable for incorporation into the work. Failure to meet any one or more of the acceptance requirements detailed below will result in rejection of the entire lot of concrete pavers.

4.2.1a COMPRESSIVE STRENGTH

For acceptance, the average compressive strength of the five (5) pavers tested in accordance with Paragraph 4.1.1a shall be 50 MPa or greater with no individual paver less than 45 MPa.

4.2.1b ABSORPTION

A lot shall be accepted based on absorption when the average absorption for the five (5) samples tested for each lot in accordance with paragraph 4.1.1b is less than or equal to 5 percent, with no individual unit having an absorption greater than 7 percent.

4.2.1c DIMENSIONAL TOLERANCES

The dimensional tolerances of ten (10) pavers sampled for each lot in accordance with Section 6.3 of CSA-A23.2 shall not vary by more than the following amounts:

Length -1.0 to mm +2.0 mm
Width -1.0 mm to +2.0 mm
Thickness ± 3.0 mm

Each side of each paver within the sample shall be normal to the wearing surface and the opposite face. The sides shall be considered normal if the sides do not deviate from specified dimensions by more than 1.6 mm.

4.2.1d ABRASION RESISTANCE

Samples tested in accordance with paragraph 4.1.1d shall not have a volume loss greater than 15 cm^3 per 50 cm^3. The average thickness loss shall not exceed 3 mm.

4.2.1e VISUAL REQUIREMENTS

All pavers shall be sound and free from defects that would interfere with the proper placing of the pavers or impair the strength or performance of the construction. Defects which impair the structural or functional performance of the wearing surface of the paver shall be sufficient reason for rejection. The Engineer, at his/her sole discretion, may allow pavers with minor chipping to remain as part of the completed pavement.

4.2.1f FREEZE THAW DURABILITY

When tested in accordance with Paragraph 4.1.1d mass lost shall not exceed 225 g/m^2 of surface area after twenty-eight (28) freeze-thaw cycles or shall not exceed 500 g/m^2 after forty-nine (49) cycles.

4.2.2 BEDDING SAND

Bedding sand shall be evaluated by the Engineer on a lot basis for compliance with the following characteristics:

4.2.2a GRADATION
The two (2) samples of bedding sand tested in accordance with 4.1.2a shall be averaged for comparison to the grading requirements of Table 1. The Contractor shall take appropriate corrective action when the acceptance tests indicate that the grading requirements are not being met.

4.2.2b MICRO-DEVAL DEGRADATION
For each sample tested in accordance with Section 4.1.2b, the maximum loss shall not exceed 8 percent.

4.2.3 JOINT SAND
Joint sand sampled and tested in accordance with Paragraph 4.1.3 shall be evaluated for compliance to the requirements of Table 2.

4.2.4 SEALER
The sealer shall meet the requirements outlined in Section 2.4 of this Specification.

4.2.5 COMPLIANCE
Where any of the individual acceptance tests for concrete pavers and/or sand fail to meet the requirements specified above, the lot shall be rejected because of non-compliance subject to the following:

4.2.5a REMOVAL OF DEFECTIVE MATERIALS
The Contractor may elect to inspect the lot, remove any items he/she considers to be defective and submit the remainder for re-sampling and re-testing by the Engineer in accordance with Section 4.1 and 4.2 of this Specification. The costs for resampling and retesting shall be borne by the Contractor. Should these further test results fail to meet the requirements, the entire lot shall be rejected. Where defective materials have been discarded from the lot, the lot shall be considered a new lot and the initial test results shall not be used in the Engineer's evaluation for compliance.

5.0 DELIVERY, STORAGE AND HANDLING

5.1 CONCRETE PAVERS
Concrete pavers shall be delivered to the project site in steel-banded, plastic-banded, or plastic wrapped cubes capable of transfer by forklift or clamp lift. The pavers shall be unloaded without damage to pavers or existing construction. The individual unit pavers shall be protected from damage during delivery, storage and construction.

5.2 SAND
Sand shall be covered with waterproof coverage to prevent exposure to rainfall or removal by wind. Covering shall be secured in place.

5.3 ACCESS
Access to buildings will be provided at all times. The paving schedule is to be coordinated to minimize interference with the normal use of the premises.

6.0 INSTALLATION

The installation of concrete pavers shall be in accordance with Part 3- Execution of the Canadian National Master Construction Specification "Concrete Unit Paving" which provides guidelines for preparation, installation and compaction of the subgrade, geotextiles, granular base, edge restraints, bedding sand, and concrete pavers. Pavers shall not be installed during heavy rain or snowfall or over frozen base materials. Sand shall not be installed if frozen, or over frozen base materials. After final compaction, all excess sand and debris shall be removed. 95 percent of the joints shall be between 2 mm and 3 mm in width. The sealer shall be applied as soon as practical after final compaction, in accordance with the sealer manufacturer's requirements regarding application methods, equipment, and rate. The joints at the interface between pavers and adjacent pavement and edge restraints shall be sealed with joint sealing filler material as directed by the Engineer. Bedding sand, pavers, and joint sand shall not be installed during periods of heavy rain or when temperatures are at 0° C or lower.

7.0 CONTRACTOR QUALITY CONTROL

7.1 GENERAL

The Contractor shall provide and maintain a quality control system that will provide methods and procedures to assure that all materials and completed construction submitted for acceptance conform to contract requirements whether manufactured or processed by the Contractor, procured from Subcontractors or vendors. Quality control testing and inspection shall be completed in accordance with the Public Works Canada publication, "Pavement Construction Methods and Inspection", AK-68-22-000 with the addition of the following sections.

7.2 EXAMINATION AND VERIFICATION PRIOR TO CONCRETE PAVER PLACEMENT

The Field Control Technician, who can be the Installer's on-site superintendent, shall also be responsible for the following:

1) Examination of surfaces designated to receive unit pavers for compliance with required installation tolerances. Verification that all surfaces to receive pavers are in proper condition, and that no conditions exist which may adversely affect progress or quality of work.
2) Verification that the base is dry and ready to support bedding material, pavers, and imposed loads.
3) Verification of base gradients and elevations.
4)Verification of location, type, installation, and elevations of adjacent edge restraints, drainage inlets, grounding lugs, and other appurtenances in the pavement.
5) Provision of adequate drainage during the entire construction phase by means of temporary drains, ditches, or other means to prevent the build-up of standing water.

7.3 QUALITY CONTROL TESTING

The Contractor shall perform any quality control tests necessary to control the production and construction processes applicable to these Specifications and as set forth in the approved Quality Control Plan.

7.3.1 PAVER PRODUCTION

The testing program for paver manufacture shall include, but not necessarily be limited to tests for control of:

a) Batch proportioning
b) Aggregate gradation (evidence from quarry tickets will be acceptable).
c) Aggregate moisture content

d) Water-cement ratio
e) Density measurements
A minimum of two (2) tests for each property shall be made for each production day. For automated plants with recordation, the Contractor may submit printed tickets, in lieu of daily testing, provided evidence of recent plant calibration is submitted to the Engineer for approval prior to the start of production.

7.3.2 BEDDING AND JOINT SAND
The Contractor shall control the gradation and moisture content of the bedding and joint sand used for installation.

8.0 METHOD OF MEASUREMENT

The quantity of each element of work installed and accepted, comprising this item, shall be in accordance with the following measurements:

8.1 CONCRETE PAVERS AND JOINT SAND
Per square metre (m^2), measured in-place, completed and accepted.

8.2 BEDDING SAND
Per tonne, measured on approved truck scales, completed and accepted.

8.3 EDGE RESTRAINT
Per linear metre, measured in-place, completed and accepted.

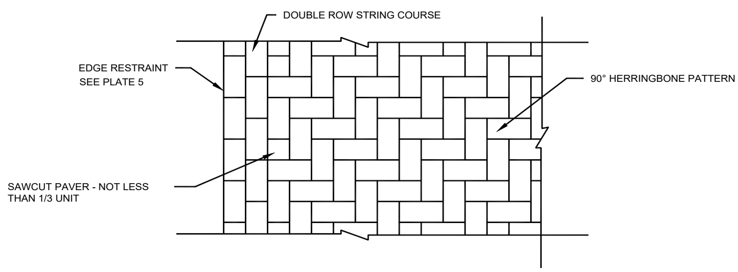
8.4 SEALER
Per square metre (m^2) completed and accepted.

9.0 MATERIALS AND TESTING REQUIREMENTS

CSA-A23.1	Concrete Materials and Methods of Concrete Construction
CSA-A23.2	Methods of Test for Concrete
CSA-A23.2-1A	Sampling Aggregates for Use in Concrete
CSA-A23.2-2A	Sieve Analysis for Fine and Coarse Aggregate
CSA-A23.2-7B	Random Sampling of Construction Materials
CSA-A23.2-16A	Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
CSA-A23.2-23A	The Resistance of Fine Aggregate to Degradation by Abrasion in the Micro Deval Apparatus
CSA-A179	Mortar and Grout for Unit Masonry

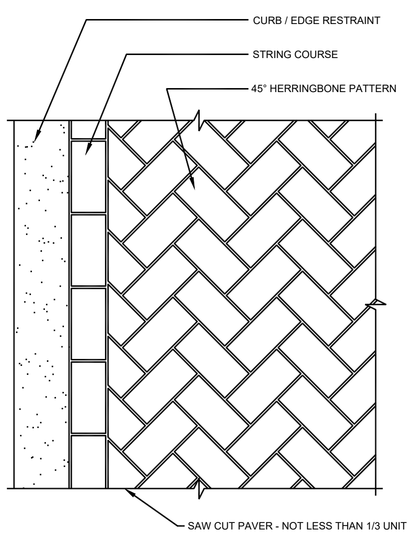
CSA-A231.2	Precast Concrete Pavers
ASTM C33	Specification for Concrete Aggregates
ASTM C140	Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units
ASTM C144	Standard Specification for Aggregate for Masonry Mortar
ASTM C566	Total Moisture Content of Aggregate by Drying
ASTM C936	Specification for Solid Interlocking Concrete Paving Units
ASTM C979	Pigments for Integrally Colored Concrete
ASTM D1557	Laboratory Compaction Characteristics of Soil Using Modified Effort
ASTM D2370	Standard Test Method for Tensile Properties of Organic Coatings
ASTM D3665	Random Sampling of Paving Materials

APPENDIX B
CONSTRUCTION DETAILS



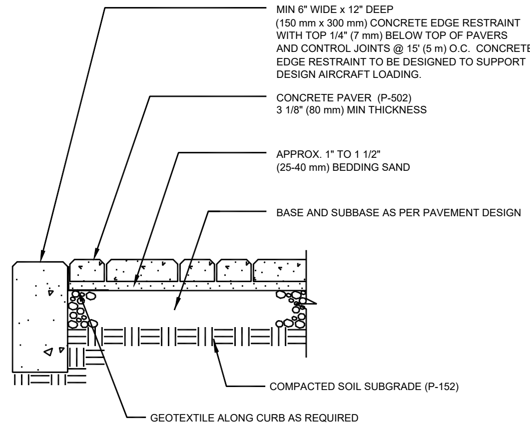
NOT TO SCALE

1 TYPICAL 90° HERRINGBONE PATTERN
FOR CONCRETE PAVER CONSTRUCTION



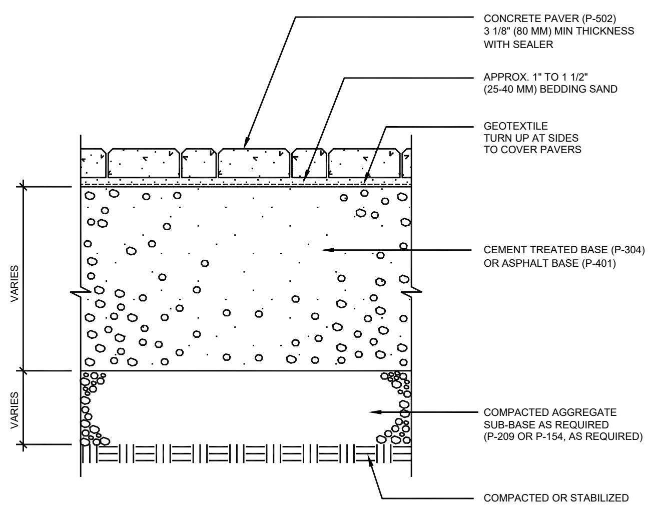
NOT TO SCALE

2 TYPICAL 45° HERRINGBONE PATTERN
FOR CONCRETE PAVER CONSTRUCTION



NOT TO SCALE

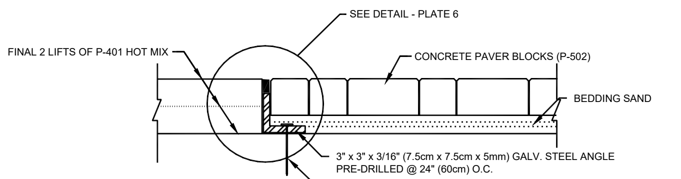
3 CONCRETE EDGE RESTRAINT



NOTE: BASE, SUB-BASE, AND SUBGRADE THICKNESS VARY WITH LOADS, SOIL STRENGTH, AND CLIMATE.

NOT TO SCALE

4 AIRFIELD PAVEMENT WITH CEMENT TREATED OR ASPHALT BASE



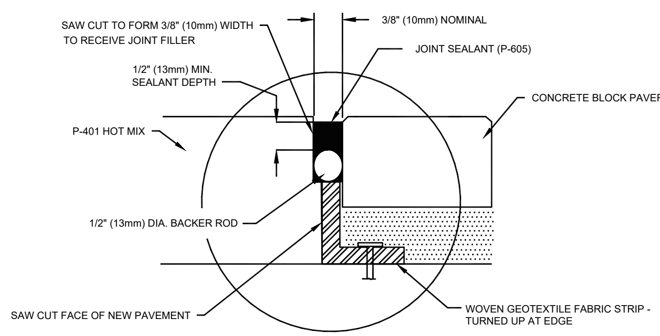
NOTES:

1) CONSTRUCT P-401 OVERLAY APPROX. 2' (60cm) PAST ANGLE LOCATION AND CUT BACK FOR ANGLE INSTALLATION

2) ADJUST ANGLE LOCATION ± 2" (5cm) TO MINIMIZE CUTTING BLOCKS

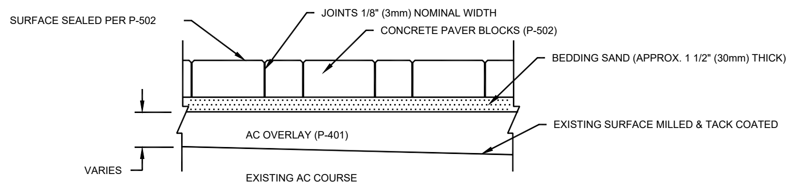
NOT TO SCALE

5 INLAY AND ANGLE EDGE RESTRAINT DETAIL



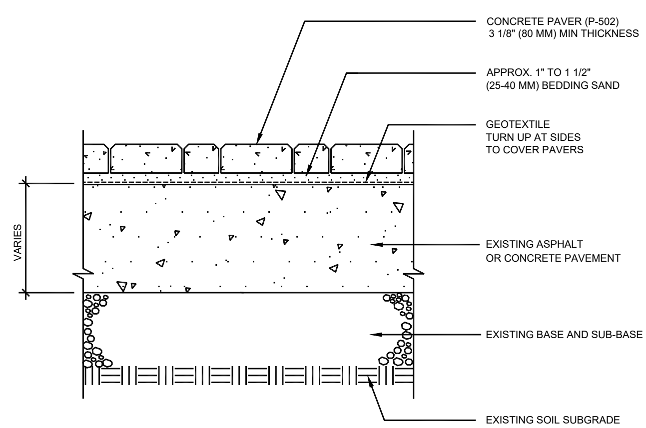
NOT TO SCALE

6 EDGE RESTRAINT JOINT DETAIL



NOT TO SCALE

7 OVERLAY OF EXISTING FLEXIBLE PAVEMENT



NOTE:

1. EXISTING ASPHALT OR CONCRETE PAVEMENT SHALL BE THOROUGHLY INSPECTED FOR AREAS IN NEED OF PATCHING OR REPLACEMENT. CONDUCT ALL REPAIRS AND FILL ALL CRACKS GREATER THAN 1/4" (7 MM) WIDE PRIOR TO PLACING GEOTEXTILE, SAND, AND PAVERS.

NOT TO SCALE

8 PAVER OVERLAY ON EXISTING ASPHALT OR CONCRETE

APPENDIX C
PAVEMENT DISTRESS SURVEY AND MAINTENANCE PROCEDURES

I. General

The following guidelines were developed by the Interlocking Concrete Pavement Institute. They are generally based on information provided in Federal Aviation Administration (FAA) Advisory Circular 150/5380-6, "Guidelines and Procedures for Maintenance of Airport Pavements".

Surface distress types shall be identified within unique randomly selected sample areas. Each sample shall 500 $m^2 \pm 100$ m^2. The method for selecting sample units is described in detail in FAA Advisory Circular 150/5380-6. The total selected sample area should be at least 50 percent of the total area (it may be 100 percent of the total area if time permits).

II. Distress Identification

1. TYPE OF DISTRESS: LOSS OF SAND IN JOINTS

Description: Normal paver paving has full joints. Full is defined as sand that comes up to the bottom of the chamfer around the sides of the paver. Sand in the joints can be lost due to any combination of the following factors; surface runoff, sucking of sand from tires, wind, or jet blast. Loss of sand will cause the units to move, often loosening and furthering more loss of sand.

Measurement: Sand loss is measured by inserting a thin ruler into joints of pavers and reading from the bottom of the sand to the bottom of the chamfer. Sampling can be done in areas subject to repeated traffic, as well as areas adjoining other pavements or edges.

Severity levels:

L	=	0 to 6 mm loss
M	=	6 mm to 19 mm loss
H	=	Over 19 mm loss

Remedy: Reapply sand to joints and seal if units have consistent joint widths.

2. NAME OF DISTRESS: INCONSISTENT JOINT WIDTHS

Description: Joint widths are specified in the original construction document. Actual joint widths should be as close to those nominally specified. Obtain baseline field measurements from sample areas subject to loads at the beginning of service. Excessive joint widths are caused by deformations, settlement, rutting, or loss of edge restraints. Variations from baseline measurements should not vary more than +3 mm or -2 mm).

Measurement: Visually inspect the area for irregular joint widths. Identify an area that exhibits this distress. Insert calipers into the joint below the chamfer at the middle of the length of the unit and read measurement. Measure the number exceeding tolerances in a 2-meter line within the area under inspection. Joint widths that are too narrow or too wide can be precursors to edge spalling or joint seal damage.

Severity levels:

L	=	Only a few joints out of dimensional tolerances, movement of only scattered units.
M	=	Joint widths are out of tolerance, concentrated in one (1) sample unit.
H	=	Joint widths are out of tolerance in several sample units.

Remedy: Once the cause is identified and solved, the units can be cleaned and replaced with joints to specification, vibrated and sealed.

3. NAME OF DISTRESS: CORNER OR EDGE SPALLING

Description: A corner or edge spall intersects the joint at an angle. It does not extend vertically through the paving unit. It can be caused by loss of sand, loads and/or settlement that cause the top edges of adjacent units to creep together and break.

Measurement: If one or more than one severity level occurs, the higher level should be recorded for the area.

Severity levels:

L	=	Spall has little or no loose particles. Width of spalling is less than 3 mm wide.
M	=	Moderately spalled with some loose, in-place particles. Spalling is 3 mm to 25 mm wide.
H	=	Spall is greater than 25 mm wide with loose, in-place, or missing particles. Tire damage or FOD is a risk.

Remedy: For M & H severity levels, remove damaged pavers, replace, and seal.

4. NAME OF DISTRESS: CRACKED PAVERS

Description: Longitudinal, transverse, or diagonal cracks are caused by loads and run vertically through the unit. Cracks can be caused by defective pavers that break under loads. The cracks divide the unit into two or more pieces. Cracks have little or no openings. The units may perform for a time in a cracked state but should be replaced as the cracking may lead to corner or edge spalling. Units generally do not crack under loss of subgrade support.

Measurement: Identify cracked pavers at each severity level.

Severity Level:

L	=	Units have cracks that are not spalled or chipped.
M	=	Units have cracks that are lightly spalled with loose particles.
H	=	Units have cracks that are severely spalled with loose or missing particles. FOD is a high risk.

Remedy: For M and H severity, remove cracked pavers, replace, and seal.

5. NAME OF DISTRESS: JOINT SEAL DAMAGE

Description: This is caused by joints opening and allowing water or soil into them. Sand or other material in the joints may loosen due to lack of sealant to bind them together. Joint seal damage from opening joints is due to greater problems such as loss of edge restraint, depressions, or rutting.

Measurement: Joint widths and visual surveys are measured against a baseline survey of areas subject to loads.

Severity levels:

L	=	Joint widths exceed baseline measurements but there is no debonding of sealant from the sand or paving unit.
M	=	Debonding of sealants from joints and paving units but no loss of stabilized sand.
H	=	Debonding of sealants allows loss of sand, sand is loose and loss has occurred. Joints may have soil/rocks in it and allow infiltration of water.

Remedy: For M & H severity, resealing may serve as a temporary solution until the units are removed, replaced with tight joints, and sealed.

6. NAME OF DISTRESS: DISINTEGRATION

Description: This is the breaking up of a unit or units into small loose particles. It is caused by defective concrete mix, unsuitable aggregates, high repetitions of freeze-thaw, deicing or anti-icing agents, or very high impact loads. Disintegration may be caused by crazing (also known as map cracking) or scaling due to manufacture with mix that was deficient in water, the action of freeze-thaw, and/or unsuitable aggregates.

Measurement: Identify areas with disintegrating pavers. Disintegration typically occurs among groups of pavers.

Severity levels:

L	=	Small cracks in surface of unit. No loose material.
M	=	Cracked surface and slight amount of loose material forming on top of units.
H	=	Most or entire surface of units are loose or missing. Rough surface is exposed.

Remedy: M & H severity, replace pavers and reseal.

7. NAME OF DISTRESS: DEPRESSIONS/DISTORTIONS

Description: These are a change in pavement surface resulting from settlement of the base, expansive soils, frost susceptible soils, or undermining of the base due to subsurface drainage problems. The transition from the areas at normal elevation to the depressed areas is gradual. Slight depressions are not noticeable except from ponding after a rainstorm.

Measurement: Depressions are measured in square metre of surface area. The maximum depth determines the level of severity. Place a 3 metre straightedge across the depressed are and measure the maximum depth in inches (meters). Depressions larger than 3 metre across must be measured by either visual estimation or by direct measurement when filled with water.

Severity levels:

L	=	Depression can be observed only by stained areas or brief ponding after a rainstorm. Taxiways and aprons: Depression ranges from 13 mm to 25 mm.
M	=	Depression are visible without ponding. Taxiways and aprons: depression ranges from 25 mm to 2 inches 50 mm.
H	=	Depression can be readily observed and severely effects riding quality. Taxiways and apron: depression is greater than 50 mm.

Remedy: Remove the units, locate and repair the cause of the settlement, reinstate sand, units, and seal.

8. NAME OF DISTRESS: SETTLEMENT OR FAULTING

Description: This is defined as a clear difference in elevation between areas of pavers caused by movement of underlying layers or differential consolidation of the sand or base.

Measurement: The surface area of the affected pavement is recorded in square feet (square meter) and differentiated by severity level.

Severity levels:

L	=	Taxiways: less than ¼-inch (6 mm); Apron: 3 mm to 13 mm difference in elevation.
M	=	Taxiways: 6 mm to 13 mm; Aprons: 13 mm to 25 mm.
H	=	Taxiways: greater than 13 mm; Apron: greater than 25 mm.

Remedy: Remove the units, locate and repair source of settlement; reinstate units at correct elevations.

9. NAME OF DISTRESS: POLISHED AGGREGATES

Description: Some aggregates polish quickly under traffic or polish naturally from weather.

Measurement: Friction testing in accordance with FAA Advisory Circular 150/5320-12, "Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces".

Severity level: Use skid resistance standards.

Remedy: Sand blast to regain roughness. Wash thoroughly, dry and seal. If units polish quickly, replace with units with harder sand/aggregate composition.

10. NAME OF DISTRESS: PUMPING AND WATER BLEEDING

Description: Pumping is the ejection of material by water through joints caused by deflection of the units under passing loads. Sand is ejected through the joint resulting in surface staining. Material on the pavement close to joints is evidence of pumping. Pumping indicates poor joint sealing usually accompanied by base or soil deformation.

Measurement: Identify area that is pumping.
Severity levels: No degrees of severity are defined. It is sufficient to indicate that pumping exists.

Remedy: Remove units, repair base, install drainage as needed, replace pavers and seal.

11. NAME OF DISTRESS: RUTTING

Description: Rutting is a surface depression in a wheel path. In many cases, ruts are only noticeable only after a rainfall when the wheel paths are filled with water. Rutting is caused by consolidation from traffic loads that can permanently deform the sand, base, or soil subgrade. Rutting is a structural deficiency that is normally indicative of a pavement structured that is underdesigned for the intended loading condition.

Measurement: The area of rutting is documented with the mean depth of the rut. Depth is measured at the deepest point (center) of the rut, along the length of the rut.

Severity level:

L = 6 mm to 13 mm
M = 13 mm to 25 mm
H = 1-inch 25 mm

Remedy: For M & H severity, remove units and sand, repair base, install pavement materials to desired elevation. Reinstate sand, pavers, vibrate with sand, clean, and seal. Full depth repair of base and subbase layers may also be required to provide adequate structural support.

12. NAME OF DISTRESS: HORIZONTAL CREEPING

Description: Creeping of units is caused by repeated braking, accelerating, or turning in an area. The joint lines will bend following the direction of the moving wheel(s). Creeping will eventually open paver joints, damage joint sealing, and accelerate deterioration.

Measurement: At the opening of the areas, two points should be marked on the pavement across areas subject to turning, braking, or accelerating. The points should align with the joints of the pavers. These are the reference lines. Deviations from these lines should be checked to monitor creeping.

Severity levels:

L = 6 mm or less deviation from reference line.
M = 6 mm to 13 mm deviation from reference line.
H = Greater than 13 mm deviation from reference line.

Remedy: For H severity, remove units back to area with stable, consistent joints. Open joints slightly in pavers adjacent to opening. Reinstall pavers in opening with consistent joints, matching those widths to those in the areas adjacent to the opening. Spread sand, vibrate, clean and seal.

13. NAME OF DISTRESS: SWELL

Description: Swell is an upward bulge in the pavement's surface. A swell is usually caused by frost action in the subgrade or swelling soil; however, swelling can be caused by other factors. Therefore, the cause of the swelling should be investigated.

Measurement: The maximum rise in pavement over a metre straightedge would be measured as well as the area of the swell.

Severity levels:

H = Less than 19 mm height differential. Swell is barely visible.

Remedy: Remove pavers, correct base and reinstall units.